



Impact of sufficiency on achieving the EU's 2030 and 2050 greenhouse gas emissions targets

Erwin M. Schau^{a,*}, Nicolò Golinucci^b, Filippo Beltrami^a, Matteo Vincenzo Rocco^b,
Matteo Giacomo Prina^a, Lorenzo Rinaldi^b, Wolfram Sparber^a

^a EURAC Research, Institute for Renewable Energy, Viale Druso 1, I-39100 Bolzano, Italy

^b Department of Energy, Politecnico di Milano, Via Raffaele Lambruschini, 4 20156 Milano, Italy

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ABSTRACT

The European Union (EU) is legally bound to achieve climate neutrality by 2050, but current greenhouse gas (GHG) trajectories indicate that this target may be missed. While technological efficiency improvements and renewable energy deployment are central to climate strategies, lifestyle-based sufficiency measures remain underexplored. This study assesses the GHG reduction potential of six energy sufficiency measures across five EU Member States—Denmark, France, Germany, Italy and Latvia—and evaluates their contribution to narrowing policy-relevant emissions gaps in National Energy and Climate Plan (NECP) trajectories.

Using the MARIO (Macroeconomic Assessment of Resource Inputs-Outputs) framework, we apply a scenario-based modelling approach comparing sufficiency scenarios against both linear projections and the European Environment Agency's "With Existing Measures" (WEM) baseline. Emission reductions are calculated using delta (absolute difference) and factor (relative ratio) metrics to establish upper and conservative bounds. Sensitivity analyses assess baseline selection.

Sufficiency measures, particularly dietary change and reduced aviation demand, show the highest mitigation potential. By 2030, the six measures reduce emissions by up to 170 Mt CO_{2e} across the five countries, increasing to 650 Mt CO_{2e} by 2050. Relative to 1990 levels, this corresponds to reductions of 0.9–4.4 % by 2030 and 1.1–16 % by 2050, depending on methodological boundary conditions. While sufficiency alone does not achieve net zero, it materially narrows the emissions gap relative to NECP trajectories, particularly in hard-to-abate sectors such as food systems and aviation.

Sufficiency therefore offers a bounded but policy-relevant complement to technological decarbonisation and warrants systematic integration into EU climate governance frameworks.

1. Introduction

The Paris Agreement of 2015 established a global target to keep warming well below 2 °C, preferably 1.5 °C [1]. Yet, current greenhouse gas (GHG) emissions trajectories fall short of this target. The IPCC concludes with high confidence that human activities have unequivocally caused global warming, reaching 1.1 °C above 1850–1900-levels in 2011–2020 partly driven by unsustainable energy use and lifestyles and consumption patterns [2]. Achieving substantial greenhouse gas reductions while promoting social equity demands solutions beyond just increasing energy efficiency through technology [3]. One key approach is adopting energy-sufficient lifestyles. In this study, sufficiency is understood as a set of social, infrastructural, and regulatory conditions

enabling reductions in energy service demand through behavioural and lifestyle changes, distinct from efficiency improvements (service provision with lower resource intensity) and renewable energy substitution (supply-side decarbonisation) [4–8]. A comprehensive conceptual framing and typology of sufficiency measures, including their positioning relative to technological decarbonisation pathways, is provided in Golinucci et al. [9].

The literature review shows that energy sufficiency represents a shift away from technology-focused solutions, emphasizing behavioural changes and social adaptations that reduce emissions and resource use. It involves restructuring daily practices, cultural norms, and infrastructure to support climate neutrality [5,7,10]. Lifestyle-based sufficiency includes actions such as reducing meat consumption, cycling

* Corresponding author.

E-mail address: erwin.schau@eurac.edu (E.M. Schau).

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instead of driving, and adopting more sustainable consumption habits [11,12]. At the international level, sufficiency is increasingly recognized in climate policy frameworks. The IPCC's "Avoid-Shift-Improve" model highlights sufficiency as a high-impact strategy, particularly in areas like diet, mobility, and infrastructure [2,13]. Sufficiency remains under-represented in EU climate strategies. The European Commission's assessment of draft NECPs finds that most countries are not on track to meet 2030 targets, with what sufficiency is largely absent [14]. Only Finland, Sweden, and Slovenia are aligned with the 2050 climate neutrality goal, primarily due to land use and forestry measures.

Several studies highlight the need for stronger integration of sufficiency. Zell-Ziegler et al. identify over 230 sufficiency-related measures in EU policy, mostly in transport, and call for improved modelling frameworks [15,16]. Lage et al. show that citizen assemblies support sufficiency more strongly than current NECPs reflect [17]. Nyfors et al. propose a comprehensive sufficiency policy framework for Finland, including regulatory, economic, and informational tools [18]. A focused assessment by Olesen and Vikkelsø [19 under review] of NECPs in Denmark, France, Germany, and Italy reveals varied national approaches: Denmark and France emphasize shared housing and carpooling, while Germany and Italy focus on public transport and remote work. These findings underscore the fragmented integration of sufficiency across member states and the need for more coherent policy alignment.

The FULFILL project identified six key sufficiency measures: (1) increasing cycling modal share, (2) dietary change toward plant-based diets, (3) reducing air travel, (4) moderating car size, (5) sharing products (e.g., washing machines), and (6) sharing housing space. These measures were selected for their quantifiability and relevance to lifestyle-driven emissions reductions [20–22].

Building on the FULFILL project [23], this study provides a quantitative, country-level assessment of the potential GHG emission reductions achievable through six lifestyle-based energy sufficiency measures across five EU Member States—Denmark, France, Germany, Italy, and Latvia—and the EU as a whole. Using a scenario-based modeling approach, this study compares sufficiency driven emission reductions against two projection baselines - a linear forecast and the European Environment Agency's "With Existing Measures" (WEM) scenario - and assess their contribution to national NECP targets and the EU's collective NDC for 2030 and 2050. By applying complementary delta and factor methods and sensitivity analysis, this paper builds on the MARIO-based framework developed and validated by Golinucci et al. [9], which provides a comprehensive EU-wide assessment of sufficiency impacts, and extend it by explicitly quantifying sufficiency's role in closing policy-relevant emissions gaps.

The remainder of the paper is structured as follows. Section 2 describes the materials and methods employed; Section 3 presents the results; Section 4 discusses the findings, policy implication and limitations. Section 5 concludes with recommendation.

2. Materials and methods

This research draws upon four primary data sources: historical emissions data and accompanying linear projections from the European Commission's DG Energy statistics [24] future emissions forecasts from the European Environment Agency based on member state policies [25], comprehensive findings from the FULFILL project [23] especially [9,19, 26], and National Energy and Climate Plans from Denmark, France, Germany, Italy, and Latvia [27].

The UNFCCC oversees Nationally Determined Contributions (NDCs), which outline each country's climate commitments under the Paris Agreement [1]. The EU submits a single NDC for all 27 member states, operationalized through National Energy and Climate Plans (NECPs) developed by each country. These NECPs follow an 18-month cycle and are evaluated by the European Commission [28].

In this paper, we focus on five EU member states—Denmark, France,

Germany, Italy, and Latvia. Additionally, the study evaluates the potential for enhancing NECP policies and the EU's NDC commitments. A key methodological component is the input/output analysis (IOA) [20], which estimates GHG reduction potentials from selected sufficiency measures and lifestyle changes. These estimates are benchmarked against a reference scenario (2020–2050), constructed from historical emissions trends and existing EU policy trajectories. The input/output analysis (IOA) method delivered detailed potential GHG emissions reductions from a set of energy sufficiency measures and lifestyle changes against the baseline emissions (defined as the "reference scenario") prior to their future adoption (2020 – 2050). The reference scenario was created starting from the historical data trends and approved EU policies influencing future evolution thinking [20].

Fig. 1 provides a visual representation of these data sources and their methodological application, which are elaborated in subsequent sections.

2.1. Historical GHG emissions

Historical GHG emissions data were obtained from the European Commission's Directorate-General for Energy, Unit A4 Energy Statistics [24]. Data are expressed in CO₂e, including CO₂, N₂O, CH₄, HFC, PFC, SF₆, and NF₃.

In Denmark, greenhouse gas emissions reached their highest point of 94.9 Mt CO₂e in 1996, before declining steadily to 44.2 Mt CO₂e by 2022. France demonstrated consistent emission reductions, decreasing from 548.9 Mt CO₂e in 1990 to 409.7 Mt CO₂e in 2022. Similarly, Italy saw emissions climb to a maximum of 604.1 Mt CO₂e in 2005, followed by a continuous decrease to 419.5 Mt CO₂e in 2022. Germany achieved substantial reductions, with emissions falling from 1262.8 Mt CO₂e in 1990 to 777.4 Mt CO₂e in 2022, partly due to post-reunification industrial restructuring that involved modernizing or closing coal-intensive facilities in former East Germany [29]. Latvia experienced a dramatic emissions decline from 26.3 Mt CO₂e in 1990 to 10.6 Mt CO₂e in 2022, with the most significant drop following the Soviet Union's collapse, after which emissions stabilized around 11 Mt CO₂e annually. Collectively, EU27 emissions decreased from 4921.9 Mt CO₂e in 1990 to 3484.5 Mt CO₂e in 2022 [24]. This reduction stems from member states' efforts to adopt cleaner energy technologies and enhance energy efficiency, along with the effects of globalization [30] as production activities shifted outside EU borders.

2.2. Projections

Two different projections were applied for the period 2020 – 2050; the linear projection based on historical emissions and EEA WEM projection, that are shortly described here.

2.2.1. Linear projections

Using historical emission data (1990–2022) from [24] shown in Fig. 2(a), we constructed linear forecasts extending to 2050 as a baseline scenario that excludes specific policy interventions. These projections extrapolate existing trends without incorporating planned measures or targets, providing a straightforward reference point for interpreting results. The linear approach offers computational simplicity and replicability, while its mathematical basis ensures consistent and reproducible transformations across analyses.

