Energy Policy 208 (2026) 114888

Contents lists available at ScienceDirect

Energy Policy

journal homepage: www.elsevier.com/locate/enpol

Efficiency only? An analysis of avoid, shift and improve strategies in EU member states' long-term mitigation policy

Simon Grabow [a,*], Tobias Riepl [b], Johannes Thema [c], Carina Zell-Ziegler [d]

[a] Institute for Spatial and Social-Ecological Transformations, University of Economics and Business Vienna, Welthandeslplatz 1, 1020, Vienna, Austria
[b] Department of Environmental Sciences and Policy, Central European University, Quellenstraße 51, 1100, Vienna, Austria
[c] Research Unit Energy Policy, Wuppertal Institute for Climate, Environment and Energy, Döppersberg 19, 42103, Wuppertal, Germany
[d] Energy & Climate Division, Oeko-Istitut, Borkumstraße 2, 13189, Berlin, Germany

ARTICLE INFO

Keywords:
Decarbonisation
European Union
Efficiency
Avoid-shift-improve
Demand reduction
Sufficiency

ABSTRACT

Despite ambitious EU targets, national emission trajectories reported by member states continue to fall short of achieving the necessary reductions. This implementation gap raises the question of what mitigation strategies and instruments member states rely on to meet internationally binding climate targets. To explore this, we scrutinise 1584 implemented, adopted, or planned mitigation policies across the sectors of agriculture, transport, energy consumption, and industry using qualitative content analyses. Our findings reveal substantial discrepancies in the distribution of mitigation strategies. Efficiency improvements dominate EU mitigation efforts, comprising 54 % of proposed measures. In contrast, policies promoting shifts to low-carbon alternatives represent only 14 %, while those avoiding energy or service demand make up just 2 %. Even when considering broader policy mixes that include elements of shifting and reducing final demand, these strategies remain underrepresented across all sectors, particularly in industry and agriculture. The remaining share of reported mitigation policies, accounting for 21 %, focus on altering broader regulatory frameworks and incentive structures, underscoring their critical role in EU member states' mitigation efforts. Additionally, we find member states to rely predominantly on economic and regulatory policy instruments, with substantial variation across mitigation strategies and sectors. Our findings carry important policy implications, unveiling EU's reliance on efficiency-centred approaches to achieve climate targets. Given the implementation gap and the untapped potential of demand-side measures, diversifying mitigation strategies could enhance the EU's ability to meet legally binding climate targets.

1. Introduction

Despite mounting evidence and wide-spread warnings of potentially catastrophic impacts of climate change since the 1990s, governments have not succeeded in bending the emissions curve (Stoddard et al., 2021; IPCC et al., 2023). Instead, global emissions still rise across all major sectors and national reduction pledges lag behind the Paris agreement, suggesting a global average temperature increase of up to 2.8 °C above pre-industrial levels by the end of this century (UNEP, 2024). In the case of the European Union (EU), annual GHG emissions continue to decline, yet current trajectories remain off track to meet its self-imposed targets of reducing net greenhouse gas emissions by 55 % in 2030 (relative to 1990 levels) and climate neutrality by 2050 (EEA, 2023a; European Commission, 2024a). At the same time, the European Commission proposed the implementation of a new ambitious 2040 target of net 90 % emission reduction from 1990 levels (European Commission, 2024b). This points towards a widening implementation gap (Fransen et al., 2023; IPCC et al., 2023) between, on the one hand, EU level target setting, and, on the other hand, member states failing to deliver the emission reductions required to meet climate goals (European Commission, 2023b). On a national level, the question of how countries translate climate pledges into laws, measures, or plans and what types of policies and instruments are best suited to deliver emission reductions remains highly contested (Perino et al., 2022; Stechemesser

* Corresponding author. Institute for Spatial and Social-Ecological Transformations, University of Economics and Business Vienna, Welthandeslplatz 1, 1020, Vienna, Austria.

E-mail addresses: simon.grabow@wu.ac.at (S. Grabow), riepl_tobias@phd.ceu.edu (T. Riepl), johannes.thema@wupperinst.org (J. Thema), c.zell-ziegler@oeko.de (C. Zell-Ziegler).

https://doi.org/10.1016/j.enpol.2025.114888
Received 13 March 2025; Received in revised form 9 September 2025; Accepted 9 September 2025
Available online 30 September 2025

et al., 2024; Baker et al., 2025). Economists have long argued that achieving an 'economic first-best approach' requires a uniform carbon price across all sectors (Rezai and van der Ploeg, 2017). For such an approach to be effective, however, the carbon price (€/tCO_2) would need to rise substantially (Edenhofer et al., 2021; Rennert et al., 2022).[1] If carbon prices remain below this necessary threshold, "remaining abatement requires stringent complementary policies" (Abrell et al., 2024, p. 2). Given that estimated carbon prices reported by EU agencies remain considerably lower than those suggested in the literature (Abrell et al., 2024), effectively addressing the implementation gap necessitates taking stock of what policies and instruments EU mitigation efforts are primarily based upon.

Recent evidence suggests current mitigation modelling (Solano Rodriguez et al., 2017; Duscha et al., 2019) and policy making are skewed towards "[…] supply-side technology solutions […]" (Creutzig et al., 2018, p. 260). Despite the potentials of such approaches to contribute to climate change mitigation (Ürge-Vorsatz and Metz, 2009; Zimmermann, 2022), a growing body of literature suggests such predominantly technology-based approaches to be insufficient for achieving the emission reductions required for staying within a 1.5 °C trajectory (Samadi et al., 2017; Barrett et al., 2022; Cordroch et al., 2022). This is corroborated by IPCC scenarios highlighting that the sole reliance on technical measures requires vast amounts of carbon to be removed from the atmosphere (Cordroch et al., 2022; IPCC et al., 2022), with a growing body of literature expressing biophysical and economic scalability concerns with regard to negative emission technologies (Smith et al., 2016; Beck and Mahony, 2018; Lenzi et al., 2018). Against this background, it becomes a prerequisite to mobilise additional strategies beyond technology-centred silver bullet approaches (Warszawski et al., 2021) to avert "Hothouse Earth" (Schröder and Storm, 2020).

This, for the first time, is acknowledged by the IPCC with the inclusion of a chapter on demand-side mitigation, aiming not only at harvesting potential efficiencies in end-user service delivery, but at shifting and reducing final demand (Creutzig et al., 2022b). Such end-use sector mitigation potentials can be classified according to the Avoid-Shift-Improve (A-S-I) framework. Originated in transport studies (Section 2.1), the framework highlights the importance of demand reduction (i.e. *avoid*) and alternative mode choice (i.e. *shift*) over efficiency improvements (i.e. *improve*) in mitigating transport emissions (Dalkmann and Brannigan, 2007; Creutzig et al., 2018). However, with an estimated global mitigation potential of *avoid* and *shift* strategies of approximately 32 % (13–54 %) by 2050 compared to a business-as-usual scenario (Creutzig et al., 2022a), strategies aimed at reducing of shifting the end-use of goods and services represent a significant mitigation lever beyond the transport sector.

But is the EU able to mobilise the full range of options available to meet its mitigation commitments? An analysis of short-term National Energy and Climate Plans (NECPs)[2] and Long-Term Strategies (LTS)[3] of EU member states suggests strategies that promote energy demand reduction to numerically play only a marginal role (Zell-Ziegler et al., 2021), despite their high approval rates at European citizen assemblies (Lage et al., 2023). In contrast, Jarre et al. (2024) indicate that demand reduction strategies, alongside a shift to low-carbon energy carriers and efficiency improvements, numerically constitute a fundamental component within energy policy databases and, consequently, mitigation efforts. However, to date, no detailed analysis of the comprehensive set of policies integrated in EU long-term emission scenarios was conducted. To address this gap, we scrutinise the following research question: *What is the prevalence of avoid, shift and improve strategies in European long-term mitigation trajectories in the end-use sectors of transport, industrial processes, energy consumption and agriculture*? We thereby contribute to existing literature threefold. First, addressing the science-policy interface, we bridge current theoretical debates on demand-side mitigation and policymaking by delivering empirical evidence on EU mitigation policy preferences. Second, by analysing a total of 1584 policies and measures[4] (PaMs) reported in emission scenarios across 27 EU member states as well as Iceland, Norway and Switzerland, we unveil weak points of European mitigation efforts by outlining discrepancies in the distribution of mitigation strategies, thereby informing decision-makers about potentials for policy development and improvement. Third, we provide a detailed breakdown of sector-specific approaches and highlight preferred policy instruments. This enhances our understanding of the EU's decarbonisation approach, enabling the identification of specific target areas for diversifying mitigation efforts.

2. Concepts and methods

2.1. The Avoid-Shift-Improve framework

Originating in the early 1990s, the framework was developed to break down four key components driving GHG emissions in the transport sector: *Activity* levels (e.g., passenger-kilometres), modal *Structure* (share by mode), energy *Intensities* (energy per kilometre), and *Fuel* carbon intensity – the Activity-Structure-Intensity-Fuel (A-S-I-F) model (Schipper and Marie-Lilliu, 1999). At a time of rapid growth in motorisation levels, transportation needs and resulting accelerating environmental consequences, A-S-I-F was first popularised in 2013 as part of the Bogota Declaration on Sustainable Transport (Dalkmann and Brannigan, 2007). Targeting the A-S-I-F drivers, three overarching strategies emerged: (a) *avoiding* mobility needs or shorten trip length to reduce overall activity levels (e.g. teleworking, improved urban planning, etc.); (b) *shifting* demand towards more efficient and less emission-intensive modes of transport (e.g. active mobility, public transport); and (c) *improving* energy-efficiency of vehicles and developing less emission-intensive fuels (Dalkmann and Brannigan, 2007; Creutzig et al., 2018). Note that the switch to low or zero-carbon fuels has been condensed into the *improve* category, reducing A-S-I-F to the widely used A-S-I framework (GIZ, 2014).

A-S-I remains to be a commonly used framework for researching transport decarbonisation pathways (Arnz and Krumm, 2023; Zhu et al., 2023; e.g. Arnz et al., 2024; Wan et al., 2025). Recent applications, however, have expanded its application to the industry sector (Sharmina et al., 2021) and the energy system (Pye et al., 2021; Jarre et al., 2024). Most notably, however, A-S-I gained momentum with the rise of demand-side mitigation strategies challenging the dominance of supply-side solutions to climate change mitigation (Creutzig et al., 2018, p. 260). Unlike supply-side approaches that focus on how goods or services are supplied, demand-side measures directly target the reduction of final (energy) demand and end-service levels (Creutzig et al., 2016, 2018; Mundaca et al., 2019; IPCC et al., 2022). Thereby, the A-S-I

[1] Achieving the emission targets is estimated to require carbon prices between €130–286 per tCO_2 in the EU ETS, and between €175–360 per tCO_2 for energy-related effort sharing emissions, with the exact levels varying according to model-specific assumptions on technology development and baseline conditions (Abrell et al., 2024).

[2] NECPs build the foundation for member states' 10-year national mitigation planning and part of the EU's mandatory reporting under the regulation on the governance of the energy union and climate action (EU)2018/1999 (European Commission, n.d.).

