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The impacts of decarbonization pathways on Sustainable Development Goals in the European Union

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Climate action to achieve the Paris Agreement should respect the United Nations Sustainable Development Goals. Here, we use an integrated assessment modelling framework comprising nine climate policy models and quantify the impacts of decarbonisation pathways on Sustainable Development Goals in the European Union at regional and national levels. We show that scenario-consistent assumptions of future socio-economic trends and current climate policies would improve energy- and carbon-related aspects of sustainability and reduce inequalities. Ambitious net-zero emissions pathways would further improve health and agricultural productivity. Furthermore, countries currently lagging in achieving sustainable development goals would see the greatest benefits from ambitious climate action. Negative socio-economic impacts from climate action on poverty, hunger, and economic growth will require specific corrective policies. While our analysis does not quantify the negative effects of less ambitious climate policy, it demonstrates where co-benefits and trade-offs of greenhouse gas mitigation and sustainable development agenda exist and can guide policy formulation.

The Paris Agreement mechanisms to propose pledges and ratchet them are bearing fruit, at least on paper: long-term pledges, if met, are projected to lead to a median temperature change estimate of below 2 °C[1–3]. However, mitigation efforts intended to deliver on these pledges have far-reaching implications that transcend climate progress across the broad spectrum of the United Nations 2030 Agenda for Sustainable Development and which go beyond the proposed SDG deadline in 2030. Understanding the intricate links between climate and sustainability objectives can help align efforts and optimise resources to deliver on both agendas, leveraging on synergies and mitigating potential trade-offs[4,5].

Since the adoption of the 2030 Agenda, several studies have been conducted to quantitatively assess national and regional progress towards the SDGs[6–9]. Such analyses rely on the latest available data for a wide set of indicators and measure the gap in achieving the targets in each specific dimension. However, this approach does not orient towards delivering on climate targets, nor account for the gap between existing and necessary policies and cannot offer long-term projections of indicator progress to help design policies that are more synergistic between the Paris Agenda and the SDGs.

When it comes to climate action (SDG 13), targeted ex-ante assessments can be undertaken with energy-economic and integrated assessment models (IAMs). Such models were originally conceived to project greenhouse gas (GHG) emissions reduction pathways and economic costs of climate policies but have continuously expanded their scope by integrating

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scientific evidence from different disciplines and insights into energy, water and land use, and climate systems of relevance to the sustainability agenda[10], thereby becoming the backbone of several studies analysing SDG outcomes of mitigation policies[11-17]. Numerous studies have focused on specific aspects of the SDG agenda, such as poverty and inequality[11], land use[16,18,19], water access and use[20,21], impacts of pollution on health[13,22-24], or biodiversity risks[25].

Nevertheless, the original purpose and structure of IAMs have partially limited the coverage of SDG dimensions and their interactions: climate action, energy, industry, and infrastructure have received most of the attention, while other environmental and social dimensions are seldom analysed[26-28]. To date, only Soergel et al.[15] offered a global assessment of climate change mitigation across a broad and diverse subset of the SDG spectrum.

Considering the limited attention SDGs have hitherto received in the political agenda[29], the heavy interconnection among SDGs[30], and the necessity to scientifically underpin holistic progress towards all sustainability dimensions[31], it is becoming increasingly necessary to widen the coverage of the SDG aspects analysed in modelling science, design approaches that enhance the robustness of results, and offer region-specific, policy-relevant insights.