2.2.2. EEA WEM projection

The EEA generates member state emission forecasts through 2050 [25] using two distinct modelling approaches: WEM (With Existing Measures) and WAM (With Additional Measures) [31]. The WEM scenario incorporates currently active and enforced policies only, establishing a baseline for evaluating the effectiveness of existing climate measures against future targets. In contrast, WAM projections encompass both current policies and planned future interventions [31]. For

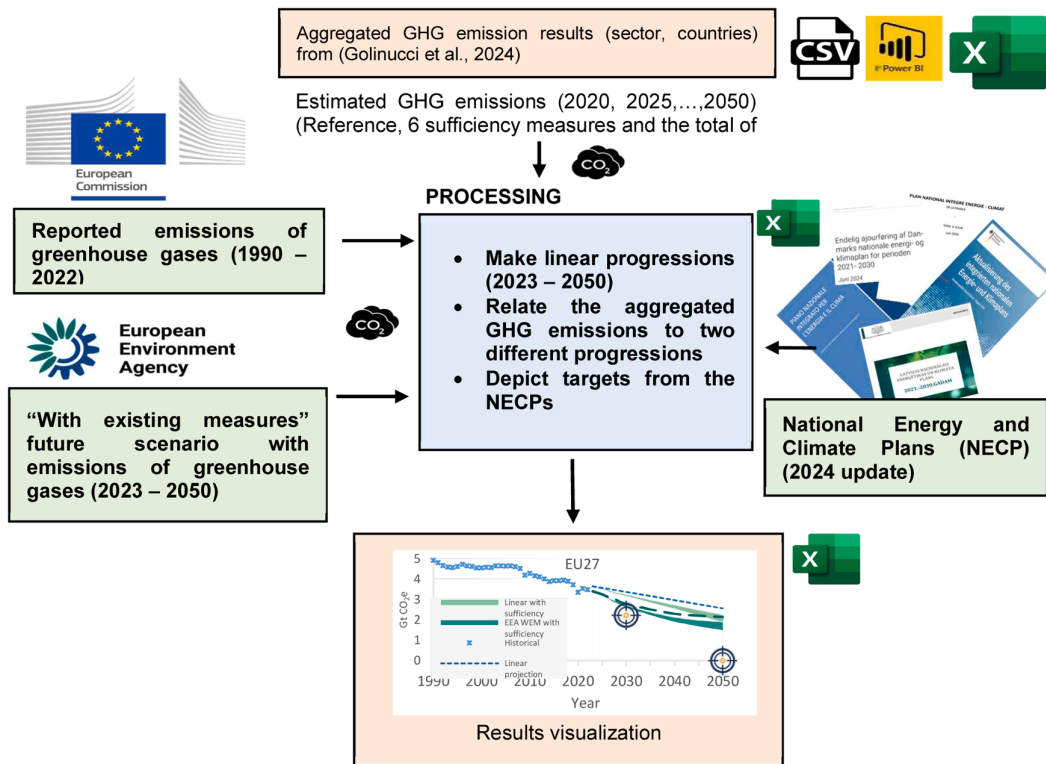


Fig. 1. Data flow diagram illustrating the integration of source materials through analysis to final visualization of results (based on [20,26]).

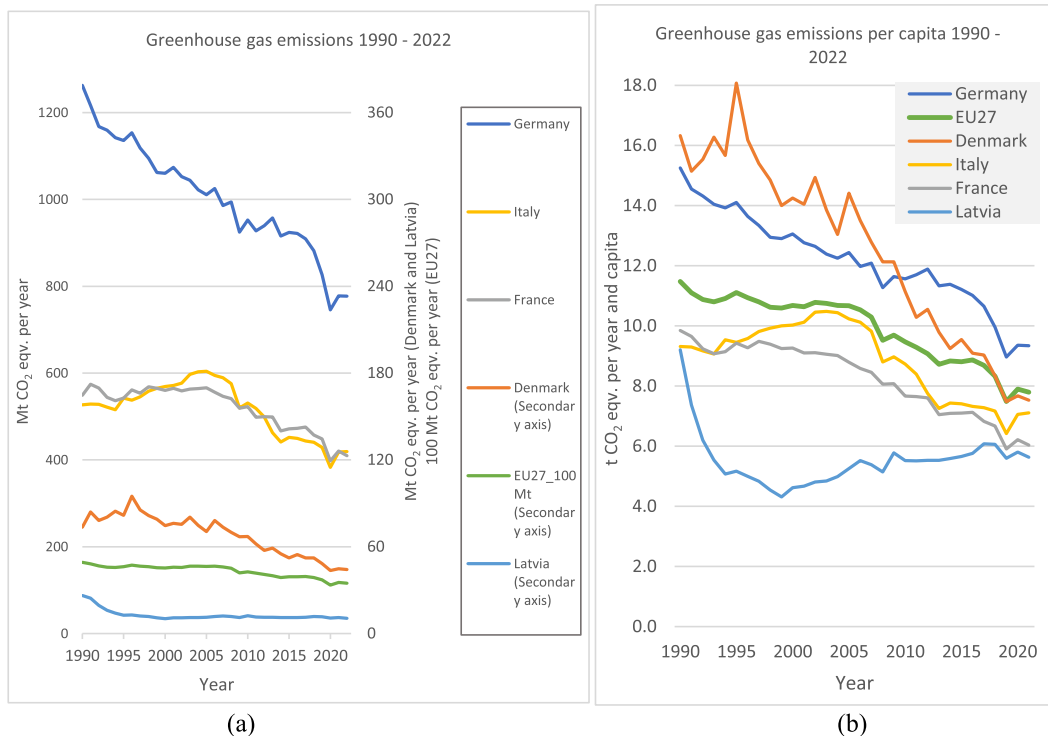


Fig. 2. GHG emissions 1990 – 2022 for the five key countries and the EU. Note the different y-axis and scales (Data source: [24]) (a) Total in Mt CO₂e, (b) per capita in t CO₂e.

this analysis, we selected the more conservative WEM projections as an additional benchmark, minimizing potential overlap with our

sufficiency measures.

2.3. MARIO used on environmentally-extended multi-regional supply

The input-output model framework MARIO can be used on any Environmentally-Extended Multi-Regional Supply and Use Table (EE-MRSUT) or Input-Output table (IOT) in general [32]. Within the FULFILL project [23], MARIO has been used to update input data annually and regionally and providing the greenhouse gas emissions data used in this study. MARIO is a Python-based IO modelling environment capable of handling multi-regional and hybrid supply-use tables across monetary and physical units. The input-output model applied in this case simulates each year based on a modified version of the input-output table derived from the hybrid Exiobase [33]. For each year, consumption grows by adjusting the final demand matrix in line with OECD GDP projections, while the mix and efficiency of key technologies are annually updated by modifying both endogenous and exogenous technical coefficients. All inputs, methods and results have been transparently documented and published in a manner that allows for full reproducibility by other researchers. These can be accessed in the dedicated code repository¹.

Reference [20] and further developed and deepened in [9] provide comprehensive details of the model, which employs supply-use input-output tables (SUT) in order to monitor industrial commodity flows. The framework incorporates production, consumption, and environmental matrices, with environmental impacts quantified in physical units and normalized into footprint matrices for elements like GHG emissions. The baseline reference scenario integrates projections for economic growth [34], sector-specific technological progress (for residential heating, private car transportation and electricity production), and business-as-usual policy evolution. To extend findings from the five focal countries to remaining EU members, the study employed clustering analysis based on intensive indicators, allowing appropriate scaling across nations of different sizes [9,20].

The methodology for calculating potential GHG reductions through sufficiency measures compares sufficiency and reference scenarios using input-output analysis to evaluate how lifestyle modifications affect overall emissions, as shown in Fig. 3.

The output of the EE-MRSUT input-output model is illustrated conceptually in Fig. 3. Emission reductions were quantified at five-year intervals from 2020 to 2050 by subtracting sufficiency scenario emissions from the reference scenario:

$$E_{\Delta} = E_{\text{REF}} - E_{\text{SUF}} \quad (1)$$

Because historical data and EEA projections show a declining trend, while the input-output model reference exhibits slight growth or stability, we additionally calculated a ratio-based indicator:

$$E_{\text{Factor}} = E_{\text{SUF}}/E_{\text{REF}} \quad (2)$$

We apply both metrics to characterise the impact of sufficiency measures. The delta metric (Eq. (1)) quantifies the absolute emission reduction (Mt CO₂e), directly reflecting the magnitude of avoided emissions (cf. Fig. 3). The factor metric (Eq. (2)) expresses the proportional change relative to the reference, providing a scale-independent measure of relative mitigation performance.

Under declining baseline projections towards 2050, these two approaches define a range of potential emission reductions. The absolute difference (E_{Δ}) reflects the upper bound of achievable savings, while the ratio-based metric (E_{Factor}) yields a more conservative estimate of relative mitigation effects, assessed against both linear and EEA WEM projections (Figs. 6–11).

The divergence between the MARIO Reference scenario and

historical/EEA projections is deliberate. While historical data and EEA trends show declining emissions, the MARIO baseline incorporates projected GDP growth and structural technological evolution (electrification and power-sector decarbonisation) under a ceteris paribus framework (cf. Sections 2.2 and 3.3.1 in [9]). This ensures sufficiency impacts are assessed against a dynamically evolving economy rather than a static baseline. The rationale and implications of this structured baseline design are explicitly documented and discussed in Section 4.2 [9]

Fig. 4 illustrates cumulative GHG emission savings from all six sufficiency measures across the five focus countries and remaining EU members (EU-22) from 2020–2050, measured in million tonnes CO₂ equivalent (Mt CO₂e). The savings potential increases over time, with the most substantial gains in later years. The EU-22 shows the highest potential, followed by Germany, France, and Italy, reflecting their larger populations. Denmark and Latvia's contributions appear minimal due to their size. Total EU savings could reach 171 Mt CO₂-eqv by 2030 and 649 Mt CO₂-eqv by 2050, assuming constant conditions. The analysis demonstrates that sufficiency measures could substantially reduce emissions throughout the EU.