[3] LTS outline countries' long-term visions for achieving climate neutrality by 2050 and offer strategic direction for national climate action in line with EU targets. However, they do not deliver a comprehensive overview of concrete policy measures.

[4] Following the definitions of the European Commission and EEA (2023), policy refers to a strategic framework, legal act, or overarching objective, while measure captures specific operational actions or interventions that implement policies. Countries are required to report both as part of Article 18 (1)(b) of the Governance of the Energy Union and Climate Action Regulation (European Parliament and European Council, 2018).

framework has been crucial for disentangling different strategies to mitigating emissions in end-use sectors (Creutzig et al., 2024). Due to its widespread use and practicality in concrete policy application, the A-S-I framework is well-suited for scrutinising EU mitigation efforts and delivering tangible outcomes for decision-makers.

2.2. Strategy definitions and consistency

As boundaries between mitigation strategies tend to be blurry in practice (Fuchs et al., 2023), it is key to establish a clear delineation. For strategy definitions, we follow Creutzig et al. (2022a), .[5] Note that the approach taken slightly deviates from the IPCC's final service-centred perspective, which classifies shifts in energy carriers in the building, industry and agricultural sector as improvements in existing technologies (Creutzig et al., 2022b). While this is justified on the grounds of such approaches not affecting final service provision, it overlooks the fundamental changes required to rapidly electrify end-use sectors (Deason and Borgeson, 2019; Wei et al., 2019). Additionally, it fails to account for the broader scope adopted by EU member states, which extends beyond end-service delivery to include the production and provision of goods and services.

In addition to *avoid*, *shift* and *improve* strategies, a *general* category was introduced to capture ambiguous PaMs that influence broader framework conditions and/or constitute a policy mix. This, for instance, applies to PaMs such as green tax reforms and the implementation of the EU's Common Agricultural Policy. Discrepancies in the granularity of national reporting further contributed to PaMs incorporating multiple strategy types (Section 4.2). To prevent the research design from systemically underreporting *shift* and *avoid* measures, we added an additional *general (A/S)* category to capture PaMs representing policy mixes that explicitly reference a switch to low-carbon alternatives and/or demand reduction. This accounts for the possibility of countries being less inclined to report *avoid* or *shift* strategies, particularly those with broader implications for end-users. Instead of being reported as standalone measures, these strategies may be embedded within more comprehensive policy packages in national reporting. We thus distinguish between the following five categories, with a detailed description including exemplary policies being available in Table 1.

i) *Avoid (coded as 1):* Mitigation strategies that "reduce unnecessary (in the sense of being not required to deliver the desired service output) energy consumption by redesigning service provisioning systems" (Creutzig et al., 2022b, p. 509).
ii) *Shift (coded as 2):* Mitigation strategies that "describe the switch to already existing competitive low-carbon technologies and service-provisioning systems" (Creutzig et al., 2022a, p. 37).
iii) *Improve (coded as 3):* Measures that improve energy- and resource-efficiency of existing technologies delivering emission reductions without changing end-use service provision, even though behavioural adoption towards new technologies by end users may be required (e.g. from combustion engines to battery electric vehicles) (Creutzig et al., 2022a).
iv) *General (coded as 4):* Mitigation options that alter the regulatory framework or incentive structure to promote the reduction of energy consumption or emissions in general (e.g. taxation structure). Strategies could either be *avoid*, *shift* or *improve* (or only two of them). This category furthermore comprises PaMs that remain vague with no clear aim being identifiable (Zell-Ziegler et al., 2021; Lage et al., 2023).
v) *General (A/S) (coded as 5):* Strategies that alter the regulatory framework or incentive structures to promote the reduction of energy consumption or emissions in general (e.g. taxation structure). In contrast to *general*, this category comprises policies that contain explicit *avoid* and/or *shift* elements.

2.3. Data source and decomposition

Under Article 18 (1)(b) of the Governance of the Energy Union and Climate Action Regulation (European Parliament and European Council, 2018), EU member states report the GHG projections of their national modelling exercises on a biennial basis. Based on the national data received, the European Environmental Agency (EEA) compiles two European emission scenarios: First, the *With-Existing-Measures* (*WEM*) scenario reflects existing policies and measures; Second, the *With-Additional-Measures* (*WAM*) scenario incorporates not only already adopted and implemented policies, but member states' proposed measures that are not yet implemented. The reported raw data covers the most recent projections from March 2023 and is thus suited for delivering a comprehensive overview of contemporary mitigation efforts across the EU. A total of 3342 PaMs are reported by 30 European countries, namely the EU27 and additionally Iceland, Norway and Switzerland.

For analysing the cross-sector distribution and instrument types, we rely on data collected as part of mandatory EU reporting requirements. Member states are required to select among the sectors of (a) energy supply, (b) energy consumption,[6] (c) transport, (d) industrial processes, (e) agriculture, (f) land use, land-use change and forestry (LULUCF), (g) waste management, and (h) other sectors.[7] In addition to sector specifications, the EEA mandates member states to specify the policy instruments through which PaMs are put into practice. In line with EU reporting standards, instruments are categorised into the following types:

(1) economic (i.e. measures that provide an economic incentive, such as subsidies, investment programmes, emission trading schemes, etc.)
(2) fiscal (i.e. measures that provide a financial incentive via taxes)
(3) voluntary/negotiated agreements (i.e. binding or voluntary standards/regulations agreed between regulators and target group)
(4) regulatory (i.e. measures that set binding standards and regulations or permitting systems, such as building regulation, etc.)
(5) information (i.e. measures such as labelling, awareness rising, voluntary standards),
(6) education (i.e. measures such as training programmes, workshops, seminars at all levels)
(7) research (i.e. measures providing of funds to allow for research programmes)
(8) planning (i.e. measures such as waste management plan, transport plan, urban planning, land use plan, etc.)

[5] We adopt a particular and influential A-S-I classification to categorize PaMs as outlined in Creutzig et al. (2022a). We acknowledge, however, that certain measures could plausibly be classified differently following alternative framework definitions.

[6] Note that energy consumption comprises the consumption of fuels and electricity by end users like households, public administration, services, industry and agriculture (European Commission and EEA, 2023).

[7] The reporting requirements stipulate that member states must classify PaMs that do not directly affect the sectors of energy supply, energy consumption, transport, industrial processes, agriculture, land use, land-use change and forestry (LULUCF), or waste management under the category of other sectors (European Commission and EEA, 2023). As the attribution of individual mitigation options to specific sectors is determined by each member state, cross-country discrepancies in the sectoral classification may arise. This may explain why only six countries reported a total of 67 PaMs under the other sectors category. Note that the category "other sectors" has been excluded from Table 1 due to reported PaMs focusing mainly on changing broader framework conditions.

Table 1
Examples of sectoral PaM coding according to avoid, shift, improve, general and general (A/S).

Sector	Policy example	Strategy	Explanation of strategy type classification
Agriculture	National buy out scheme for livestock farmers for voluntary ending of NH3 intensive farms (#1111)	Avoid	PaM aims at reducing the total number of NH3 intensive livestock farms
	Change in people's diet (#212); 7-AG-06: Biogas plants (#293); Strategy to promote plant-based protein (#446)	Shift	PaMs aim at shifting from emission-intensive animal-based foods to less emission intensive protein sources or providing renewable energy sources via biogas plants
	Agricultural Investment Fund for energy efficiency, renewable energy-precision fertilization and guidance for farmers (#39); MAG-2: Improvement of livestock facilities and manure management systems (#146)	Improve	PaMs aim at improving existing agricultural practices and energy efficiency
	Implementation of EU agricultural policies (#17); Strategy for Growth in Agriculture (#224)	General	PaM refers to the implementation of broader framework conditions, with individual strategy applications of avoid, shift and/or improve remaining unclear
Energy consumption	Every kWh matter. Consumption-reducing information campaign. Swedish Energy Agency is carrying out an information campaign to contribute to changed habits and increased knowledge to reduce electricity use (#1555)	Avoid	PaM aims at energy demand reduction
	Support scheme for the production of electricity from renewable energy sources for own use (#175); Fossil exit for heating (#87)	Shift	PaMs aim at phasing out fossil-based technologies and/or fosters switch to renewables in the heating sector
	Thermal Improvement of Building Stock (#8), Energy performance of buildings regulation (#92)	Improve	PaM aims at improving energy efficiency and performance of the buildings stock
	Carbon tax on fossil fuels (#715); EU Emission Trading Scheme (ETS) (#7); Energy advice network for citizens (#1354)	General	PaM refers to the implementation of broader framework conditions that could trigger application of avoid, shift and/or improve strategies
	Climate Neutral New Buildings (#7); Government-wide Programme for a Circular Economy (RBCE): 'A Circular Economy in the Netherlands by 2050' (#1082)	General (A/S)	PaMs represent a strategy mix that contains avoid and/or shift aspects, such as the switch to renewable energy systems in the building sector or a circular economy approach promoting the reduction and reuse of resources
Industrial processes	Restrictions and prohibitions on placing certain products and equipment on the market (#192)	Avoid	PaM aims at directly limiting the consumption of certain emission- or resource-intensive products
	Renewable energy systems use in industry (#904); Production and use of hydrogen (#911)	Shift	PAMs aim at shifting towards low-carbon technologies in production processes by promoting the use of renewables or hydrogen
	Tax deduction for (Energy Efficiency) investments by companies (#24); Increasing energy efficiency in companies (#920)	Improve	PaMs aim at fostering energy efficiency to lower energy needs per unit of production
	State credit guarantees for green investments (#1541); National Competitiveness Strategy 2021–2027 (#1292);	General	PaMs aim at changing broader framework conditions, lack specificity and could incentivise the application of avoid, shift and/or improve strategies
	Strategy for Circular Economy 2030 (#1293)	General (A/S)	PaMs represent a strategy mix that contains avoid and/or shift aspects, such as the reduction and reuse of resources
Transport	Realization of the "15-min City" (#953); Prohibit advertising aircrafts (#541)	Avoid	PaMs aims at lowering overall transport demand by fostering compact cities designs or prohibiting the advertisement of an emission-intensive mode of travel
	Promote modal shift to the waterway (and rail) network (#147); National bicycle sharing scheme (#1056)	Shift	PaMs aim at shifting from road to waterway or active transport, thus supporting low-emission modes of service provision
	Accelerated deployment of charging infrastructure for electric and hybrid vehicles (#114); Making an additional domestic ferry climate neutral (#326)	Improve	PaM aims at incentivising market penetration of BEVs thus lowering the emission intensity of car-based transport without changing travel behaviour and/or demand, or electrifying an additional ferry without improving user experience
	Climate change communication (#1512); Financial incentives for Comprehensive Transport Strategies by local communities to promote planning of sustainable transport (#1350)	General	PaMs aim at changing broader framework conditions, lack specificity and could incentivise the application of avoid, shift and/or improve strategies
	Spatial policy aimed at modal shift and fewer trips (#23)	General (A/S)	PaMs represent a strategy mix that contains both avoid and shift aspects by aiming at shifting modal split and avoiding overall transport demand

(9) other (i.e. measures that do not fit in any of the above)

Note that member states can assign one or multiple instrument types to individual PaMs, leading to a discrepancy of 563 between the total number of analysed PaMs and the reported instrument types. Since sector and instrument type reporting is a member state responsibility, interpretation bias may arise. Despite the availability of detailed reporting guidelines (European Commission and EEA, 2023), we find minor inconsistencies in reporting across member states.[8]

Our central concern to analyse PaMs incorporated into the European *WEM* and *WAM* scenarios necessitated further raw data decomposition. First, 1182 PaMs not included in any projection scenario were excluded from the raw data, leaving a total of 2159 PaMs. Second, due to our primary focus on end-use sectors, we excluded PaMs affecting the energy supply, LULUCF and waste sector. As a result, the analysis is limited to the sectors of agriculture, energy consumption, industrial processes, transport and other sectors. Limiting the analysis to end-use sectors further reduced the number of PaMs to a total of 1,584, with descriptive statistics on country shares shown in SM B.Res_Country. These refinements are justified for two reasons: Firstly, supply-side decarbonisation strategies tend to be relatively straightforward and accepted,[9] whereas mitigation in end-use sectors, which directly affects end-users, is highly contested (Creutzig et al., 2018; Mundaca et al., 2019; Freeman et al., 2024). Secondly, end-use sectors are pivotal to achieve European

[8] The EU's Emission Trading Scheme, for instance, was reported as part of the sector of industry in the case of Croatia, energy consumption in the case of Finland and Austria, and other sectors in the case of Norway and Switzerland.