This constitutes the motivation of this study, which employs a diverse range of models typically used in climate policy analysis to understand the sustainability implications of the European Union's (EU) climate policies and pledges. Our model ensemble includes one partial equilibrium model (GCAM), two computable general equilibrium models (GEMINI-E3, ICES-XPS), one macroeconometric model (NEMESIS), one energy system model (EU-TIMES), and two sectoral models (FORECAST and ALADIN), altogether allowing to robustly assess several socioeconomic, climate, and resource SDG dimensions. To measure aspects of human health and environment, we further couple GCAM with one atmospheric model for air quality and short-lived climate pollutants (TM5-FASST) and a global climate carbon-cycle model (HECTOR) (more details in the Method section) (see "Model descriptions" and "Model harmonisation" in Methods along with Fig. 1 for more details on the modelling framework and the harmonised variables). The decision concerning indicator coverage by a specific model was influenced not only by its capacity to output the indicator but also by the models' relevance in addressing them, as is the case, for example, with the GDP-related indicators, which only come from the macroeconomic models. Our study performs the first multi-model assessment of climate neutrality vis-à-vis SDG progress for the EU and its Member States, thereby achieving greater geographical granularity than previous efforts. Being a frontrunner in international climate action[32] yet with challenges in achieving progress towards SDGs[33], the EU offers an example of a region with relative heterogeneity in the achievement of sustainability[34] and climate goals[35] within a common economic area and high-level policy harmonisation framework. To take advantage of that, we perform a deep dive at the country level and quantify national progress and prospects and identify leaders and laggards.

Using this diverse range of modelling tools under a closely harmonised scenario design process to limit outcome gaps due to model structures[36], the approach allows a broad-ranging analysis and more robust assessment of the emissions, energy system, and broader SDG consequences of this region's climate neutrality pathways. Indicator outcomes are obtained by averaging results across all models covering them.

Our choice of indicators draws from the United Nations' Inter-Agency Expert Group[37] and our model ensemble capabilities. Most SDG indicator-related metrics stem directly from the models used, while a small subset, mainly related to within-country social dimensions, are computed in the
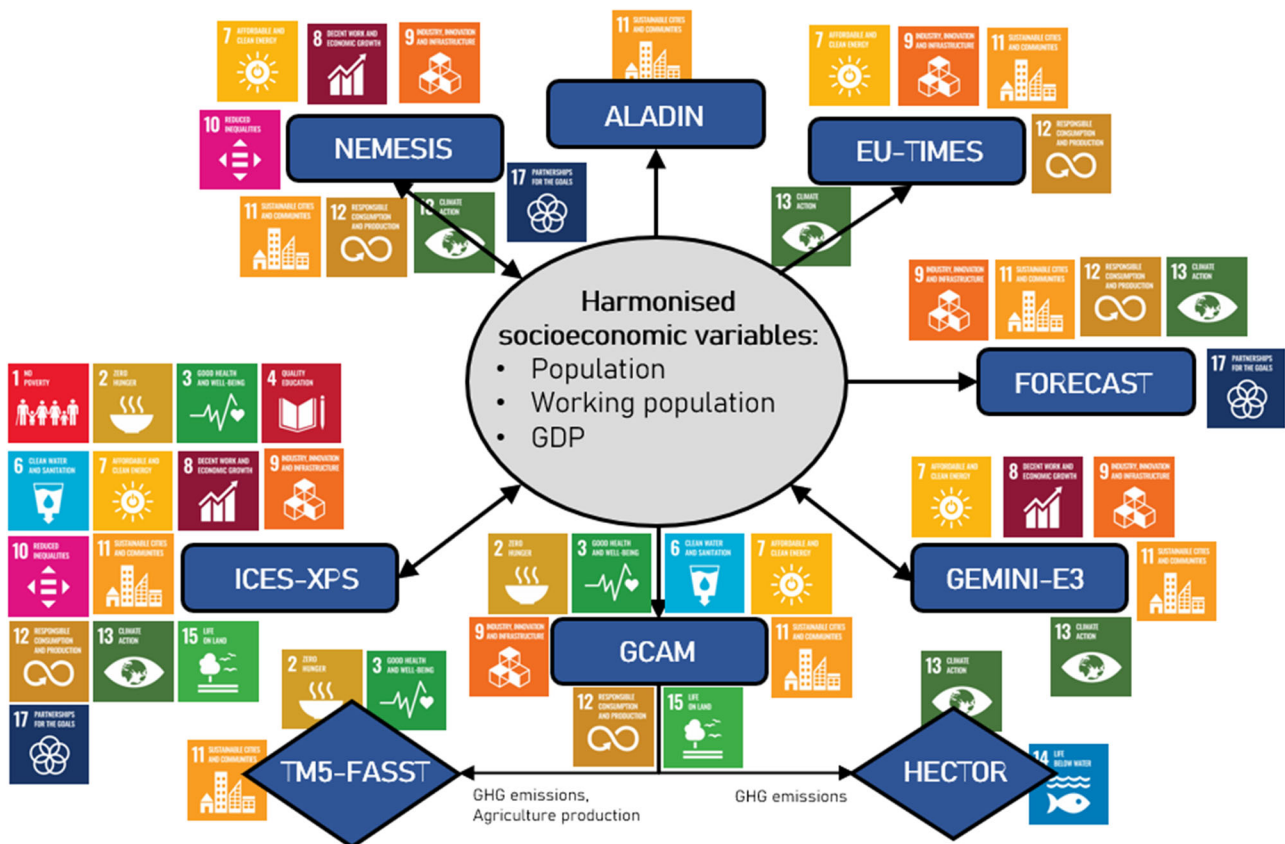
Fig. 1 | Overview of the modelling framework and SDG coverage. Harmonised socioeconomic variables are at the core of the modelling process and feed into the different models through one-directional or bi-dimensional linkages in the case of NEMESIS, GEMINI-E3 and ICES-XPS. Variables passed by GCAM to TM5-FASST and Hector are detailed for each linkage. Credit (symbols): United Nations. Please note the content of this figure and study has not been approved by the United Nations and does not reflect the views of the United Nations or its officials or Member States.