Fig. 5 illustrates country-specific GHG reduction potentials for each sufficiency measure. The varying scales on the y-axis reflect the wide range of potential savings across measures. While Denmark and Latvia show minimal contributions due to their size, the combined data from the five focus countries plus the remaining 22 EU nations represents the complete EU27.

The 'biking more' sufficiency measure (Fig. 5a) shows EU-wide progress by 2030, totaling 7.8 Mt CO₂-e, with Germany (1.0 Mt CO₂-e) and Italy (0.7 Mt) leading the gains before stabilizing. Dietary changes (Fig. 5b) demonstrate substantial growth potential, projecting 515 Mt CO₂e reduction across the EU by 2050.

Aviation-related reductions (Fig. 5c) begin modestly through 2025, accelerate until 2035, then stabilize, achieving 31 Mt CO₂e savings by 2030 and 101 Mt CO₂e by 2050. Vehicle size modifications (Fig. 5d) follow a similar trajectory but at lower magnitudes, reaching 21 Mt CO₂e in EU-wide reductions by 2050.

Fig. 5e shows the sharing of products (washing machines). GHG emissions reduction potential demonstrates a marginal impact in the initial years, with minimal graphical representation before 2025. The trajectory exhibits a stepwise incremental pattern, escalating in a projected total potential GHG reduction for the European Union of 0.15 Mt CO₂ equivalent (CO₂e) by 2030, to 1.8 Mt CO₂e by 2050.

2.4. NECPs and sufficiency policies for five European countries

This section examines the Danish, French, German, Italian and Latvian NECPs, analysed in the period between July and August 2024. Building on prior FULFILL project research, particularly [19], our analysis focuses specifically on how existing sufficiency policies within these NECPs align with our studied measures, rather than providing comprehensive NECP documentation (which is available in studies like [15]). Across all examined NECPs, we identified two consistent priorities: renewable energy expansion (particularly solar and wind) and enhanced energy security through reduced fossil fuel dependence. Currently, some country-level plans also incorporate sufficiency-oriented policies.

A summary of sufficiency-oriented policies is reported in Table 1.

The five EU countries' NECPs comprehensively urge the shift towards more sustainable ways to produce and consume energy, while highlighting the contribution of behavioural changes to complement such efforts. Overall, as regards Denmark, the NECP [35] establishes ambitious climate targets: 70 % GHG reduction by 2030 (from 1990 baseline) and climate neutrality by 2045, with a goal of 110 % emissions reduction by 2050. The NECP pivots on a substantial expansion of renewable energy infrastructure, specifically targeting a quadrupled renewable electricity production by 2030. This will be predominantly

¹ https://github.com/SESAM-Polimi/FULFILL_MARIO

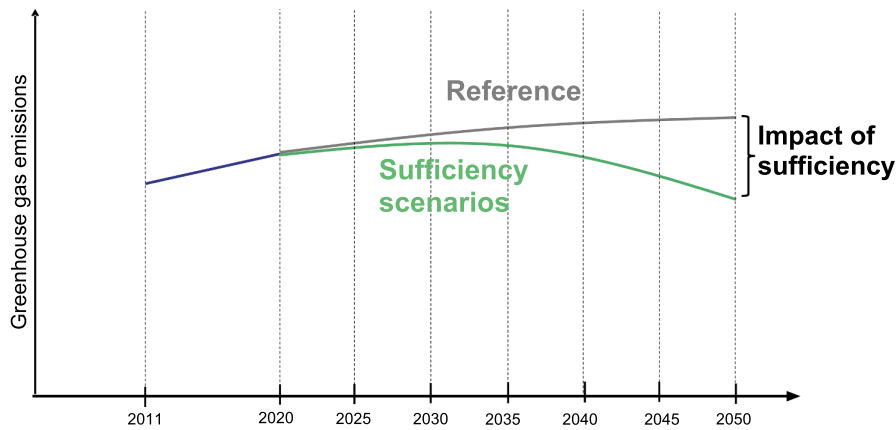


Fig. 3. Qualitative comparison of GHG emissions between reference and sufficiency scenarios in the FULFILL project framework (based on [20]).

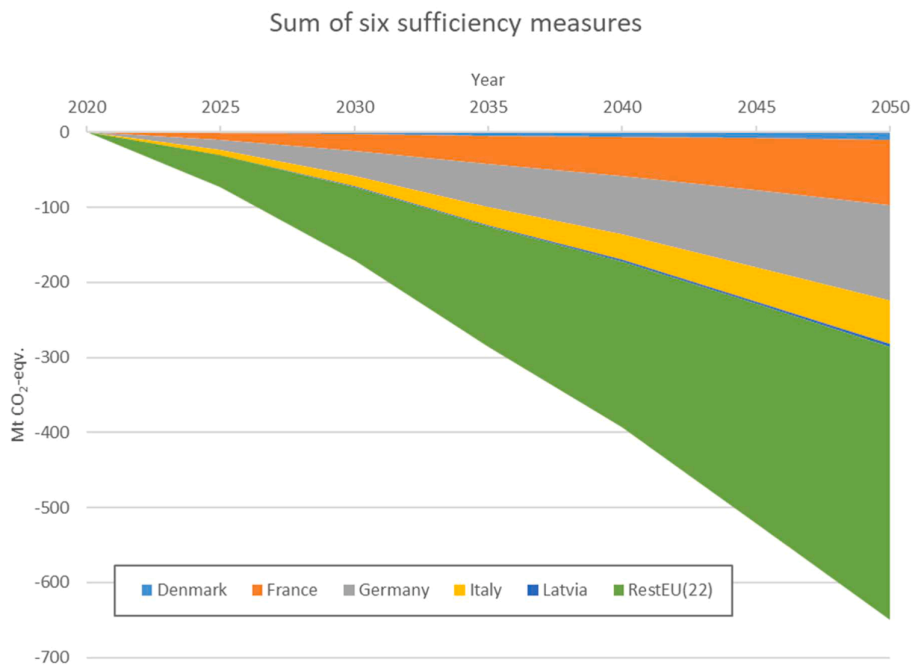


Fig. 4. Cumulative greenhouse gas (GHG) emission reductions achievable through implementing all six sufficiency measures across EU member states through 2050, as determined by [20].

accomplished through offshore wind farm developments and the establishment of energy islands. The plan also encompasses comprehensive energy efficiency enhancements across residential, commercial, and public sectors using financial incentives, regulations, and public awareness campaigns. To strengthen energy security, Denmark aims to decrease fossil fuel reliance while fostering international energy partnerships with neighbouring nations. As for France, its NECP [37] sets ambitious emission reduction goals and is oriented towards achieving net zero emissions by 2050, concurrent with a 40 % reduction from 1990 baseline levels by 2030. These decarbonisation targets are substantiated by the French National Low Carbon Strategy (SNBC 2), which delineates precise carbon budgetary allocations, establishing an annual carbon budget of 357 Mt CO₂e for 2024–2028 and 299 Mt CO₂e for 2029–2033. Germany's NECP [39] sets an ambitious trajectory, establishing progressive climate targets: 65 % GHG reduction by 2030 from 1990 levels, 88 % by 2040, and carbon neutrality by 2045, with federal agencies targeting neutrality by 2030.

Conversely, the 2024 Italian NECP reveals shortfalls in meeting 2019 INECP targets. Renewable energy projections for 2030 fall short at 26 % versus the targeted 30 %, while final energy consumption is projected to reach 111 million tons of oil equivalent (Mtoe), exceeding the target of 104 Mtoe[40]. The Italian NECP attributes these shortcomings to three main factors: unrealistic initial targets, incomplete policy implementation, and external disruptions including the pandemic, economic fluctuations, and geopolitical conflicts. Lastly, Latvia's updated 2024 NECP [41] targets 65 % emission reductions by 2030 (from 1990 baseline), moving towards full climate neutrality by 2050.