[9] The contemporary approach to decarbonisation is to electrify end-use sectors, such as transport and heating, "[…] while decarbonising the electricity systems upon which they will increasingly come to rely" (Christophers, 2024, p. 120). Despite spiking demand, undoubtedly, posing challenges for the decarbonisation of the energy system, many supply-side technologies, such as renewable energy sources (e.g. solar, wind, hydroelectric power), have matured and proven to be viable alternatives to fossil fuels.

climate targets by collectively accounting for approximately 68 % of the EU's emissions in 2022, excluding emissions generated by the energy supplied to these sectors (EEA, 2023b).

Except for the case of France (FR), Luxembourg (LU), Italy (IT) and Spain (ES), PaMs are reported in English. Wherever possible (FR, LU), PaMs were analysed in the language of their reporting. In other cases (IT, ES), the respective policies – a total of 261 PaMs – were translated into English using the AI-powered translation and language tool DeepL[10]. We estimate inaccuracies in the analysis due to linguistic bias to be minimal due to the cautious coding approach applied necessitating all PaMs involving categorisation uncertainties to be reviewed by two peer coders, some of whom examined the material in both the original and translated language.

2.4. Process of categorising PaMs

After decomposing the raw data, individual PaMs were analysed and classified applying qualitative content analysis (Kuckartz, 2012, 2019). The coding procedure can be divided into three steps, with an overview of the process and the measures taken to prevent coding bias presented in Fig. 1. In the initial phase, the corresponding author conducted a pre-screening of the data, involving a first coding round. PaMs matching our predefined strategy definitions were coded accordingly, while those that did not match these definitions were assigned to a separate *TBC* (i.e. to be clarified; coded as 6) category for further clarification in the larger coder group. To ensure accuracy and prevent coder bias, a cautious approach was adopted, where any uncertainties regarding the classification of individual PaMs qualified the measure to be classified as *TBC*. This process qualified 665 PaMs (42 %) for the peer-reviewed coding procedure.

In the second step, the team of four authors carried out the analysis and classification of PaMs requiring further scrutiny. This process involved randomly assigning individual authors to analyse a specific subset of countries and their respective PaMs. We follow the proceedings of Zell-Ziegler et al. (2021) and Lage et al. (2023) by pairing each author with a peer analyst for a predefined set of countries. To test our approach, we performed a preliminary coding run for a subset of 29 PaMs to foster a coherent understanding of the framework applied among all coders and facilitate discussions around strategy ambiguities. Subsequently, all authors coded a set of 325–340 PaMs of randomly assigned countries individually, with each PaM being independently reviewed by an author and a blind-peer analyst. Again, the category *TBC* (coded as 6) enabled coders to highlight PaMs that required clarification in the larger group of authors. Coders were furthermore required to outline their reason for coding choice in an additional column in the coding sheet.

Finally, coding results were compared between coders, with cross-coder discrepancies being observable in the case of 287 PaMs (43 % of the 665 peer-coded PaMs). This reflects the peer-reviewed coding procedure's focus on PaMs that were not clearly attributable during the initial coding round, highlighting the complexity of strategy identification. To resolve this, non-consistently coded PaMs were individually discussed and final classifications agreed upon during regular coder meetings.

3. Results

Before diving into the findings by country (Section 3.1), sector (Section 3.2) and instrument type (Section 3.3 & 3.4), Fig. 2 presents a broad overview of the connections between the various categories of interest. The majority of reported PaMs by EU member states (76 %) are part of national *WEM* scenarios representing already existing measures. *WAM* reporting is comparatively limited, accounting for only 388 PaMs or 24 %. Regarding the sectoral distribution, the largest shares of reported PaMs are attributed to transport (36 %), energy consumption (32 %), and agriculture (18 %). The relatively low share of industry-related PaMs (10 %) is largely due to emissions from industrial processes being covered by the EU Emission Trading Scheme (ETS), where rising certificate prices are expected to drive decarbonisation efforts. Note that other sectors has been excluded from the visual representation in the following sections due to its coherent composition, which primarily consists of measures that modify broader framework conditions, hindering a meaningful cross-sector comparison. Our analysis reveals the dominant role of improving the energy-efficiency of existing technologies (54 %) in EU emission scenarios, while shifts towards low-carbon provisioning systems and (energy) demand reduction measures remain underrepresented, with 14 % and 2 % respectively. While policy-mixes with explicit *avoid* and/or *shift* components account for an additional 10 %, there remains a substantial portion (21 %) of measures that represent broader regulatory changes or remain ambiguous. This trend is consistent across both *WEM* and *WAM* scenarios, which exhibit a similar distribution of strategy types. Among the policy instruments proposed by EU member states, economic (33 %) and regulatory instruments (27 %) predominate. This contrasts with Zell-Ziegler et al.'s (2021) findings on the significance of fiscal measures in NECPs. Differences arise due to variations in instrument definitions, with our analysis following the EEA categorising subsidies and infrastructure investments as economic instead of fiscal instruments.

3.1. Findings by country

The number of PaMs reported to the EEA by member states as part of their national reporting duties varies widely, ranging from 130 in France to just 3 in Bulgaria, with an average reporting of 53 PaMs (SM B. Res_Country). This variation may reflect cross-country differences in the amount of implemented, adopted, or planned mitigation policies or discrepancies in the granularity of national reporting. Some countries provide highly detailed reports by breaking down comprehensive policy packages into individual measures. For example, Finland reports 4 PaMs that aim at fostering a modal shift towards active mobility, whereas Austria lists only a single measure. The cross-country comparison thus hinges on country-specific reporting approaches, with a more detailed discussion being provided in Section 4.2.

Fig. 3 illustrates the cross-country distribution of mitigation strategies. *Avoid* measures are notably uncommon features across national emission trajectories, with over half of EU member states not reporting any (energy) demand reduction strategies. Even in countries such as Finland, Iceland, and Luxembourg that report the highest share of *avoid* strategies, they constitute only 4 % of reported measures. Regarding *shift* strategies focusing on low-carbon technology adoption, we find significant cross-country variations. In Malta and Iceland, they account for 29 % and 27 % of measures, respectively, whereas Ireland and Switzerland report the lowest shares at 4 %. Some countries, such as Austria, Cyprus, and Ireland, report low levels of *avoid* and *shift* strategies but a high proportion of *general (A/S)*, suggesting a tendency to classify strategies that directly influence final consumers as part of broader policy mixes. Portugal stands out, with 48 % of its reported measures incorporating *avoid* and *shift* strategies. This reflects its strong efforts in promoting shared mobility and modal shifts to drive transport decarbonisation as well as its leadership in renewable energy adoption (IEA, 2021). Across all member states, *improve* strategies dominate, ranging from 38 % in Switzerland to 79 % in Slovakia. Notably, even in the transport sector — where low-carbon alternatives typically represent a high share — Slovakia's approach remains heavily focused on *improve* strategies, such as establishing fuel efficiency standards and promoting battery electric vehicles. *General* strategies are employed in all EU member states, emphasising the critical role of changing broader framework conditions and incentive structures for mitigating emissions.

[10] https://www.deepl.com/en/translator.

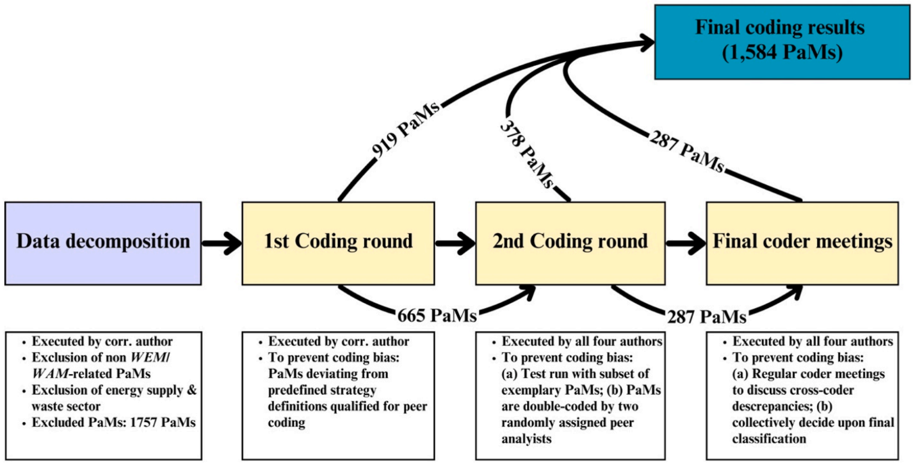

Fig. 1. Flow chart demonstrating the coding procedure.

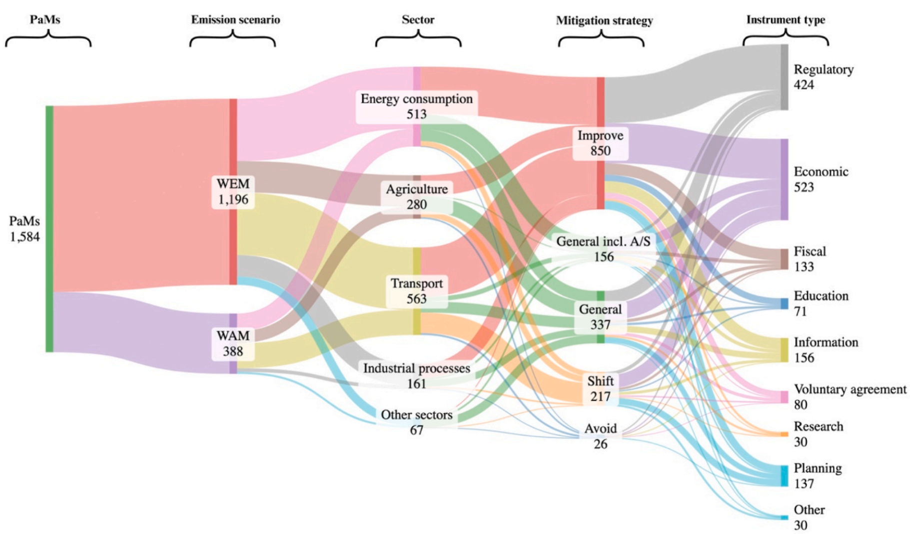

Fig. 2. Sankey diagram showing connections between coding categories. As countries were able to allocate multiple instrument types for individual PaMs, in- and outflows were matched by calculating the respective share per instrument type. The distribution between countries was excluded and colours selected for visualisation purposes. (For interpretation of the references to colour in this figure legend, the reader is referred to the Web version of this article.)