ICES-XPS SDG module[38,39]. This module runs a set of cross-country panel data regressions and combines the obtained coefficients with ICES-XPS model outputs in an out-of-sample estimation procedure. More details on the indicator selection and value normalisation are available in the "Methods" section.

Results

Designing scenarios compatible with mid- and long-term climate targets

Our analysis builds an in-depth quantitative assessment of the performance of EU Member States (plus the United Kingdom, hereafter EU+) in several SDG indicators under a current policy scenario, which reflects the currently implemented emission abatement policies. The model harmonisation exercise preceding this study is detailed in Giarola et al.[36] (see the "Methods" section for more details) and the reference scenario (Current Policies) is based on Nikas et al.[32] that reflects mitigation efforts up to 2030; for the post-2030 period, a carbon price equivalent to policy effort in 2030 is extrapolated until 2050 based on the per capita GDP national growth rate. This baseline scenario additionally includes the effect of the COVID-19 pandemic on GDP projections and fossil fuel prices[40].

The reference scenario is used as a benchmark to understand the implications of two EU Net-Zero Emissions (NZE) scenarios incorporating the 55% GHG emissions reduction target by 2030[41] and the climate neutrality target by 2050[42]. The two NZE scenarios differ in the way the mitigation burden is shared across sectors (Table 1). NZE Benchmark explores the most cost-efficient pathway—i.e., models are allowed to choose the most cost-efficient abatement allocation given the emission pledge. EU emissions are classified according to their source either in the EU Emissions Trading System (EU-ETS), which encompasses electricity, energy-intensive industries, and aviation, or the Effort Sharing Regulation (ESR) which covers domestic transport, buildings, agriculture, and waste. On the other hand, the NZE Policy Standard assumes the sectoral emission split of the 'Fit for 55' policy package, i.e. a reduction of −40% and −62% for 2030 relative to 2005 for ESR and EU-ETS sectors, respectively[41], and −80% in ESR and according adjustment towards net-zero[35], respectively. All other non-EU regions' assumed mitigation efforts correspond to their current policies across both scenarios.

The mitigation scenarios are selected for exploring two different pathways to reaching net-zero. No additional policies are assumed to specifically target SDG progress. However, the differences in these scenarios are already instructive in indicating some of the potential ways to dampen trade-offs and/or enhance synergies, such as the use of revenues generated by carbon taxes to provide compensation for the most vulnerable, or the support for research and development projects focused on low-carbon technologies.