3. Results

3.1. Results by country and EU aggregated

Figs. 6–10 analyse GHG emission trajectories (1990–2050) for Denmark, France, Germany, Italy, Latvia, while Fig. 11 depict the

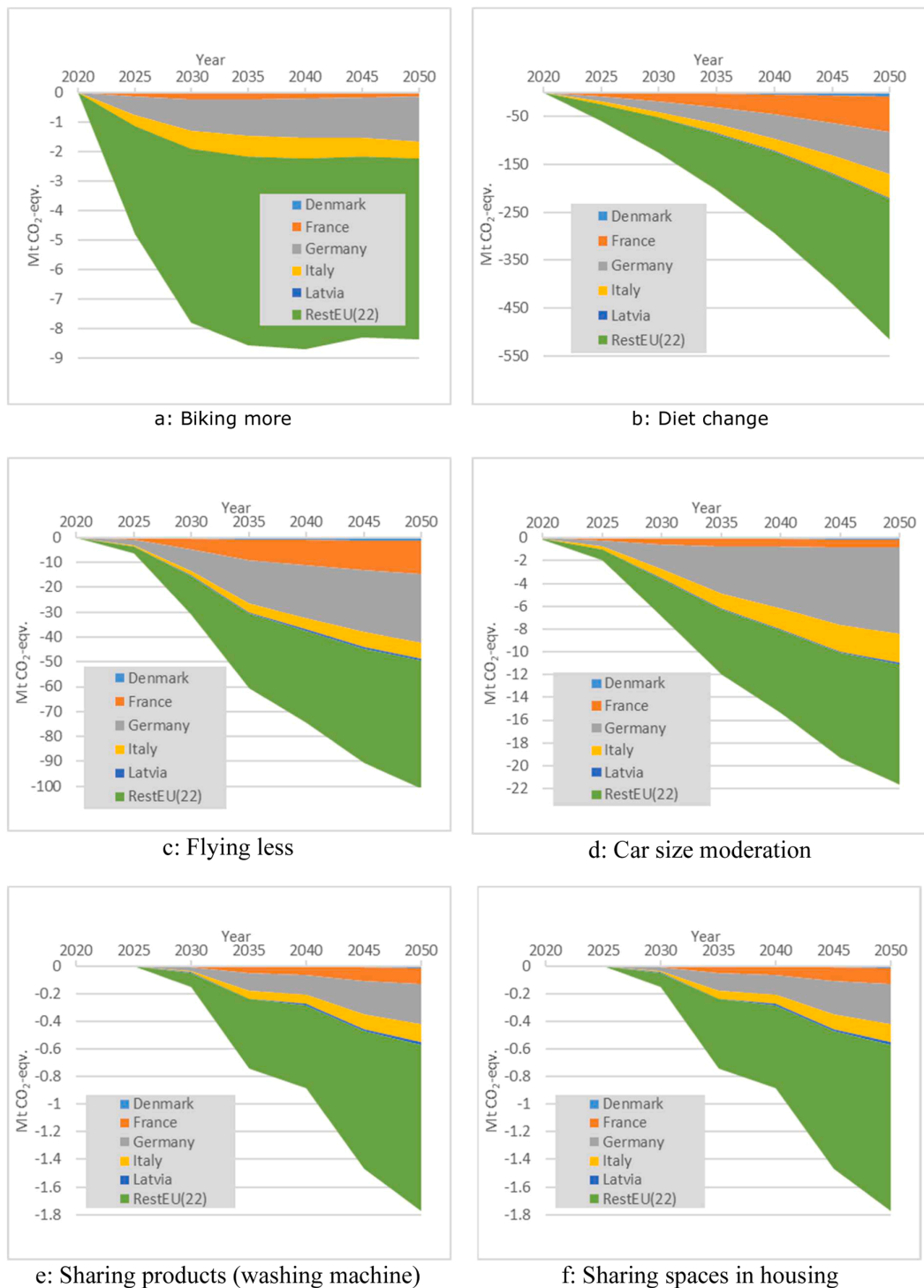


Fig. 5. Country-specific greenhouse gas reduction potential across the six sufficiency initiatives a-f. X-axis with years 2020 – 2050 and y-axis in Mt CO₂-equivalent. Note the y-axis scale that is different for each sufficiency measure a-f. (Data source: [20]).

situation for EU as a total (27 member states), contrasting historical data against future projections and sufficiency scenarios relative to national NECP and EU NDC targets. Blue markers trace historical emissions from 1990–2022, showing overall decline. Two projection methodologies extend from 2023–2050: a linear trend (blue dashed line) and the EEA WEM projection (green dashed line). Each region features two

sufficiency scenarios incorporating our six measures: The scenario analyses incorporate two distinct projection pathways: "Linear with Sufficiency" (represented in light green) and "With Existing Measures (WEM) with Sufficiency" (depicted in dark green), both demonstrating enhanced emission reduction potential. The green-shaded zones represent probabilistic emission ranges, delimited by the sufficiency factor

Table 1

Cross-country comparison of sufficiency policies for the five selected EU countries.

Country's NECP	Status of sufficiency policies
Denmark	The Danish NECP (June 2024) [35] incorporates several sufficiency initiatives, with notable focus on sustainable transportation. The government supports cycling infrastructure through dedicated state funding, municipal co-financing programs, and a new national cycling advisory centre. While dietary measures are not explicitly included in the NECP, Denmark's Official Dietary Guidelines [36] address food-related climate impacts through Nordic regional collaboration. For aviation, Denmark will introduce a passenger tax (averaging DKK 100) in 2025, projected to decrease air travel by 4 % within 2030 [35]. However, this measure's effectiveness may be limited since some tax revenue will subsidize regional airports and domestic flights, potentially undermining the broader emission reduction goals [19].
France	The French NECP [37] addresses dietary impacts through programs aimed at reducing meat and dairy consumption [19]. Within the transportation sector, France implements aviation reduction strategies through air ticket taxation and restrictions on short-haul flights when rail alternatives exist within 2.5 h [19,38]. France also leads in high-speed rail development, having added "757 km of additional new high-speed lines between 2015 and 2020" [37], facilitating a shift from air travel to more environmentally efficient rail transport. Additionally, France's comprehensive cycling strategy, outlined in the Mobility Guidance Act, encompasses multiple initiatives. Employers receive incentives to support sustainable commuting, including subsidies for electric and cargo bike purchases and bonuses for trading in older vehicles. The legislation mandates secure bike parking in new construction projects and provides tax benefits to companies offering bicycle commuting options. Building on the success of the 2018 cycling plan, France has enhanced its cycling infrastructure development through the 2022–2027 cycling and active mobility initiative, which emphasizes both physical infrastructure and cultural adoption, particularly in educational settings ([19,37]).
Germany	The German National Cycling Plan 3.0 (NRVP 3.0) aims to double cycling distance by 2030 through comprehensive infrastructure development. The plan combines physical improvements (daily commuter routes, tourist paths, parking facilities) with institutional support, including professional training programs for municipal workers through the "Inviting Cycling Networks" initiative. Germany is developing digital mobility platforms to integrate bicycle sharing with other transportation options, while establishing seven academic positions dedicated to sustainable transport research. These efforts are reinforced by Road Traffic Act amendments that prioritize environmental protection and public health [39]. Addressing dietary impacts, the Federal Ministry of Food and Agriculture is developing a comprehensive nutrition strategy. This framework combines policy tools to create an environment conducive to sustainable food choices, emphasizing accessibility and consumer empowerment in making healthier, more sustainable dietary decisions. For transportation reform, Germany has adjusted pricing structures to favour rail travel, reducing long-distance rail VAT from 19 % to 7 % in January 2020 while raising aviation taxes in April 2020. This policy aims to correct historical price imbalances that favoured air travel. However, the initiative's effectiveness is potentially undermined by continuing aviation subsidies, with tax relief for domestic flights reaching €504 million in 2023 [19,39].
Italy	The Italian NECP (Integrated NECP)[40] advocates for "[...] a substantial shift in lifestyles and consumption patterns towards more energy-efficient behaviour and lower emissions, to which new generations are certainly more sensitive, acting through the sources of public training and information, together with ways of promoting/discouraging behaviour according to their sustainability" (p. 5). As concerns the transportation sector, Italy has implemented cycling infrastructure development plans aligned with sufficiency objectives. A 2018 law requires larger municipalities (population over 100,000) and metropolitan areas to develop comprehensive 'bicibility plans' within their Sustainable Urban Mobility Plans (SUMP). To support this initiative, detailed implementation guidelines were released in October 2020, providing planning

Table 1 (continued)

Country's NECP	Status of sufficiency policies
Latvia	frameworks for communities of all sizes. The comprehensive cycling infrastructure guide was subsequently integrated into the national Master Plan for Cycling (ratified in 2022) [40]. Latvia's updated 2024 NECP [41] promotes cycling through strategic e-bike infrastructure development, including charging stations near residential areas and parking facilities, along with financial assistance for low-income households to acquire e-bikes. Latvia emphasizes micromobility expansion through dedicated cycling paths and broader infrastructure. The NECP explicitly recognizes behavioural change as a key driver, stating: "It is necessary to promote behavioural change in society by diversifying public transport services, developing micro-mobility and transport sharing opportunities, transforming urban planning solutions" [41]. Transportation initiatives focus on optimizing public transit networks, with particular emphasis on rail service and multimodal connectivity. The plan aims to create seamless connections between various transport modes, including trains and buses, potentially reducing air travel demand. Despite having three international airports with partial rail connections [42], the NECP does not explicitly address aviation reduction strategies. Similarly, the plan omits specific measures regarding dietary changes, product sharing, or space-sharing initiatives [41].

(upper boundary) and sufficiency delta (lower boundary), as elaborated in the methodology section. These range parameters are applicable to both linear projection and EEA WEM projection methodologies. The strategic implementation of sufficiency measures serves to minimise the discrepancy between projected emissions trajectories and the National Determined Contribution (NDC) and NECP targets, which are demarcated in blue and orange target symbol. While linear projections maintain consistent decline, EEA WEM projections show diminishing reductions in later years.

Across the five countries analysed (Denmark, France, Germany, Italy, and Latvia), the sufficiency measures show varying degrees of effectiveness depending on national contexts and projection methods. Denmark and Latvia demonstrate the highest relative potential to meet 2050 targets, particularly under optimistic delta scenarios. France and Germany benefit from sufficiency measures but still fall short of neutrality without additional interventions. Italy consistently shows the lowest sufficiency impact, highlighting structural challenges. This comparative overview underscores the importance of tailoring sufficiency strategies to national circumstances and combining them with broader policy instruments.

3.2. Cross-country synthesis of sufficiency impacts (Figs. 6–11)

Figs. 6–11 present the historical trajectories, projection baselines (linear and EEA WEM), and sufficiency-enhanced pathways for Denmark, France, Germany, Italy, Latvia and the EU27 aggregate. Rather than interpreting each country separately, three consistent patterns emerge across all cases.