3.2. Findings by sector

Variations in the distribution of mitigation strategies are observed not only between countries but across sectors. As visualised in Fig. 4, demand reduction plays only a marginal role in all sectors. In the agricultural sector, where *avoid* strategies assume the largest share at 4 %, common measures include reducing food waste and loss and promoting local food production. Strategies fostering low-carbon alternatives, in contrast, vary more substantially across sectors. The transport sector's high proportion of *shift* strategies (23 %) is largely due to the widespread acceptance of policies promoting mode shifts, e.g. by expanding public transport infrastructure (Gota et al., 2019; Tsoi et al., 2021). In agriculture, *shift* strategies primarily involve dietary changes, organic farming practices, and fuel switching in production processes. Interestingly, *general (A/S)* strategies concentrate in the sector of energy consumption at 19 %, reflecting a tendency to report strategy mixes that combine energy efficiency improvements with fuel switching elements for building decarbonisation. Across all sectors, *improve* strategies dominate. This highlights the emphasis of EU mitigation policy on (energy) efficiency improvements as a key mitigation lever (Bertoldi and Mosconi, 2020).

3.3. Findings by instrument type and strategy

Fig. 5 shows the relative distribution of instrument types, providing insights into whether mitigation strategies tend to rely on specific policy instruments. While economic instruments constitute the largest share across all strategies, we observe substantial cross-strategy variations. The high overall share of economic instruments can be traced back to their broad definition, which includes not only market-based incentives but also public investment programmes and subsidies (European Commission and EEA, 2023). Within the *general (A/S)* category, many PaMs aim to adjust economic incentive structures, encouraging final consumers to reduce (energy) demand or switch to renewable alternatives through measures such as emissions trading schemes and subsidy programs. Given that approximately 60 % of reported *shift* strategies target the transport sector, where public infrastructure expansion is a key priority, the prominent role of economic instruments in this domain is unsurprising. Regulatory instruments also play a significant role, particularly in *improve* and *avoid* approaches. The regulatory nature of *improve* strategies arises from their emphasis on establishing minimum standards, such as biofuel blending requirements in the transport sector, building energy efficiency standards, and regulations of fluorinated

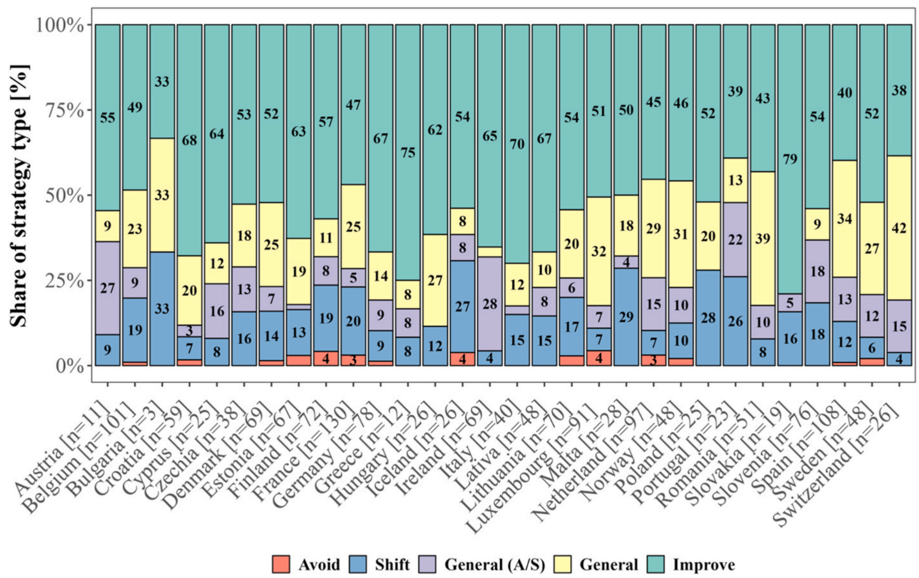

Fig. 3. Relative distribution of mitigation strategies by country.

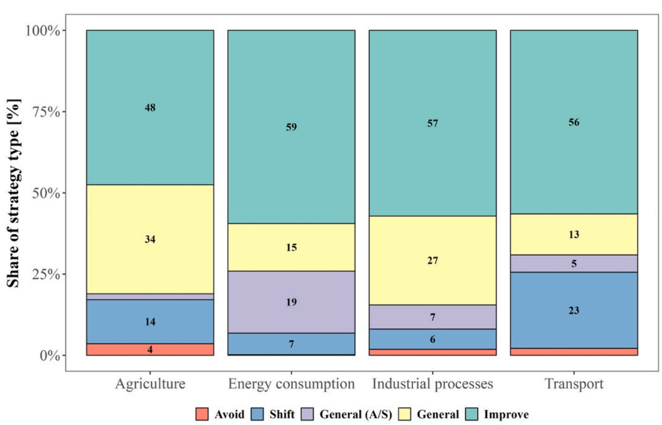

Fig. 4. Sectoral distribution of mitigation strategies. For clarity in visualisation, the category other sectors was excluded.

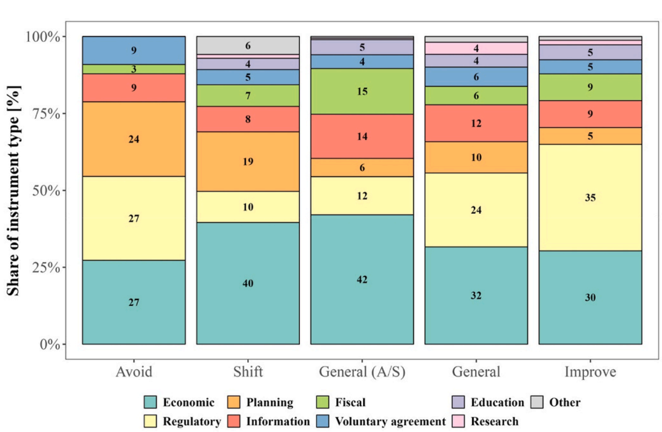

Fig. 5. Relative distribution of instrument type across mitigation strategies.

GHG in industrial processes. Additionally, planning instruments are notably more prevalent in strategies fostering low-carbon provisioning and demand reduction, mainly encompassing infrastructure and mobility plans, such as urban redesigns to reduce car-based transportation. However, due to their long-term nature, they tend to deliver emission reductions more gradually compared to other policy instruments. Finally, fiscal and information-based instruments make up a relatively small share of reported PaMs, while voluntary agreements, education, research, and other policy tools are rarely proposed.

3.4. Findings by instrument type and sector

To scrutinise whether certain sectors rely on specific policy instruments, Fig. 6 visualises the distribution by instrument type and sector. Economic instruments consistently play a prominent role across all sectors, highlighting their importance as the main vehicle by which member states leverage mitigation potentials. Their significance is particularly evident in the agricultural sector (38 %). This underscores the EU's agricultural policy focus on subsidies and financial support measures, despite only a small share being allocated to agri-environment-climate measures (Chemnitz and Bechava, 2019). We furthermore observe substantial cross-sectoral differences in the use of regulatory instruments ranging from 21 % in agriculture to 42 % in industry. Regulations in the industry sector encompass binding standards and permitting systems, reflecting member states' proposed approaches for implementing the EU's Fluorinated Gas Regulation (Regulation (EU) 2024/573) within their jurisdictions. Although

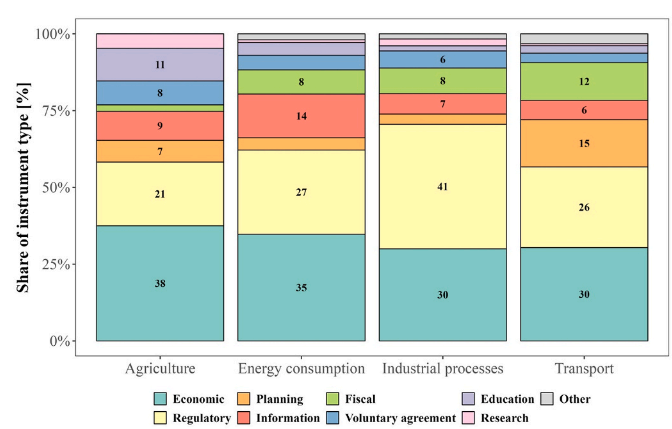

Fig. 6. Relative distribution of instrument type per sector. For clarity in visualisation, the category other sectors was excluded.

informational and planning instruments also contribute, their influence is less pronounced. For instance, information-based tools such as energy efficiency labelling support decarbonisation efforts in the sector of energy consumption (15 %), while mobility plans play a prominent role in transport policy (15 %). Furthermore, fiscal instruments remain relatively limited across all sectors, with the most notable exception in the transport sector, where vehicle taxes and mileage-based schemes are frequently proposed.

4. Discussion, limitations and future research needs

4.1. Novel empirical evidence on EU mitigation policy preferences

EU member states' reported policies fall significantly short of the emission reductions required to meet EU targets. Our findings on the discrepancies in the distribution of mitigation strategies suggest that EU member states fail to leverage the full range of available emission reduction levers. While efficiency improvements in existing technologies dominate the portfolio of reported PaMs, shifts to competitive low-carbon provisioning systems play only a minor role, and demand reduction measures are rarely considered. Our results parallel Zell-Ziegler et al. (2021), who examine the role of sufficiency policies in NECPs and LTS. While NECPs focus on achieving the EU's 2030 energy and climate targets, LTS outline a vision for a climate-neutral economy by 2050 — often without detailing specific policy measures. Using *avoid* and *shift* strategies as proxies for sufficiency measures in line with Arnz and Krumm (2023), our analysis identifies a higher share of 16 % compared to 8 % reported by Zell-Ziegler et al. (2021). This suggests that member states propose a slightly higher share of strategies promoting low-carbon alternatives and (energy) demand reductions in long-term mitigation scenarios compared to short-term plans. One possible explanation is that policymakers may prioritise other political objectives (e.g. restoring economic growth) over near-term mitigation efforts, thereby deferring climate action to future administrations (Lamb et al., 2020). Differences in reported shares may also result from variations in strategy definitions, as Zell-Ziegler et al. (2021) do not classify renewable energy systems in the building and industry sector as sufficiency.