First, sufficiency measures systematically narrow the emissions gap relative to both projection baselines, and their relative contribution increases over time. By 2030, the combined six measures reduce emissions by approximately 1–4 percentage points relative to 1990 levels, depending on country and methodological boundary (factor versus delta). By 2050, this contribution expands to roughly 5–16 percentage points. The widening effect reflects both cumulative behavioural uptake and the increasing divergence between projected baselines and net-zero targets in the absence of demand-side intervention. However, under conservative (factor-based) assumptions, sufficiency measures alone do not close the 2050 neutrality gap in any of the five countries or at EU level.

Second, the mitigation effect is structurally dominated by two measures: dietary change and reduced aviation demand. Across all

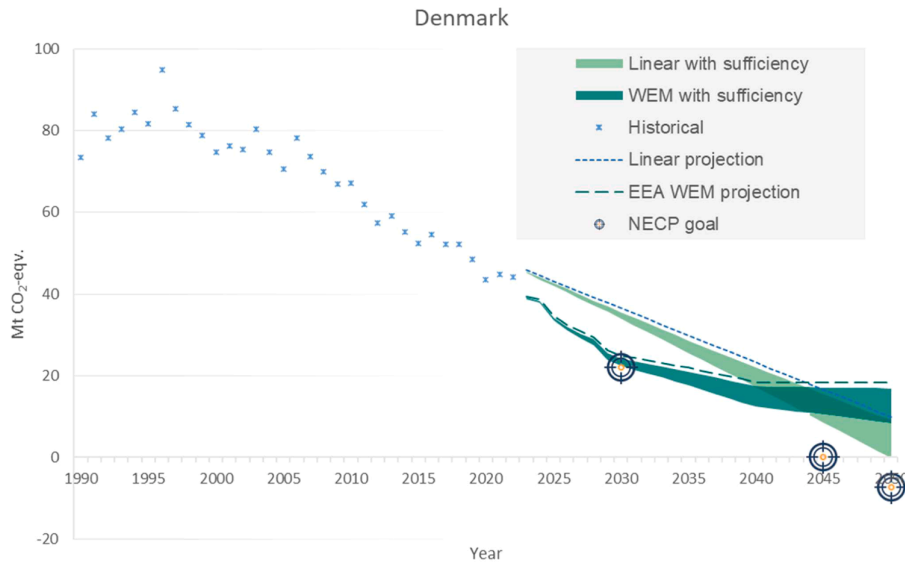


Fig. 6. Denmark: GHG emissions; historical, projections and sufficiency measures and NECP- goals (based on [20,24,25,35]).

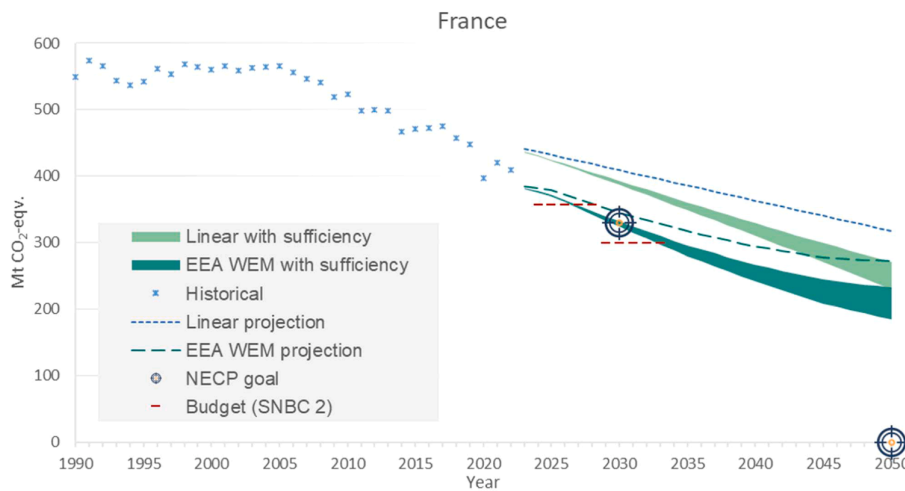


Fig. 7. France: GHG emissions; historical data, future projections and sufficiency measures and NECP established goals and carbon budgetary allocations (based on [20,24,25,37]).

national contexts, dietary shifts provide the largest single contribution to emissions reduction, followed by reductions in air travel. Other measures—cycling, moderation of car size, sharing of products, and sharing of housing space—remain quantitatively smaller in comparison. Although absolute reductions differ according to country size and baseline emissions, the ranking of measures is remarkably stable. Germany and France show the largest absolute reductions due to scale, while Denmark and Latvia appear closer to neutrality in relative terms. Italy exhibits comparatively weaker leverage from sufficiency under both projection methods. Nonetheless, the internal hierarchy of measures is consistent across all cases. This cross-country coherence indicates that the results are not artefacts of national modelling assumptions but reflect structural characteristics of sectoral emissions. The dominance of diet and aviation corresponds to sectors where technological substitution pathways remain limited and where baseline projections show either slow decline or structural persistence. These findings are fully consistent with the EU-wide modelling results reported in Golinucci et al [9], which likewise identify dietary change and

aviation demand reduction as the most resilient and high-impact sufficiency levers across Europe.

Third, the interaction between technological decarbonisation and behavioural sufficiency becomes increasingly visible towards 2050. Under the EEA WEM projection, progressive electrification of transport and decarbonisation of electricity supply reduce the marginal mitigation potential of certain transport-related sufficiency measures. In particular, cycling and car size moderation deliver diminishing emissions savings when vehicle fleets and electricity mixes become cleaner. This effect is especially evident in Germany and France under WEM trajectories, where electrification significantly lowers transport-related carbon intensity. As residual emissions approach zero, factor-based savings shrink accordingly, while delta-based estimates tend to preserve larger absolute differences. By contrast, dietary change and aviation demand reduction remain comparatively robust under decarbonisation, since they target sectors less affected by electricity decarbonisation dynamics. This confirms a central insight from [9]: sufficiency measures aimed at structurally hard-to-abate sectors retain relevance even under

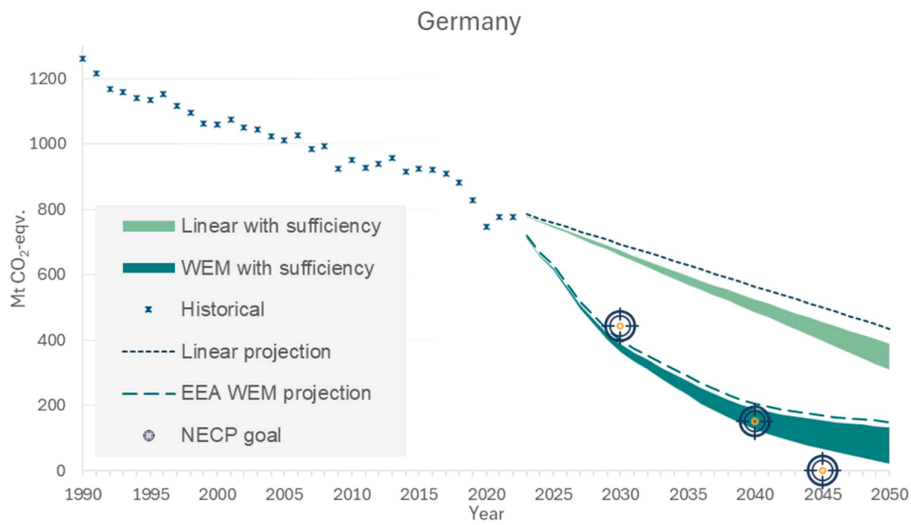


Fig. 8. Germany: GHG emissions; projections and sufficiency measures and NECP- goals (based on [20,24,25,39]).

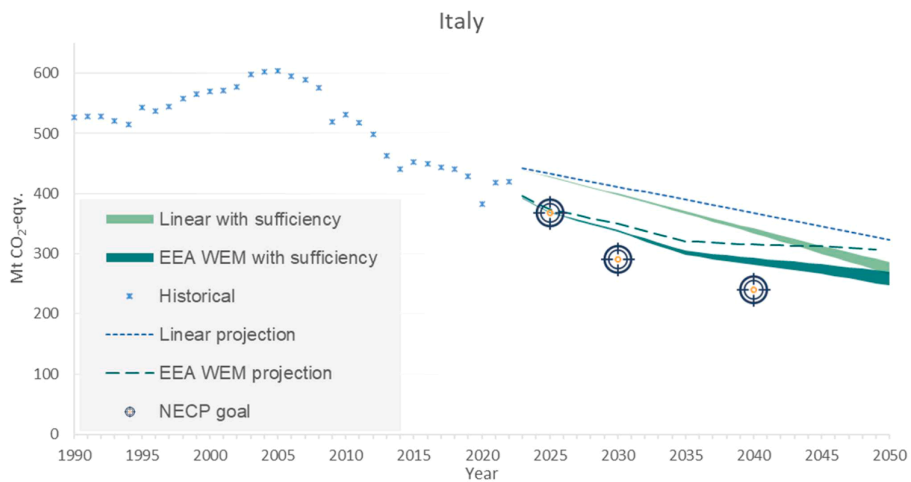


Fig. 9. Italy: GHG emissions; projections and sufficiency measures and NECP- goals (based on [20,24,25,40]).

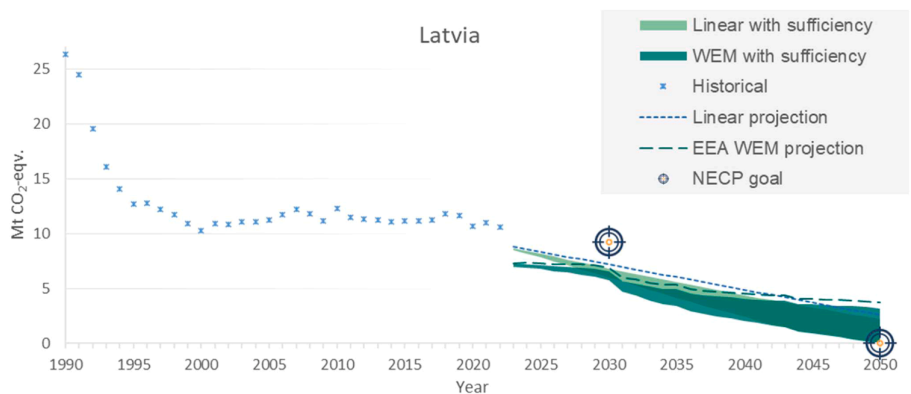


Fig. 10. Latvia, GHG emissions; future projections and sufficiency measures and NECP- targets (based on [20,24,25,41]).

accelerated technological transitions, whereas those targeting already-decarbonising sectors lose relative importance over time.

At EU27 scale, the aggregated picture mirrors national findings.

Sufficiency measures narrow the 2030 emissions gap by up to approximately 3–4 percentage points relative to 1990 levels and contribute between 5 and 13 percentage points by 2050, depending on

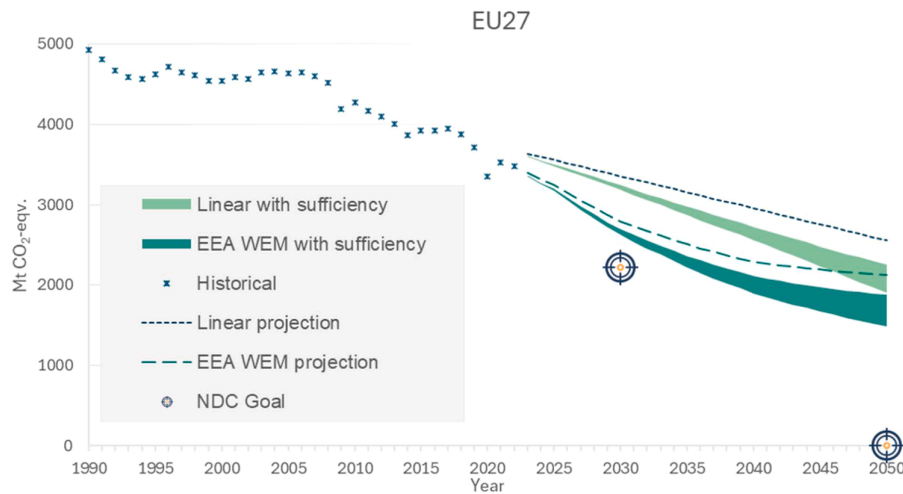


Fig. 11. European Union (27 member states), GHG emissions; projections and sufficiency measures and NDC goals (based on [20,24,25,43]).

methodological boundary conditions. The widening band between delta and factor estimates reflects increasing long-term uncertainty and the structural divergence between growth-based reference trajectories and declining policy baselines. Even under optimistic assumptions, however, sufficiency alone does not deliver climate neutrality at EU level.

Overall, the results demonstrate that sufficiency provides a meaningful but bounded contribution to climate mitigation. Its quantitative impact increases over time and is highly concentrated in a small subset of measures, most notably dietary change and aviation demand reduction. The consistency of this pattern across all five countries and at EU level reinforces the robustness of the findings and aligns closely with the broader European assessment in Golinucci et al. [9]. The analysis therefore supports a complementary mitigation strategy in which high-impact sufficiency measures operate alongside technological decarbonisation and structural efficiency improvements, rather than substituting for them.

4. Discussion

The results of this research underscore the role sufficiency measures could be in bridging the GHG emissions gap in the EU as it strives to meet its 2030 and 2050 targets. Notwithstanding the demonstrated efficacy of these sufficiency measures in emissions reduction, the analytical findings presented in Fig. 11 unequivocally underscore the necessity for supplementary strategic interventions and policy frameworks. These additional measures are crucial to bridging the substantive gap between the current emissions trajectory and the National Determined Contribution (NDC) objectives for both 2030 and 2050.

We investigated a set of six sufficiency measures, namely, cycling more, diet change, flying less, moderation of car size, sharing products and sharing spaces in housing. In summary, the selected set of all six sufficiency measures together could (compared to 1990 levels);

- By 2030, contribute to a reduction of 0.9 (Denmark) to 4.4 (Latvia) percentage points
- By 2050, the potential reduction ranges from 1.4 (Latvia) to 16 (France) percentage points.

The EU as a whole lies between these extremes, notable 1.3 – 5.1 percentage points in 2030 to 5.1 - 13.2 percentage points in year 2050. These findings align with the broader objectives of the European Climate Law and the Fit for 55 package, which emphasize not only technological innovation but also behavioural and systemic shifts. Sufficiency measures, though underrepresented in current NECPs, offer a

complementary pathway to achieving the EU's legally binding climate neutrality target by 2050.

This sections first discuss the methods and data used and then interprets and discuss the results, before it discuss policy implications and points to limitations and outlook.

The sufficiency scenarios were derived from the MARIO input-output model, which was built on a detailed and double-checked emissions dataset from Environmentally-Extended Multi-Regional Supply and Use Tables (EE-MRSUTs) [9]. However, it is important to note that the simulations incorporate only selected aspects of future developments. As a result, a widening gap ("fork") emerges between emissions in the reference scenario (E_{REF}) and those realistically expected in the future. This is due to the inherent limitation that it is not feasible to comprehensively modify all technological coefficients and carbon intensities across every sector and country globally through 2050. Consequently, while the model provides robust comparative insights, it does not fully capture the dynamic decarbonization potential embedded in future technological transitions.

The dual use of delta (absolute difference) and factor (relative ratio) approaches, combined with the dual use of linear and European Environment Agency With Existing Measures (EEA WEM) projections, yields four distinct future emissions trajectories with sufficiency scenarios. These trajectories represent methodological boundaries: the delta method paired with linear projections defines the upper bound (maximum potential reduction), while the factor method with EEA WEM projections defines the lower bound (minimum potential reduction). Together, these combinations form a result area that expands over time, visually represented as a widening band in Figs. 6–11. This result area reflects the increasing uncertainty associated with long-term projections of sufficiency measures, emphasizing the importance of presenting both optimistic and conservative estimates to inform robust climate policy decisions. From a policy perspective, delta estimates illustrate potential absolute savings under growth-based reference assumptions, whereas factor-based estimates provide a conservative, scale-independent benchmark for assessing proportional progress toward declining targets. Divergence between the two reflects baseline structure rather than contradictory mitigation effects.

The sensitivity analysis using alternative baseline periods for Italy (2005–2022) and Latvia (2000–2022) (c.f. annex for details) underscores how methodological choices influence the perceived effectiveness of sufficiency measures. For Italy, selecting a post-Kyoto baseline reveals a steeper historical decline in emissions, thereby reducing the apparent contribution of sufficiency—dropping from 1.8 % to 1.5 % by 2030 and from 6.7 % to 0.8 % by 2050. Conversely, Latvia's

alternative baseline, which excludes the post-Soviet industrial collapse of the 1990s, results in higher projected emissions and thus amplifies the relative impact of sufficiency measures—from 1.3 % to 2.0 % by 2030 and from 1.4 % to 6.2 % by 2050. These findings highlight the importance of baseline selection in emissions modelling and reinforce the need for transparent methodological justification.

Notably, dietary changes and reduced air travel emerge as pivotal sufficiency strategies that can substantially contribute to emissions reduction. The agricultural sector, which is closely linked to the diets-related GHG emissions, and air-transport show a historical trend of only small GHG emission reduction or light increase as seen in the German and Italian NECPs.

Therefore, it is essential to recognize that the effectiveness of these sufficiency measures is not uniform across EU member states. Variations in economic conditions, cultural attitudes, and existing infrastructure mean that the impact of these measures can differ significantly from one country to another. This disparity highlights the need for tailored approaches that consider local contexts, ensuring that sufficiency measures are adapted to fit the unique circumstances of each member state.

Moreover, the research reveals a substantial gap between the current NECPs and the projections towards 2050. This gap signals an urgent need for more aggressive actions and policies to align with the ambitious climate targets set by the EU. It is imperative for policymakers to recognize that while sufficiency measures are vital, they cannot be the sole strategy employed. A multi-faceted approach that includes technological advancements and systemic changes across various sectors is necessary to achieve the desired emissions reductions.

While the delta approach (E_{Δ}) (c.f. methodology section) provides a clear and intuitive measure of absolute emission reductions, it carries a significant risk of overestimation—particularly in long-term projections and when emissions are decreasing (nearing the policy set goal of net zero emissions in year 2050). This stems from its reliance on a reference scenario that assumes continued economic growth with growth (OECD's projection of GDP) and stable emission intensities, which may not reflect future decarbonization trends. As emissions decrease over time, the absolute difference between reference and sufficiency scenarios can become artificially inflated, portraying an overly optimistic view of sufficiency's mitigation potential. This is especially problematic when the delta method is used in isolation, as it may suggest that sufficiency measures alone could close the emissions gap—an interpretation not supported by more conservative, ratio-based methods. Delta values are useful for illustrating the magnitude of change but must be interpreted with caution. They should always be considered alongside factor-based results (E_{Factor}), which offer a scale-independent and more conservative estimate of impact. This dual-method approach ensures a more balanced and realistic assessment of sufficiency's role in climate mitigation.

Further, sufficiency measures themselves, by definition, cannot imply negative emissions (i.e., CO_2 uptake). Conversely, in the factor approach, the effect of sufficiency measures is reduced as GHG emissions in the projections decrease (towards zero, which is the goal for year 2050). This reflects the decarbonisation of society, for example, through a cleaner energy mix with more renewables and lower GHG emissions. With the factor approach, the savings due to sufficiency are less because there are fewer GHG emissions left to be saved by the sufficiency measures.