Jarre et al. (2024) extend the A-S-I framework to the energy sector, encompassing both energy generation and consumption. Applied to five policy databases, including the one analysed in this study, their findings provide insights into the broader direction of energy policies, indicating (energy) efficiency improvements to dominate. However, *shift* and *avoid* measures represent significantly higher shares compared to our analysis, at 28 % and 19 %, respectively. These discrepancies can be attributed to two factors. First, methodological differences: Jarre et al. (2024) consider measures not included in any projection scenario and classify policies based on country-reported sub-sector policy objectives, rather than analysing individual PaMs. This approach is likely to overestimate the reported share of (energy) demand reduction strategies, as countries classify a broad range of mitigation efforts – including efficiency-driven reductions in energy use – under the sub-sector goal of *demand management/reduction*, which is then categorised as *avoid* strategy.[11] Second, differences in strategy definitions: Jarre et al.'s (2024) definition of *avoid* strategies comprises measures aimed at avoiding unnecessary energy consumption (e.g., teleworking to reduce mobility demand) and energy efficiency improvements that reduce energy use under *ceteris paribus* conditions. However, the critical question for mitigation strategies is not *if* they lower energy requirements and emission, as this is an inherent *ex-ante* assumption, but *how* such strategies aim to achieve proposed reductions.[12] For example, while improved building envelopes reduce energy and heating demand, we contest their classification as *avoid* strategy due to insulation technologies being readily available. Moreover, such an approach overlooks the energy consumption and emissions associated with more systemic inefficiencies of contemporary housing systems such as the overconsumption of floor space or the proliferation of secondary and tertiary homes (zu Ermgassen et al., 2022; Lage et al., 2024; Horn et al., 2025).

Thus, rather than focusing on singular strategies (Zell-Ziegler et al., 2021) or providing a broad overview of energy policy tendencies at global and EU levels (Jarre et al., 2024), our results provide the first comprehensive stocktake of mitigation policies proposed by EU member states as part of their long-term emission scenarios. By presenting findings by country and sector, we identify concrete opportunities for strategy diversification. Italy, for instance, exhibits one of the highest shares of *improve* measures, with strategies focused on (energy) demand reduction and low-carbon alternatives limited to transport and energy consumption. Diversifying emission reduction efforts in the agricultural and industry sector could thus help Italy better achieve its mitigation objectives. Additionally, our analysis is the first to fully capture EU member states' preferences for policy instruments, which is heavily skewed toward economic and regulatory instruments.

4.2. Limitations

Our results have several limitations. Baseline data of member state reporting tends to be incomplete, with only 49 % of data entries being reported. We therefore centre our analysis on indicators for which country reporting is readily available and complete. Analysing the prevalence of mitigation strategies, however, does not account for their actual mitigation potentials. Due to incomplete reporting of quantitative indicators – particularly on GHG emission reduction potentials and ex-post emissions savings – it remains challenging to assess the actual relevance of different strategies for mitigating emissions. At the global level, *avoid* and *shift* strategies are estimated to account for approximately 32 % of the total mitigation potential by 2050 compared to a business-as-usual scenario (Creutzig et al., 2022a). For the European context, we draw on a meta-analysis conducted by Ivanova et al. (2020) to estimate average mitigation potentials for a range of consumption-oriented measures across the transport, building, and agricultural sector. As shown in Table 2, *avoid* and *shift* strategies demonstrate significant potential for contributing to the EU's mitigation targets. In particular, policies promoting car-free living, the adoption of renewable energy systems in the building sector, and dietary changes exhibit the highest mitigation potentials. Nevertheless, based on the subset of PaMs for which GHG reduction potentials are reported, it appears that countries do not fully leverage the potential of *avoid* and *shift* strategies and/or tend to attribute relatively low mitigation impacts to them. Approximately 57 % of the projected yearly GHG reductions in 2050 are attributed to *improve* strategies, which comprise two-thirds of quantified PaMs. In contrast, mitigation potential reporting of *avoid* measures is scarce (1 % of quantified PaMs), with countries projecting demand reduction measures to account for as little as 0 % to projected annual GHG emissions reductions in 2040. *Shift* measures account for 12 % of quantified PaMs and 8 % of estimated annual emission reduction potentials. Meanwhile, *general A/S* represents only 12 % of reported policies yet contributes 33 % of the projected reductions. This is largely due to Ireland reporting substantial mitigation potentials for housing sector policy-mixes that incorporate fuel-switch elements. It is important to acknowledge GHG emission reduction potentials are only reported for a non-representative sample, comprising 293 PaMs (18 %)

[11] Measures such as "5-HO-03: Substitution of individual oil-based furnaces," "5-HO-08: Phasing out oil and gas boilers through subsidies for conversion to green solutions," and "Setting the framework and promoting voluntary action" are all incorrectly classified as avoid following Jarre et al. (2024).

[12] *Ex-post* rebound effects may occur. This, however, may apply to all strategies considered (Figge et al., 2014; Sorrell et al., 2020).

Table 2
Quantified mitigation potentials for selected policy measures, adapted from Ivanova et al. (2020) to reflect the EU context. Mitigation potentials are calculated using a consumption-based methodology, with shares based on the GHG footprints of average EU citizens in 2020 (eurostat, 2025). Measures marked with * are those repetitively mentioned (n ≥ 10) in the EEA dataset.

Sector	Measures	GHG reduction potential	A-S-I Strategy	References
Transport	Live car-free	16 % [1.5 $tCO_2eq\ cap^{-1}\ year^{-1}$]	Avoid	(Wynes and Nicholas, 2017; Sköld et al., 2018)
	Shift to public transport*	12 % [1.1 $tCO_2eq\ cap^{-1}\ year^{-1}$]	Shift	(Ivanova et al., 2018; Lekve Bjelle et al., 2018; Sköld et al., 2018; IGES, 2019)
	Less transport by air	9 % [0.9 $tCO_2eq\ cap^{-1}\ year^{-1}$]	Avoid	(Ivanova et al., 2018; Lekve Bjelle et al., 2018; Sköld et al., 2018; IGES, 2019; Vita et al., 2019)
	Shift to active transport*	8 % [0.8 $tCO_2eq\ cap^{-1}\ year^{-1}$]	Shift	(Woodcock et al., 2013; Ivanova et al., 2018; Sköld et al., 2018; IGES, 2019; Vita et al., 2019; Moran et al., 2020)
	Telecommuting	6 % [0.5 $tCO_2eq\ cap^{-1}\ year^{-1}$]	Avoid	(IGES, 2019; Vita et al., 2019; Moran et al., 2020)
Buildings	Heat pump	9 % [0.9 $tCO_2eq\ cap^{-1}\ year^{-1}$]	Shift	(Ivanova et al., 2018; Sköld et al., 2018; IGES, 2019)
	Renewable-based heating*	7 % [0.7 $tCO_2eq\ cap^{-1}\ year^{-1}$]	Shift	(Ivanova et al., 2018; Sköld et al., 2018; IGES, 2019)
	Renewable electricity*	7 % [0.6 $tCO_2eq\ cap^{-1}\ year^{-1}$]	Shift	(Wynes and Nicholas, 2017; Sköld et al., 2018; IGES, 2019; Vita et al., 2019)
	Hot water saving	4 % [0.4 $tCO_2eq\ cap^{-1}\ year^{-1}$]	Avoid	(Lekve Bjelle et al., 2018; IGES, 2019)
	Less living space/co-housing	4 % [0.3 $tCO_2eq\ cap^{-1}\ year^{-1}$]	Avoid	(Ivanova et al., 2018; Sköld et al., 2018; IGES, 2019; Moran et al., 2020)
Agriculture	Vegan diet	10 % [0.9 $tCO_2eq\ cap^{-1}\ year^{-1}$]	Shift	(Werner et al., 2014; Hallström et al., 2015; Wynes and Nicholas, 2017; González-García et al., 2018; IGES, 2019; Vita et al., 2019)
	Organic food*	6 % [0.6 $tCO_2eq\ cap^{-1}\ year^{-1}$]	Shift	(Lekve Bjelle et al., 2018; Sköld et al., 2018; Vita et al., 2019)
	Vegetarian diet	6 % [0.6 $tCO_2eq\ cap^{-1}\ year^{-1}$]	Shift	(Werner et al., 2014; Hallström et al., 2015; Wynes and Nicholas, 2017; González-García et al., 2018; Sköld et al., 2018; IGES, 2019; Vita et al., 2019)
	Shift to lower carbon meats	4 % [0.3 $tCO_2eq\ cap^{-1}\ year^{-1}$]	Shift	(Hallström et al., 2015; Wood et al., 2018; IGES, 2019; Moran et al., 2020)
	Food waste reduction	3 % [0.2 $tCO_2eq\ cap^{-1}\ year^{-1}$]	Avoid	(Bellarby et al., 2013; Salemdeeb et al., 2017; Lekve Bjelle et al., 2018; IGES, 2019; Vita et al., 2019)

reported by 9 countries. Thus, beyond their numerical dominance, efficiency-oriented measures appear to be regarded as the primary lever for achieving required emission reductions in line with the EU's long-term mitigation targets. At the same time, EU member states show limited confidence in (energy) demand reduction as a viable mitigation strategy – contradicting a growing body of scientific literature. This aligns with findings by Wynes and Nicholas (2017), who note that government resources on climate change mitigation often overlook key high-impact consumption strategies. Possible reasons why member states underreport demand reduction strategies and consider *avoid* measures as low-impact – despite the substantial mitigation potential identified in the literature (Table 2) – may include concerns over feasibility and a reluctance to interfere with consumer sovereignty (Section 4.3).

Our findings on the prevalence of mitigation strategies are influenced by the varying levels of detail in country reporting. Cross-country differences in the number of reported PaMs can skew the analysis in favour of states that report at a more granular level, regardless of their emission share, population size, or GDP. As a result, countries with a higher number of reported PaMs are weighted more heavily in the overall results. To account for this, we adopted a relative comparison approach in Fig. 3, which presents the distribution of mitigation strategies by member state. An overview of the number of reported PaMs per country is provided in Fig. 3 and SM B.Res_Country. We believe this approach remains valid under the reasonable assumption that, while reporting granularity may vary between countries, it tends to be consistent within countries across sectors and instrument types – thus enabling both intra- and inter-country relative comparisons. Importantly, these cross-country differences in reporting do not affect our other findings, as these reflect a comprehensive stocktake of EU mitigation efforts rather than a cross-country comparison. However, a high level of abstraction and policy-mix reporting complicates strategy classification. To prevent systematic underreporting, the category *general (A/S)* was introduced to capture policy mixes that include *shift* and/or *avoid* elements which might otherwise have been overlooked within the broader *general* category. Despite potential discrepancies in reporting detail, we believe that focusing on relative shares by country (Fig. 3) and introducing an additional coding category has contributed to providing solid insights into country-specific and EU-wide strategic preferences shaping mitigation policy.

4.3. Potential further research avenues

Despite featuring marginal shares, approximately half of EU member states have reported strategies aimed at reducing absolute (energy) service levels, while all member states incorporate strategies to transition towards low-carbon technologies. The predominance of technology- and efficiency-oriented solutions in climate change mitigation may be attributed to their perceived feasibility. This feasibility is rooted in the notion that implementing such solutions is less contingent on the uncertainties and complexities inherent in the political, social and economic transformations required for broader societal change (Stoddard et al., 2021; Freeman et al., 2024). Another contributing factor to the dominance of *improve* strategies could be their alignment with the predominant political-economic interests of powerful economic actors who exert influence on policymaking and regulation, such as through firm-to-state lobbying (Bärnthaler et al., 2024). Therefore, further investigation is needed to understand why some countries place greater emphasis on *avoid* and *shift* strategies compared to others and to explore the specific contextual factors influencing policy choices among member states.

While mitigation strategies share the overarching goal of curbing emissions, they differ in the mechanisms through which these are achieved. However, individual strategies and instruments should not be viewed as mutually exclusive or as standalone solutions for mitigating emissions. Instead, these strategies are inherently interdependent, involving numerous synergies and trade-offs (Creutzig et al., 2016; Stechemesser et al., 2024). The expansion of public transportation, for instance, is more effective in condensed urban areas, where urban planning that promotes compact urban forms can create synergistic effects by facilitating greater use of public transport and active mobility (Rode et al., 2017). Potential rebound effects may further undermine the realization of mitigation potentials associated with individual or combined mitigation policies (Figge et al., 2014; Shove, 2018). Investigating interaction effects and rebound dynamics thus represents a promising avenue for future research.

The EU's commitment to cushion potential adverse social and economic impacts of a transition is firmly embedded in its pledge "to leave no one behind" (European Commission, 2023a). To explore the extent to which mitigation is linked with issues of social justice, we identified PaMs that explicitly reference social inclusion, justice, and inequality. Our analysis reveals that only 24 PaMs (1.5 % of the total) explicitly address these topics. While member states' emission scenarios primarily focus on achieving mitigation objectives, it is notable that the connection between climate and social policy is rarely made. This is particularly surprising given the significant social implications of the EU's primary policy instrument, the ETS, which disproportionately affects low-income households due to rising certificate prices (Fragkos et al., 2021; Landis et al., 2021). Further research is therefore needed to examine how member states address the distributional consequences of climate mitigation strategies and policy instruments, particularly for vulnerable and low-income populations.

5. Conclusion and policy implications

Given the EU's implementation gap and the need to mobilise diverse mitigation levers to stay within a 1.5-degree trajectory, we analyse 1583 measures from EU member states' long-term emission projections to assess what strategies European mitigation efforts are primarily based upon.

We find EU member states to primarily rely on efficiency improvements in existing technologies to reduce energy consumption and emission. Despite being reported by all EU member states, policies that require more fundamental changes such as shifting towards competitive low-carbon technologies or avoiding unnecessary (energy) consumption by redesigning service-provisioning systems remain underrepresented across all sectors. Diversifying mitigation portfolios in these sectors could involve various policies, such as promoting the sharing economy, vegetarian diets, or incentivising organic food production, all of which are associated with significant emission reduction potentials (Table 2). Moreover, policymakers are inclined to propose economic and regulatory instruments to mitigate sectoral emissions, which appear to be central for effective instrument mixes (Stechemesser et al., 2024). One implication of our works is that current EU mitigation efforts may underutilize the full range of available strategies and instruments. While the EU's reliance on *improve* measures does not inherently undermine mitigation effectiveness – given the substantial potential attributed to these strategies by many countries (Section 4.2) – additional efforts will be required to align with internationally binding climate targets. In this context, our analysis highlights potential opportunities to broaden mitigation portfolios beyond (energy) efficiency improvements. It furthermore points towards a science-policy gap, where the growing body of research on the potential benefits of *avoid* and *shift* strategies has not been adequately translated into policy. This is particularly concerning since reducing energy service levels is not only considered an important emission reduction lever (Ivanova et al., 2020; Cordroch et al., 2022; Creutzig et al., 2022a; Wiese et al., 2024), but could carry multiple co-benefits. These include lowering pressures on energy supply decarbonisation and the expansion of renewables (Best et al., 2022; Arnz et al., 2024), reducing investment requirements (Zozmann et al., 2021; Barrett et al., 2022), and improving human health and wellbeing (Roy et al., 2021; Creutzig et al., 2022a).

We concur with Zell-Ziegler et al. (2021) that a critical initial step is the integration of (energy) demand reduction within the EU's short-term policy framework – the 2030 Climate and Energy Ambition – to complement its existing pillars of decarbonisation, energy efficiency, internal energy market, as well as research, innovation and competitiveness. This would require member states to report on implemented and planned national demand reduction strategies, thereby elevating their importance not only in short-term but long-term mitigation planning. Furthermore, the European Commission plays a key role in assessing national policies and has the authority to issue recommendations. While these are non-binding, member states are required to consider them and explain in subsequent reporting duties how they have been addressed (European Parliament and European Council, 2018). This mechanism could be leveraged by the Commission to align national mitigation planning with state-of-the-art mitigation research on strategy diversification and the potential importance of (energy) demand reduction measures for net-zero pathways (Barrett et al., 2022; Arnz et al., 2024; Stechemesser et al., 2024).

Through addressing knowledge gaps regarding mitigation potentials, investment needs, and economic impacts of mitigation strategies, and by providing robust evidence-based recommendations, research at the science-policy interface may support the integration of a broader set of mitigation strategies into mainstream policymaking. Further work on the political economy of climate action, including analysis of key actors, vested interests, and institutional dynamics, remains essential to understanding barriers to implementation.

CRediT authorship contribution statement

Simon Grabow: Writing – review & editing, Writing – original draft, Visualization, Project administration, Methodology, Formal analysis, Conceptualization. **Tobias Riepl:** Writing – review & editing, Writing – original draft, Visualization, Formal analysis. **Johannes Thema:** Writing – review & editing, Formal analysis. **Carina Zell-Ziegler:** Writing – review & editing, Formal analysis.

Funding

SG's contributions were funded by the Austrian Climate and Energy Fund under the Austrian Climate Research Program (ACRP), project "Quantifying Qualitative Transformation Pathways towards Climate-friendly Living" [grant nbr. 48583527] and "Transforming essential provision systems through eco-social corridors" [project nbr. FO999913168]. JT and CZZ conducted this research as part of the project 'The role of energy sufficiency in energy transition and society' funded by the German Federal Ministry of Education and Research (BMBF), within the framework of the Strategy Research for Sustainability (FONA), as part of its Social-Ecological Research funding priority [grant nbrs. 01UU2004B (JT) and 01UU2004C (CZZ)].

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 the paper.

Acknowledgements

We would like to thank Nathan Barlow and Richard Bärnthaler for their valuable feedback on earlier versions of the manuscript.

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.enpol.2025.114888.

Data availability

The data is publicly available, with the reference provided in the reference section.

References

Abrell, J., Bilici, S., Blesl, M., Fahl, U., Kattelmann, F., Kittel, L., et al., 2024. Optimal allocation of the EU carbon budget: a multi-model assessment. Energy Strategy Rev. 51, 101271. https://doi.org/10.1016/j.esr.2023.101271.

Arnz, M., Krumm, A., 2023. Sufficiency in passenger transport and its potential for lowering energy demand. Environ. Res. Lett. 18, 094008. https://doi.org/10.1088/1748-9326/acea98.

Arnz, M., Göke, L., Thema, J., Wiese, F., Wulff, N., Kendziorski, M., et al., 2024. Avoid, Shift or Improve passenger transport? Impacts on the energy system. Energy Strategy Rev. 52, 101302. https://doi.org/10.1016/j.esr.2024.101302.

Baker, J., Kammerer, M., Castro, P., Ingold, K., 2025. The vertical policy harmonization indices: assessing the gap between climate mitigation pledges and policies. Clim. Policy 1–16. https://doi.org/10.1080/14693062.2024.2443482.

Bärnthaler, R., Novy, A., Arzberger, L., Krisch, A., Volmary, H., 2024. The power to transform structures: power complexes and the challenges for realising a wellbeing economy. Humanit. Soc. Sci. Commun. 11, 1–16. https://doi.org/10.1057/s41599-024-03065-7.

Barrett, J., Pye, S., Betts-Davies, S., Broad, O., Price, J., Eyre, N., et al., 2022. Energy demand reduction options for meeting national zero-emission targets in the United Kingdom. Nat. Energy 7, 726–735. https://doi.org/10.1038/s41560-022-01057-y.

Beck, S., Mahony, M., 2018. The politics of anticipation: the IPCC and the negative emissions technologies experience. Glob. Sustain. 1, e8. https://doi.org/10.1017/sus.2018.7.

Bellarby, J., Tirado, R., Leip, A., Weiss, F., Lesschen, J.P., Smith, P., 2013. Livestock greenhouse gas emissions and mitigation potential in Europe. Glob. Change Biol. 19, 3–18. https://doi.org/10.1111/j.1365-2486.2012.02786.x.

Bertoldi, P., Mosconi, R., 2020. Do energy efficiency policies save energy? A new approach based on energy policy indicators (in the EU Member States). Energy Policy 139, 111320. https://doi.org/10.1016/j.enpol.2020.111320.

Best, B., Christ, M., Santarius, T., Wiese, F., 2022. Exploring energy sufficiency: new challenges and options in times of crisis. TATuP-Z. Für Tech. Theor. Prax. 31, 10–15. https://doi.org/10.14512/tatup.31.2.10.

Chemnitz, C., Bechava, S., 2019. Agriculture atlas. Facts and figures on EU farming policy. Heinrich Böll Stiftung, bird life international, friends of the Earth Europe. Available at: https://eu.boell.org/sites/default/files/agricultureatlas2019_web_190507.pdf. (Accessed 14 February 2025).

Christophers, B., 2024. The Price is Wrong: Why Capitalism Won't save the Planet. Verso Books, London New York.

Cordroch, L., Hilpert, S., Wiese, F., 2022. Why renewables and energy efficiency are not enough - the relevance of sufficiency in the heating sector for limiting global warming to 1.5 °C. Technol. Forecast. Soc. Change 175, 121313. https://doi.org/10.1016/j.techfore.2021.121313.

Creutzig, F., Fernandez, B., Haberl, H., Khosla, R., Mulugetta, Y., Seto, K.C., 2016. Beyond technology: demand-side solutions for climate change mitigation. Annu. Rev. Environ. Resour. 41.

Creutzig, F., Roy, J., Lamb, W.F., Azevedo, I.M.L., Bruine de Bruin, W., Dalkmann, H., et al., 2018. Towards demand-side solutions for mitigating climate change. Nat. Clim. Change 8, 260–263. https://doi.org/10.1038/s41558-018-0121-1.

Creutzig, F., Niamir, L., Bai, X., Callaghan, M., Cullen, J., Díaz-José, J., et al., 2022a. Demand-side solutions to climate change mitigation consistent with high levels of well-being. Nat. Clim. Change 12, 36–46. https://doi.org/10.1038/s41558-021-01219-y.

Creutzig, F., Roy, J., Devine-Wright, P., Díaz-José, J., Geels, F., Grubler, A., et al., 2022b. Demand, services and social aspects of mitigation. IPCC 2022 Clim. Change 2022 Mitig. Clim. Change Contrib. Work. Group III Sixth Assess. Rep. Intergov. Panel Clim. Change PR Shukla J Skea R Slade Al Khourdajie R Van Diemen McCollum M Pathak Some P Vyas R Fradera M Belkacemi Hasija G Lisb. Luz J Malley. https://doi.org/10.1017/9781009157926.007.