These identified methodological limitations underscore the importance of critically evaluating projection methodologies, incorporating nuanced economic-emissions relationship analyses, and timely update the data basis with the new concurrent factors.

All data sources used in this study—including historical emissions data from the European Commission (DG Energy), projections from the European Environment Agency (EEA), and sufficiency scenario outputs from the FULFILL project—were harmonized through a standardized preprocessing pipeline. Emissions data were converted to consistent units ($\text{Mt CO}_2\text{e}$), including conversion from kilotonnes (kt) to megatonnes (Mt) by applying a factor of 0.001. Time frames were aligned to

cover the period 1990–2050, and country-level datasets were cross-checked for completeness and consistency.

4.1. Policy implications: Prioritisation, resilience and NECP integration

The results demonstrate that sufficiency policy must be selective rather than generic. Across all five countries and at EU level, dietary change and reduced aviation demand provide the largest and most robust mitigation effects. This confirms the prioritisation logic established in Golinucci et al. [9], which identifies these domains as high-impact and resilient under varying transition speeds. The added contribution of this study is to show that these same measures deliver the greatest leverage for narrowing the gap between current NECP trajectories and national climate targets.

Policy design should therefore concentrate on sectors where technological substitution is limited and baseline emissions remain persistent. In the food system, actionable integration requires climate-aligned dietary targets embedded in national nutrition strategies, public procurement rules, VAT differentiation, and Common Agricultural Policy reform. Mandatory climate labelling, revised public catering standards, and gradual subsidy reallocation from meat towards plant-based production would operationalise dietary sufficiency within existing regulatory structures. The modelling indicates that such interventions remain effective even under accelerated electrification and power-sector decarbonisation.

In aviation, demand management must complement technological innovation. Progressive frequent flyer levies, removal of aviation fuel tax exemptions, kerosene taxation within EU competence, and systematic substitution of short to medium-haul flights with rail alternatives (high speed & night trains) represent concrete instruments consistent with the emissions profiles observed in this analysis. Aviation remains a structurally hard-to-abate sector; consequently, demand reduction retains mitigation relevance under both linear and WEM transition pathways.

The results also underscore the importance of resilience under transition speed. Measures targeting sectors already undergoing rapid decarbonisation—particularly passenger car transport—show declining marginal climate impact over time. Cycling promotion and car size moderation yield co-benefits in health and resource use, but their long-term emissions leverage diminishes as fleets electrify. Policymakers should therefore differentiate between complementary measures and structurally indispensable ones. Dietary change and aviation demand reduction fall into the latter category.

Crucially, sufficiency must be institutionally embedded in NECP governance rather than referenced rhetorically. The analysed NECPs rarely contain quantified demand-reduction targets or measurable behavioural indicators. EU Member States should incorporate explicit metrics—such as per capita aviation kilometres, meat consumption levels, and residential floor area—alongside renewable energy and efficiency benchmarks. These indicators should be tied to specific policy instruments and monitored within the NECP reporting cycle. At EU level, the governance framework could be strengthened by requiring quantified sufficiency contributions in future NECP updates.

For policymakers, delta results indicate maximum absolute reduction potential under projected growth, while factor results offer a more conservative measure of proportional progress under decarbonising baselines. Differences between them arise from structural baseline assumptions, not from inconsistencies in the mitigation performance of sufficiency measures.

This study suggests that sufficiency supplement technological decarbonisation. Under conservative assumptions, sufficiency alone does not achieve net zero in any analysed country. Its policy relevance lies in gap reduction. High-impact sufficiency measures can materially narrow the distance between projected trajectories and legally binding targets, particularly in sectors where technological solutions are insufficient. A robust mitigation strategy therefore combines renewables,

efficiency and prioritised sufficiency within an integrated planning framework aligned with NECP and NDC objectives.

4.2. Limitations and outlook

As any research, this also has several limitations and a limited scope, necessitating further investigations.

Firstly, the set of sufficiency measurements described in this paper investigated a subset of all possible sufficiency measures. One example is clothing, despite its significant environmental impact, was not addressed, even though Vita et al. [44] have highlighted its importance: Clothing has a more significant quantitative impact (measured as CO₂e) than food, with an 86 % reduced carbon footprint compared to the average, versus 43 % for food [44]. Other excluded sufficiency policies include the 15-minute city concept (e.g., Paris), shifting from cars to public transport, repairing goods, sharing products beyond washing machines (such as cars), building-related policies like lower indoor temperatures, reduced heating/cooling in unoccupied rooms, and urban planning for tiny houses.

The six investigated sufficiency measurements also vary in scope. For instance, the sharing product measurement considers only washing machines, while the dietary change measure encompasses all food products, covering a significant portion of the agricultural sector. Notably, reducing food waste was not included in this study's scope.

Secondly, analysed NECPs prioritise energy efficiency and technological improvement initiatives. Certain national climate strategies already incorporate complementary sufficiency strategies, such as cycling promotion measures in countries like Germany and Denmark. While these transport-focused interventions demonstrate strategic alignment, their relatively modest greenhouse gas emissions reduction potential—particularly when compared to dietary modifications and aviation demand reduction—does not fundamentally alter the overarching research conclusions.

Third, regarding geographical and supply chain considerations: The research concentrates on EU27 member states' national GHG emissions, deliberately acknowledging the limitation of neglecting external supply chain effects. Golinucci et al. [20] indicates that sufficiency measures could generate emissions savings outside the EU27 approximating 50 % of internal reductions, representing approximately 1 % of global emissions. This finding suggests potential secondary benefits, including enhanced capacity for other nations to achieve their NDCs and supporting inter-EU member state climate objectives through interconnected supply chain dynamics.

Projection Uncertainties and Technological Developments: The analysis's temporal projection to 2050 inherently encompasses significant uncertainties. Potential disruptions from technological advancements, policy transformations, and unpredictable global events—ranging from pandemics to climate change-induced environmental modifications—could substantively recalibrate anticipated GHG emissions trajectories and sufficiency measure effectiveness. The maximum savings attributable to sufficiency are contingent upon slow decarbonization in the food sector, particularly for meat and dairy products, which are significant sources of methane and other GHGs. Emerging technological innovations like lab-grown meat and potential aviation industry transformations introduce additional complexity, with their widespread adoption and emissions reduction potential remaining speculative.

Economic Growth and Emissions Correlation: The underlying input-output model framework predisposes the analysis towards assumptions of continuous economic growth, aligned with OECD projections. This approach recognises the conventional correlation between economic expansion and increased GHG emissions [45]. However, potential economic deceleration—whether induced by sufficiency measures, climate change impacts, or alternative factors—could significantly modulate the anticipated emissions reduction from sufficiency measures overly optimistic.

Sufficiency measures also contribute to the EU's Just Transition agenda by promoting equitable access to low-carbon lifestyles and reducing overconsumption among high-emitting groups. Their implementation can help mitigate social inequalities while advancing climate goals, particularly when paired with inclusive governance and redistributive fiscal policies.

5. Conclusions and recommendations

5.1. Conclusions

This study set out to quantify the contribution of selected sufficiency measures to closing the emissions gap between current trajectories and the EU's 2030 and 2050 climate targets, with explicit reference to national NECPs. The results provide a clear quantitative answer.

Across the five analysed Member States and at EU27 level, the combined implementation of six sufficiency measures reduces emissions by approximately 1–4 percentage points by 2030 and 5–16 percentage points by 2050, relative to 1990 levels, depending on methodological boundary conditions (factor versus delta). At EU scale, sufficiency contributes up to ~3–4 percentage points toward the 55 % reduction target in 2030, and 5–13 percentage points toward climate neutrality by 2050. In absolute terms, cumulative EU-wide savings reach approximately 170 Mt CO₂e by 2030 and 650 Mt CO₂e by 2050 under central assumptions.

However, sufficiency alone does not achieve net zero in any of the analysed countries or EU under conservative assumptions. Its primary role is gap reduction rather than full target delivery. In countries where NECP trajectories remain significantly above neutrality pathways—particularly France, Germany and Italy—high-impact sufficiency measures narrow the projected 2050 gap but do not eliminate it. Denmark and Latvia approach neutrality only under optimistic assumptions. The quantitative contribution of sufficiency is therefore material but bounded.

Two measures account for most of the mitigation effect: dietary change and reduced aviation demand. Their dominance is consistent across all five countries and aligns closely with the EU-wide modelling results reported in Golinucci et al. [9], which identify similar sectoral magnitudes and structural robustness. Importantly, these measures remain effective even under accelerated electrification and power-sector decarbonisation, as they target structurally hard-to-abate sectors. By contrast, transport-related measures such as cycling and car size moderation lose relative importance as vehicle fleets electrify.

The contribution of this paper lies in linking sufficiency modelling to policy alignment. Whereas previous EU-wide work quantified macro-economic and emissions impacts, this study evaluates how sufficiency interacts with NECP trajectories and national climate targets. The analysis demonstrates that integrating prioritised sufficiency measures into NECPs can measurably reduce the gap between projected emissions and legally binding targets, particularly in sectors where technological pathways are insufficient.

These conclusions must be interpreted in light of methodological constraints. The input-output framework assumes continued economic growth and does not endogenously capture price effects, rebound dynamics or full technological substitution across all sectors. The delta method may overstate long-term savings when residual emissions approach zero, while the factor method provides a more conservative estimate. Sensitivity analyses for Italy and Latvia confirm that baseline selection influences perceived sufficiency impact. Consequently, the upper-bound results should be interpreted as potential ranges rather than deterministic forecasts.

Despite these limitations, the directional robustness of the findings is clear. Sufficiency measures, when strategically prioritised, provide a quantifiable and policy-relevant contribution to closing the EU's emissions gap. They do not replace renewable deployment or efficiency improvements but complement them within a triadic mitigation strategy.