Creutzig, F., Roy, J., Minx, J., 2024. Demand-side climate change mitigation: where do we stand and where do we go? Environ. Res. Lett. 19, 040201. https://doi.org/10.1088/1748-9326/ad33d3.

Dalkmann, H., Brannigan, C., 2007. Urban transport and climate change. Module 5e. Sustainable transport: a sourcebook for policy-makers in developing cities. GIZ Bonn and Eschborn, Germany: Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ) GmbH Available at: https://changing-transport.org/wp-content/uploads/2007_dalkmann_brannigan_transportandclimatechange.pdf. (Accessed 15 August 2024) 1-57.

Deason, J., Borgeson, M., 2019. Electrification of buildings: potential, challenges, and outlook. Curr. Sustain. Energy Rep. 6, 131–139. https://doi.org/10.1007/s40518-019-00143-2.

Duscha, V., Denishchenkova, A., Wachsmuth, J., 2019. Achievability of the Paris Agreement targets in the EU: demand-side reduction potentials in a carbon budget perspective. Clim. Policy 19, 161–174. https://doi.org/10.1080/14693062.2018.1471385.

Edenhofer, O., Kosch, M., Pahle, M., Zachmann, G., 2021. A whole-economy Carbon Price for Europe and How to Get There.

EEA, 2023a. Overview of Reported Integrated National Climate and Energy Policies and Measures in Europe in 2023. European Topic Centre Climate Change Mitigation. European Environment Agency. Available at: https://www.eionet.europa.eu/etcs/etc-cm/products/etc-cm-report-2023-06. (Accessed 12 August 2024).

EEA, 2023b. Trends and Projections in Europe 2023. European Environment Agency, Copenhagen. Available at: https://www.eea.europa.eu/publications/trends-and-projections-in-europe-2023. (Accessed 6 June 2024).

European Commission, 2023a. A green transition that leaves no one behind. Available at: https://ec.europa.eu/commission/presscorner/api/files/document/print/en/ac_23_3426/AC_23_3426_EN.pdf. (Accessed 8 January 2025).

European Commission, 2023b. Climate Action Progress Report 2023. European Commission, Brussels. Available at: https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX:52023DC0653. (Accessed 16 July 2024).

European Commission, 2024a. Climate strategies & targets - European Commission. Available at: https://climate.ec.europa.eu/eu-action/climate-strategies-targets_en. (Accessed 20 March 2024).

European Commission, 2024b. Securing our Future Europe's 2040 Climate Target and Path to Climate Neutrality by 2050 Building a Sustainable, Just and Prosperous Society. European Commission, Strasbourg. Available at: https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=COM%3A2024%3A63%3AFIN. (Accessed 16 July 2024).

European Commission, EEA, 2023. Reporting Guidelines on Integrated Policies and Measures Under EU 2018/1999. European Commission & European Environmental Agency. Available at: https://www.eionet.europa.eu/reportnet/docs/govreg/policies-and-measures/reporting-guidelines-dataflow-9-to-14-policies-and-measures.pdf/view. (Accessed 30 September 2024).

European Commission (n.d.). National energy and climate plans. Available at: https://commission.europa.eu/energy-climate-change-environment/implementation-eu-countries/energy-and-climate-governance-and-reporting/national-energy-and-climate-plans_en (Accessed July 22, 2024).

European Parliament, and European Council, 2018. Regulation (EU) 2018/1999 of the EUROPEAN parliament and of the council. Available at: https://eur-lex.europa.eu/legal-content/EN/TXT/HTML/?uri=CELEX%3A32018R1999.

eurostat (2025). EU GHG emissions from the production and consumption (footprint) perspectives. https://ec.europa.eu/eurostat/databrowser/view/cli_gge_foot/default/table?lang=envv. (Accessed 4 June 2025).

Figge, F., Young, W., Barkemeyer, R., 2014. Sufficiency or efficiency to achieve lower resource consumption and emissions? The role of the rebound effect. J. Clean. Prod. 69, 216–224. https://doi.org/10.1016/j.jclepro.2014.01.031.

Fragkos, P., Fragkiadakis, K., Sovacool, B., Paroussos, L., Vrontisi, Z., Charalampidis, I., 2021. Equity implications of climate policy: assessing the social and distributional impacts of emission reduction targets in the European Union. Energy 237, 121591. https://doi.org/10.1016/j.energy.2021.121591.

Fransen, T., Meckling, J., Stünzi, A., Schmidt, T.S., Egli, F., Schmid, N., et al., 2023. Taking stock of the implementation gap in climate policy. Nat. Clim. Change 13, 752–755. https://doi.org/10.1038/s41558-023-01755-9.

Freeman, R., Seljom, P.M.S., Valkering, P., Krook-Riekkola, A., 2024. Low energy demand scenarios for OECD countries: fairness, feasibility and potential impacts on SDGs. In: Labriet, M., Espegren, K., Giannakidis, G., Ó Gallachóir, B. (Eds.), Aligning the Energy Transition with the Sustainable Development Goals: Key Insights from Energy System Modelling. Springer Nature Switzerland, Cham, pp. 17–40. https://doi.org/10.1007/978-3-031-58897-6_2.

Fuchs, D., Lorek, S., Mamut, P., Rossmoeller, A., 2023. Fifty shades of sufficiency: semantic confusion and no policy. In: Jörgens, H., Knill, C., Steinebach, Y., Jörgens, H., Knill, C., Steinebach, Y. (Eds.), Routledge Handbook of Environmental Policy, pp. 347–357.

GIZ, 2014. Transport and climate change. Module 5e sustainable transport: a sourcebook for policy-makers in developing cities. Gesellschaft für internationale Zusammenarbeit (GIZ). https://doi.org/10.13140/2.1.4286.8009.

González-García, S., Esteve-Llorens, X., Moreira, M.T., Feijoo, G., 2018. Carbon footprint and nutritional quality of different human dietary choices. Sci. Total Environ. 644, 77–94. https://doi.org/10.1016/j.scitotenv.2018.06.339.

Gota, S., Huizenga, C., Peet, K., Medimorec, N., Bakker, S., 2019. Decarbonising transport to achieve Paris Agreement targets. Energy Effic 12, 363–386. https://doi.org/10.1007/s12053-018-9671-3.

Hallström, E., Carlsson-Kanyama, A., Börjesson, P., 2015. Environmental impact of dietary change: a systematic review. J. Clean. Prod. 91, 1–11. https://doi.org/10.1016/j.jclepro.2014.12.008.

Horn, S., Gough, I., Rogers, C., Tunstall, R., 2025. Meeting housing needs within planetary boundaries: a UK case study. Ecol. Econ. 230, 108510. https://doi.org/10.1016/j.ecolecon.2024.108510.

IEA, 2021. Portugal 2021. International Energy Agency. https://doi.org/10.1787/3b485e25-en.

IGES, 2019. Technical Report. 1.5-DEGREE LIFESTYLES: Targets and Options for Reducing Lifestyle Carbon Footprints. Institute for Global Environmental Strategies, Aalto University, D-mat ltd, Japan. Available at: https://www.iges.or.jp/en/publication_documents/pub/technicalreport/en/6719/15_Degree_Lifestyles_MainReport.pdf. (Accessed 3 June 2025).

IPCC, 2022. Summary for policymakers. In: Masson-Delmotte, V., Zhai, P., Pörtner, H.-O., Roberts, D., Skea, J., Shukla, P.R., Pirani, A., Moufouma-Okia, W., Péan, C., Pidcock, R., Connors, S., Matthews, J.B.R., Chen, Y., Zhou, X., Gomis, M.I., Lonnoy, E., Maycock, T., Tignor, M., Waterfield, T. (Eds.), Global Warming of 1.5°C: IPCC Special Report on Impacts of Global Warming of 1.5°C above Pre-industrial Levels in Context of Strengthening Response to Climate Change, Sustainable Development, and Efforts to Eradicate Poverty. Cambridge University Press, Cambridge, UK and New York, NY, USA, pp. 3–24. https://doi.org/10.1017/9781009157940.

IPCC, 2022. Glossary. *Climate Change 2022: Mitigation of Climate Change*. In: Shukla, P.R., Skea, J., Al Khourdajie, R., van Diemen, R., McCollum, D., Pathak, M., Some, S., Vyas, P., Fradera, R., Belkacemi, M., Hasija, A., Lisboa, G., Luz, S., Malley, J. (Eds.), Contribution of Working Group III to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change. https://doi.org/10.1017/9781009157926.020.

IPCC, 2023. In: Core Writing Team, Lee, H., Romero, J. (Eds.), *Climate Change 2023: Synthesis Report*. Contribution of Working Groups I, II and III to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change. IPCC, Geneva, Switzerland, pp. 35–115. https://doi.org/10.59327/IPCC/AR6-9789291691647.

Ivanova, D., Vita, G., Wood, R., Lausselet, C., Dumitru, A., Krause, K., et al., 2018. Carbon mitigation in domains of high consumer lock-in. Glob. Environ. Change 52, 117–130. https://doi.org/10.1016/j.gloenvcha.2018.06.006.

Ivanova, D., Barrett, J., Wiedenhofer, D., Macura, B., Callaghan, M., Creutzig, F., 2020. Quantifying the potential for climate change mitigation of consumption options. Environ. Res. Lett. 15, 093001. https://doi.org/10.1088/1748-9326/ab8589.

Jarre, M., Noussan, M., Campisi, E., 2024. Avoid–shift–improve: are demand reduction strategies under-represented in current energy policies? Energies 17, 4955. https://doi.org/10.3390/en17194955.

Kuckartz, U., 2012. Qualitative Inhaltsanalyse: Methoden, Praxis, Computerunterstützung. Beltz Juventa.

Kuckartz, U., 2019. Qualitative text analysis: a systematic approach. In: Kaiser, G., Presmeg, N. (Eds.), Compendium for Early Career Researchers in Mathematics Education. Springer International Publishing, Cham, pp. 181–197. https://doi.org/10.1007/978-3-030-15636-7_8.

Lage, J., Thema, J., Zell-Ziegler, C., Best, B., Cordroch, L., Wiese, F., 2023. Citizens call for sufficiency and regulation — a comparison of European citizen assemblies and National Energy and Climate plans. Energy Res. Social Sci. 104, 103254. https://doi.org/10.1016/j.erss.2023.103254.

Lage, J., Cordroch, L., Thema, J., Vondung, F., Schöpf, D., 2024. Housing for millions without new buildings? An analysis of the theoretical housing potential of under-occupied dwellings in the European building stock. Environ. Res. Lett. https://doi.org/10.1088/1748-9326/ad9c97.

Lamb, W.F., Mattioli, G., Levi, S., Roberts, J.T., Capstick, S., Creutzig, F., et al., 2020. Discourses of climate delay. Glob. Sustain. 3.

Landis, F., Fredriksson, G., Rausch, S., 2021. Between- and within-country distributional impacts from harmonizing carbon prices in the EU. Energy Econ. 103, 105585. https://doi.org/10.1016/j.eneco.2021.105585.

Lekve Bjelle, E., Steen-Olsen, K., Wood, R., 2018. Climate change mitigation potential of Norwegian households and the rebound effect. J. Clean. Prod. 172, 208–217. https://doi.org/10.1016/j.jclepro.2017.10.089.

Lenzi, D., Lamb, W.F., Hilaire, J., Kowarsch, M., Minx, J.C., 2018. Don't deploy negative emissions technologies without ethical analysis. Nature 561, 303–305. https://doi.org/10.1038/d41586-018-06695-5.

Moran, D., Wood, Richard, Hertwich, Edgar, Mattson, Kim, Rodriguez, Joao F.D., Schanes, Karin, et al., 2020. Quantifying the potential for consumer-oriented policy to reduce European and foreign carbon emissions. Clim. Policy 20, S28–S38. https://doi.org/10.1080/14693062.2018.1551186.

Mundaca, L., Ürge-Vorsatz, D., Wilson, C., 2019. Demand-side approaches for limiting global warming to 1.5 °C. Energy Effic 12, 343–362. https://doi.org/10.1007/s12053-018-9722-9.

Perino, G., Jarke-Neuert, J., Schenuit, F., Wickel, M., Zengerling, C., 2022. Closing the implementation gap: obstacles in reaching net-zero pledges in the EU and Germany. Polit. Govern. 10, 213–225. https://doi.org/10.17645/pag.v10i3.5326.

Pye, S., Broad, O., Bataille, C., Brockway, P., Daly, H.E., Freeman, R., et al., 2021. Modelling net-zero emissions energy systems requires a change in approach. Clim. Policy 21, 222–231. https://doi.org/10.1080/14693062.2020.1824891.

Rennert, K., Errickson, F., Prest, B.C., Rennels, L., Newell, R.G., Pizer, W., et al., 2022. Comprehensive evidence implies a higher social cost of CO2. Nature 610, 687–692. https://doi.org/10.1038/s41586-022-05224-9.

Rezai, A., van der Ploeg, F., 2017. Second-best renewable subsidies to De-carbonize the economy: commitment and the green Paradox. Environ. Resour. Econ. 66, 409–434. https://doi.org/10.1007/s10640-016-0086-3.

Rode, P., Floater, G., Thomopoulos, N., Docherty, J., Schwinger, P., Mahendra, A., et al., 2017. Accessibility in cities: transport and urban form. In: Meyer, G., Shaheen, S. (Eds.), Disrupting Mobility: Impacts of Sharing Economy and Innovative Transportation on Cities. Springer International Publishing, Cham, pp. 239–273. https://doi.org/10.1007/978-3-319-51602-8_15.

Roy, J., Some, S., Das, N., Pathak, M., 2021. Demand side climate change mitigation actions and SDGs: literature review with systematic evidence search. Environ. Res. Lett. 16, 043003. https://doi.org/10.1088/1748-9326/abd81a.

Salemdeeb, R., Font Vivanco, D., Al-Tabbaa, A., zu Ermgassen, E.K.H.J., 2017. A holistic approach to the environmental evaluation of food waste prevention. Waste Manag. 59, 442–450. https://doi.org/10.1016/j.wasman.2016.09.042.

Samadi, S., Gröne, M.-C., Schneidewind, U., Luhmann, H.-J., Venjakob, J., Best, B., 2017. Sufficiency in energy scenario studies: taking the potential benefits of lifestyle changes into account. Technol. Forecast. Soc. Change 124, 126–134. https://doi.org/10.1016/j.techfore.2016.09.013.

Schipper, L., Marie-Lilliu, C., 1999. Transportation and CO2 emissions : flexing the link - a path for the World Bank. World Bank Environmentally and Socially Sustainable Development. World Bank, Washington DC. Available at: https://documents.worldbank.org/en/publication/documents-reports/documentdetail/826921468766156728/Transportation-and-CO2-emissions-flexing-the-link-a-path-for-the-World-Banlk.

Schröder, E., Storm, S., 2020. Economic growth and carbon emissions: the road to "Hothouse Earth" is paved with good intentions. Int. J. Polit. Econ. 49, 153–173. https://doi.org/10.1080/08911916.2020.1778866.

Sharmina, M., Edelenbosch, O.Y., Wilson, C., Freeman, R., Gernaat, D.E.H.J., Gilbert, P., et al., 2021. Decarbonising the critical sectors of aviation, shipping, road freight and industry to limit warming to 1.5–2°C. Clim. Policy 21, 455–474. https://doi.org/10.1080/14693062.2020.1831430.

Shove, E., 2018. What is wrong with energy efficiency? Build. Res. Inf. 46, 779–789. https://doi.org/10.1080/09613218.2017.1361746.

Sköld, B., Baltruszewicz, M., Aall, C., Andersson, C., Herrmann, A., Amelung, D., et al., 2018. Household preferences to reduce their greenhouse gas footprint: a comparative study from four European cities. Sustainability 10, 4044. https://doi.org/10.3390/su10114044.

Smith, P., Davis, S.J., Creutzig, F., Fuss, S., Minx, J., Gabrielle, B., et al., 2016. Biophysical and economic limits to negative CO2 emissions. Nat. Clim. Change 6, 42–50. https://doi.org/10.1038/nclimate2870.

Solano Rodriguez, B., Drummond, P., Ekins, P., 2017. Decarbonizing the EU energy system by 2050: an important role for BECCS. Clim. Policy 17, S93–S110. https://doi.org/10.1080/14693062.2016.1242058.

Sorrell, S., Gatersleben, B., Druckman, A., 2020. The limits of energy sufficiency: a review of the evidence for rebound effects and negative spillovers from behavioural change. Energy Res. Social Sci. 64, 101439. https://doi.org/10.1016/j.erss.2020.101439.

Stechemesser, A., Koch, N., Mark, E., Dilger, E., Klösel, P., Menicacci, L., et al., 2024. Climate policies that achieved major emission reductions: global evidence from two decades. Science 385, 884–892. https://doi.org/10.1126/science.adl6547.

Stoddard, I., Anderson, K., Capstick, S., Carton, W., Depledge, J., Facer, K., et al., 2021. Three decades of climate mitigation: why haven't we bent the global emissions curve? Annu. Rev. Environ. Resour. 46, 653–689. https://doi.org/10.1146/annurev-environ-012220-011104.

Tsoi, K.H., Loo, B.P.Y., Banister, D., 2021. "Mind the (Policy-Implementation) gap": transport decarbonisation policies and performances of leading global economies (1990–2018). Glob. Environ. Change 68, 102250. https://doi.org/10.1016/j.gloenvcha.2021.102250.

UNEP, 2024. Emissions Gap Report 2024: No More Hot Air … Please! with a Massive Gap between Rhetoric and Reality, Countries Draft New Climate Commitments. United Nations Environment Programme. Available at: https://wedocs.unep.org/20.500.11822/46404. (Accessed 22 January 2025).

Ürge-Vorsatz, D., Metz, B., 2009. Energy efficiency: how far does it get us in controlling climate change? Energy Effic 2, 87–94. https://doi.org/10.1007/s12053-009-9049-7.

Vita, G., Lundström, J.R., Hertwich, E.G., Quist, J., Ivanova, D., Stadler, K., et al., 2019. The environmental impact of green consumption and sufficiency lifestyles scenarios in Europe: connecting local sustainability visions to global consequences. Ecol. Econ. 164, 106322. https://doi.org/10.1016/j.ecolecon.2019.05.002.

Wan, T., Fu, H., Li, X., Wu, F., Luo, C., Zhang, L., 2025. Assessment of decarbonization pathway for Chinese road transport sector based on transportation-energy integration systems framework. Energy 317, 134727. https://doi.org/10.1016/j.energy.2025.134727.

Warszawski, L., Kriegler, E., Lenton, T.M., Gaffney, O., Jacob, D., Klingenfeld, D., et al., 2021. All options, not silver bullets, needed to limit global warming to 1.5 °C: a scenario appraisal. Environ. Res. Lett. 16, 064037. https://doi.org/10.1088/1748-9326/abfeec.

Wei, M., McMillan, C.A., de la Rue du Can, S., 2019. Electrification of industry: potential, challenges and outlook. Curr. Sustain. Energy Rep. 6, 140–148. https://doi.org/10.1007/s40518-019-00136-1.

Werner, L.B., Flysjö, A., Tholstrup, T., 2014. Greenhouse gas emissions of realistic dietary choices in Denmark: the carbon footprint and nutritional value of dairy products. Food Nutr. Res. https://doi.org/10.3402/fnr.v58.20687.

Wiese, F., Taillard, N., Balembois, E., Best, B., Bourgeois, S., Campos, J., et al., 2024. The key role of sufficiency for low demand-based carbon neutrality and energy security across Europe. Nat. Commun. 15, 9043. https://doi.org/10.1038/s41467-024-53393-0.

Wood, R., Moran, D., Stadler, K., Ivanova, D., Steen-Olsen, K., Tisserant, A., et al., 2018. Prioritizing consumption-based carbon policy based on the evaluation of mitigation potential using input-output methods. J. Ind. Ecol. 22, 540–552. https://doi.org/10.1111/jiec.12702.

Woodcock, J., Givoni, M., Morgan, A.S., 2013. Health impact modelling of active travel visions for England and Wales using an integrated transport and health impact modelling tool (ITHIM). PLoS One 8, e51462. https://doi.org/10.1371/journal.pone.0051462.

Wynes, S., Nicholas, K.A., 2017. The climate mitigation gap: education and government recommendations miss the most effective individual actions. Environ. Res. Lett. 12, 074024. https://doi.org/10.1088/1748-9326/aa7541.

Zell-Ziegler, C., Thema, J., Best, B., Wiese, F., Lage, J., Schmidt, A., et al., 2021. Enough? The role of sufficiency in European energy and climate plans. Energy Policy 157, 112483. https://doi.org/10.1016/j.enpol.2021.112483.

Zhu, Y., Ma, H., Sha, C., Yang, Y., Sun, H., Ming, F., 2023. Which strategy among avoid, shift, or improve is the best to reduce CO2 emissions from sand and gravel aggregate transportation? J. Clean. Prod. 391, 136089. https://doi.org/10.1016/j.jclepro.2023.136089.

Zimmermann, P., 2022. Transformationspfade für den europäischen Gebäudesektor: Vergleich von Umwelteinsparungen durch Suffizienz-, Konsistenz- und Effizienzmaßnahmen. TATuP - Z. Für Tech. Theor. Prax. 31, 32–39. https://doi.org/10.14512/tatup.31.2.32.

Zozmann, E., Eerma, M.H., Manning, D., Økland, G.L., del Angel, C.R., Seifert, P.E., et al., 2021. The Potential of Sufficiency Measures to Achieve a Fully Renewable Energy System – A Case Study for Germany. https://doi.org/10.48550/arXiv.2109.00453.

zu Ermgassen, S.O.S.E., Drewniok, M.P., Bull, J.W., Corlet Walker, C.M., Mancini, M., Ryan-Collins, J., et al., 2022. A home for all within planetary boundaries: pathways for meeting England's housing needs without transgressing national climate and biodiversity goals. Ecol. Econ. 201, 107562. https://doi.org/10.1016/j.ecolecon.2022.107562.