5.2. Recommendations

First, policy prioritisation should focus on high-impact, transition-resilient domains—specifically food systems and aviation demand. Embedding quantified dietary and aviation demand indicators within NECPs would directly target persistent emissions sources.

Second, NECP governance should require measurable demand-side indicators alongside energy supply targets. Metrics such as per capita meat consumption and aviation kilometres travelled would operationalise sufficiency within formal climate planning.

Third, sufficiency measures should be evaluated in conjunction with transition speed. Measures targeting rapidly decarbonising sectors should not be overestimated in long-term mitigation strategies.

Finally, future research should expand sectoral coverage and incorporate rebound dynamics, endogenous price responses and technological uncertainty to refine the quantitative bounds presented here.

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7. Declaration of generative AI and AI-assisted technologies in the writing process

During the preparation of this work the authors used AI tools like Microsoft 365 Copilot and ChatGPT to improve language and readability. After using this tool/service, the authors reviewed and edited the content as needed and take full responsibility for the content of the publication.

CRedit authorship contribution statement

Erwin M. Schau: Writing – review & editing, Writing – original

Annex. Sensitivity assessment

As part of the sensitivity assessment, alternative baseline periods were selected for linear projection analyses: 2005–2022 for Italy (Fig. A-1) and 2000–2022 for Latvia (Fig. A-2). The selection of these divergent baseline periods was predicated on identified historical discontinuities in emissions trajectories, specifically the observed structural shifts in 2005 for Italy and 2000 for Latvia. The sensitivity analysis underscores the importance of methodological flexibility and contextual consideration in emissions reduction forecasting, highlighting the intricate relationship between baseline selection and projected outcomes.

Italy Sensitivity Analysis:

Fig. A-1 delineates alternative results for Italy, utilising linear projections grounded in the 2005–2022 timeframe, as an alternative to the conventional 1990–2022 period. The year 2005 represents a critical inflection point, coinciding with the ratification of the Kyoto Protocol, which mandated substantial greenhouse gas (GHG) emissions reductions.

draft, Visualization, Validation, Methodology, Investigation, Formal analysis, Conceptualization. **Nicolò Golinucci:** Writing – review & editing, Writing – original draft, Visualization, Methodology, Formal analysis, Data curation, Conceptualization. **Filippo Beltrami:** Writing – review & editing, Writing – original draft, Visualization, Methodology, Formal analysis, Data curation, Conceptualization. **Matteo Vincenzo Rocco:** Writing – review & editing, Writing – original draft, Visualization, Methodology, Funding acquisition, Formal analysis, Conceptualization. **Matteo Giacomo Prina:** Writing – review & editing, Writing – original draft, Visualization, Methodology, Formal analysis, Conceptualization. **Lorenzo Rinaldi:** Writing – review & editing, Writing – original draft, Visualization, Methodology, Formal analysis, Conceptualization. **Wolfram Sparber:** Writing – review & editing, Writing – original draft, Visualization, Supervision, Project administration, Methodology, Funding acquisition, Formal analysis, Conceptualization.

Declaration of competing interest

The authors declare the following financial interests/personal relationships which may be considered as potential competing interests:

Wolfram Sparber reports financial support was provided by European Union. Matteo Vincenzo Rocco reports financial support was provided by European Union. If there are other authors, they declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper

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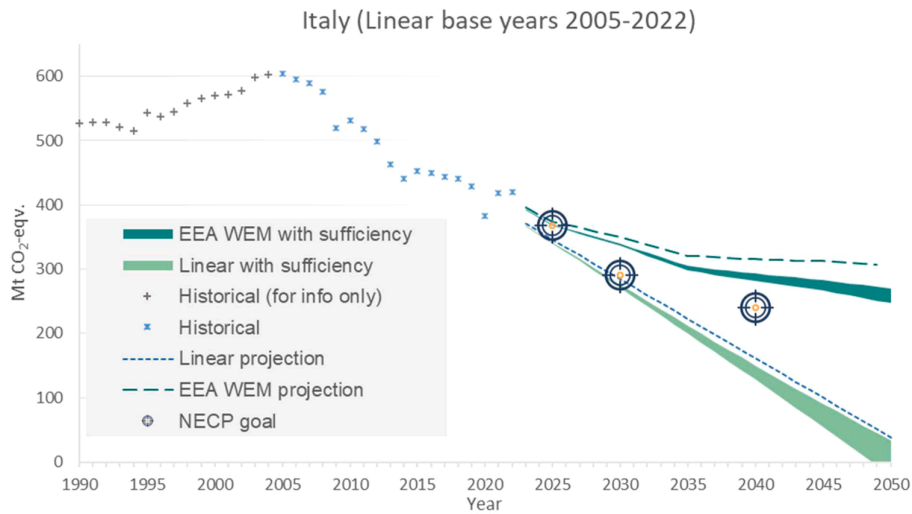


Fig. A-1. Sensitivity analysis for Italy, base years 2005 - 2022 (c.f. Fig. 10) (based on [20,24,25,40]).

Empirical data demonstrates Italy's capacity to reverse the escalating GHG emissions trend in 2005, establishing a pronounced linear reduction trajectory towards 50 Mt CO₂e by 2050. Extrapolating observed data from 2005–2022 into the future (2023–2050) by linear approximation suggests that Italy is well-positioned to meet its 2025 and 2030 targets, and comfortably achieve the less stringent 2040 objective.

Under this alternative linear projection, sufficiency measures present a potential pathway to carbon neutrality by 2050. The analysis reveals nuanced effectiveness contingent on the analytical approach: 1) An optimistic delta approach suggests promising carbon neutrality prospects and 2) a more conservative factor approach indicates comparatively reduced effectiveness. As anticipated, the potential emissions savings derived from sufficiency measures demonstrate a diminishing gradient when overall GHG emissions are substantially reduced, a phenomenon clearly illustrated by the alternative linear projection based on the 2005–2022 period. Specifically, for this alternative linear projection, the contribution from the six sufficiency measures could be 1.5 percentage points by 2030 (instead of 1.8 percentage points in Fig. 10) and as low as 0.8 percentage points by 2050 (instead of 6.7 percentage points in Fig. 10).

Latvia Sensitivity Analysis:

Fig. A-2 presents alternative results for Latvia, employing a linear trend based on the 2000–2022 timeframe. The methodological approach deliberately excludes the significant industrial restructuring period of the 1990s, which followed the dissolution of the Soviet Union and the Eastern Bloc, treating this epoch as a statistical outlier to ensure more representative contemporary emissions analysis.

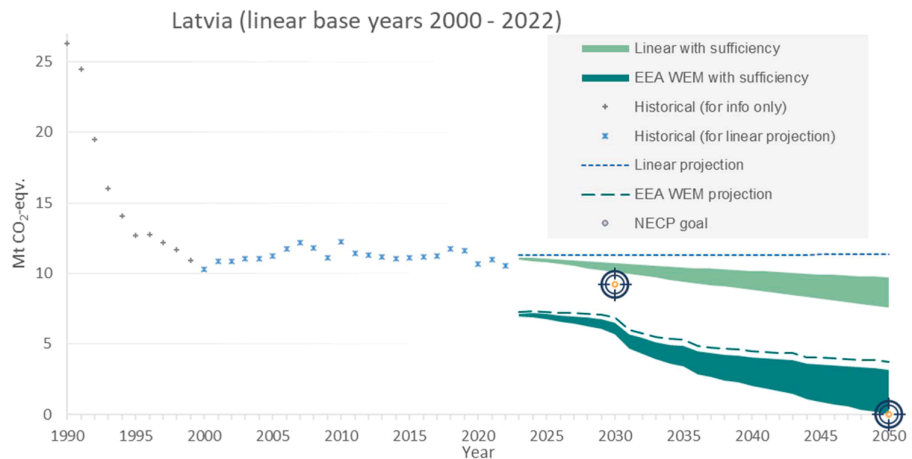


Fig. A-2. Latvia, GHG emissions; EEA projection and own projection (with alternative base years 2005 – 2022) and sufficiency measures and goals (based on [20,24, 25,41]).

Key findings using this alternative linear baseline indicate that Latvia faces significant challenges in meeting its 2030 and 2050 GHG emission reduction targets. By excluding the anomalous post-Soviet economic transition period, the analysis provides a more accurate assessment of Latvia's current emissions trajectory and identifies sufficiency measures as a crucial, but not sufficient strategy to bridge the gap between projected emissions and national climate objectives. Specifically, for this alternative linear projection, the contribution from the six sufficiency measures could be 2.0 percentage points by 2030 (instead of 1.3 percentage points in Fig. 10, both with 1990 as the reference year) and as much as 6.2 percentage points by 2050 (instead of 1.4 percentage points in Fig. 10). The analysis underscores the complexity of emissions projections and the importance of contextual understanding in developing effective climate mitigation strategies.

While both Italy and Latvia benefit from sufficiency measures, their trajectories and sensitivities differ markedly. Italy's alternative baseline (2005–2022) reflects a post-Kyoto emissions decline, which reduces the apparent impact of sufficiency measures—dropping from 1.8 % to 1.5 % by

2030 and from 6.7 % to 0.8 % by 2050. In contrast, Latvia's alternative baseline (2000–2022), which excludes the post-Soviet industrial collapse, results in higher projected emissions and thus amplifies the relative contribution of sufficiency—rising from 1.3 % to 2.0 % by 2030 and from 1.4 % to 6.2 % by 2050. These contrasting outcomes highlight how historical context and baseline selection shape the perceived effectiveness of sufficiency strategies. While Latvia shows greater relative gains, Italy's lower impact underscores the need for more ambitious sufficiency integration in national policy.

Data availability

Data will be made available on request.

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