The difference between indicator values under Current Policies and NZE scenarios is largely endogenously determined. The overall socioeconomic indicator progress across time is mainly due to the socioeconomic scenario assumptions that are reproduced endogenously in the general equilibrium (GEMINI-E3 and ICES-XPS) and macro-econometric (NEMESIS) models; on the other hand, the evolution of technology-, energy- and environment-related indicators across scenarios are imputable to different mitigation targets across

scenarios—further explanations on the outcome endogeneity of the specific indicators are detailed in Methods.

EU+ SDG performance

We report progress in 32 indicators across 15 SDGs—SDGs 5 and 16 on gender equality and peace, justice, and strong institutions were excluded due to limited model capabilities to quantify relevant indicators. SDG indicator outcomes are averaged across all models covering them. To compare results across goals and countries, indicator results are normalised on a 0–100 scale using benchmarks derived from SDG and EU+ policy targets (e.g., emissions, renewable electricity shares) or previous SDG quantitative studies or progress reports (food prices, research and development expenditure, etc.). Wherever this was not possible, we defined the upper and lower bounds by looking at the distribution of indicator values across time and scenarios following Schmidt-Traub et al.[43] (e.g., water price index, energy intensity of industrial production). Details on indicator normalisation and benchmarks are provided in Supplementary Table S1. Planned mitigation efforts will affect SDG-aligned objectives far beyond the proposed deadline for the SDG Agenda in 2030, so the study focuses on 2050 as a long-term horizon. Nevertheless, in order not to neglect the fact that the initial time horizon of the SDG Agenda was 2030, an additional section in the Supplementary Information (Supplementary Discussion; Supplementary Fig. S1) is dedicated to analysing the indicator evolution in the EU+ region between 2020 and 2030. It can be inferred from that analysis that the indicator evolution between 2020 and 2030 is only moderate for most of the indicators but is already pointing in the direction of the levels reached in 2050.

As it can be inferred from Fig. 2, implementing Current Policies in the EU+ would result in overall sustainability improvement across almost all SDG indicators. In 2050, EU+ citizens would be wealthier (SDG 8), experience lower poverty and inequality between and within countries (SDG 1 and SDG 10), attain higher education levels (SDG 4) (due mainly to socioeconomic trends), and have higher life expectancy (SDG 3). It should be noted here, nonetheless, that—on top of the explanatory factors detailed in the "Methods" section—inequality levels also depend on political factors that fall beyond the scope of this study[44]. Mitigation efforts resulting from Current Policies would expectedly increase renewable electricity shares (SDG 7), reduce industrial energy consumption (SDG 12) and improve residential (SDG 11 and SDG 13), transport (SDG 11), and industrial (SDG 9 and SDG 12) carbon footprints. Additional synergies would include reductions in mortality associated with air pollution (SDG 3) and ocean acidification (SDG 14).

Large performance variation between 2020 and 2050 is observed for renewable electricity share (SDG 7) and PM 2.5 concentration (SDG 11) (from 30% to 55% and from 9 to 4.6 $\mu g\,m^{-3}$, respectively). Between-country Gini and Palma ratios (SDG 10) would also undergo substantial performance improvements in 2050 with respect to 2020 in Current Policies (from 0.18 to 0.14 and from 1.2 to 0.9) mainly due to socioeconomic variable trends and, to a lesser extent, to the equalising effect of mitigation strategies (which are costlier for high-income countries close to the technology frontier). On the other hand, abatement policies could imply faster natural resource depletion rates reflected in indicators such as food prices (SDG 2), freshwater withdrawals (SDG 6), or natural and forest cover (SDG 15) due to the resource consumption required for target achievement. It is worth

Table 1 | Scenario settings for the EU

Scenario name	2030 emissions target	2050 emissions target
Current policies	Reduction targets at the MS level	Extrapolation of efforts based on projected per capita GDP growth rates
NZE Benchmark	Most cost-effective way to reach −55% relative to 1990 (a definitive approval of the EU carbon sink targets for 2030, currently under discussion, could allow for a more ambitious GHG emission reduction with respect to 1990 levels.)	Most cost-effective way to reach climate neutrality
NZE Policy Standard	−61% in ETS and −40% in ESR relative to 2005	−80% in ESR and required reductions in ETS to reach climate neutrality
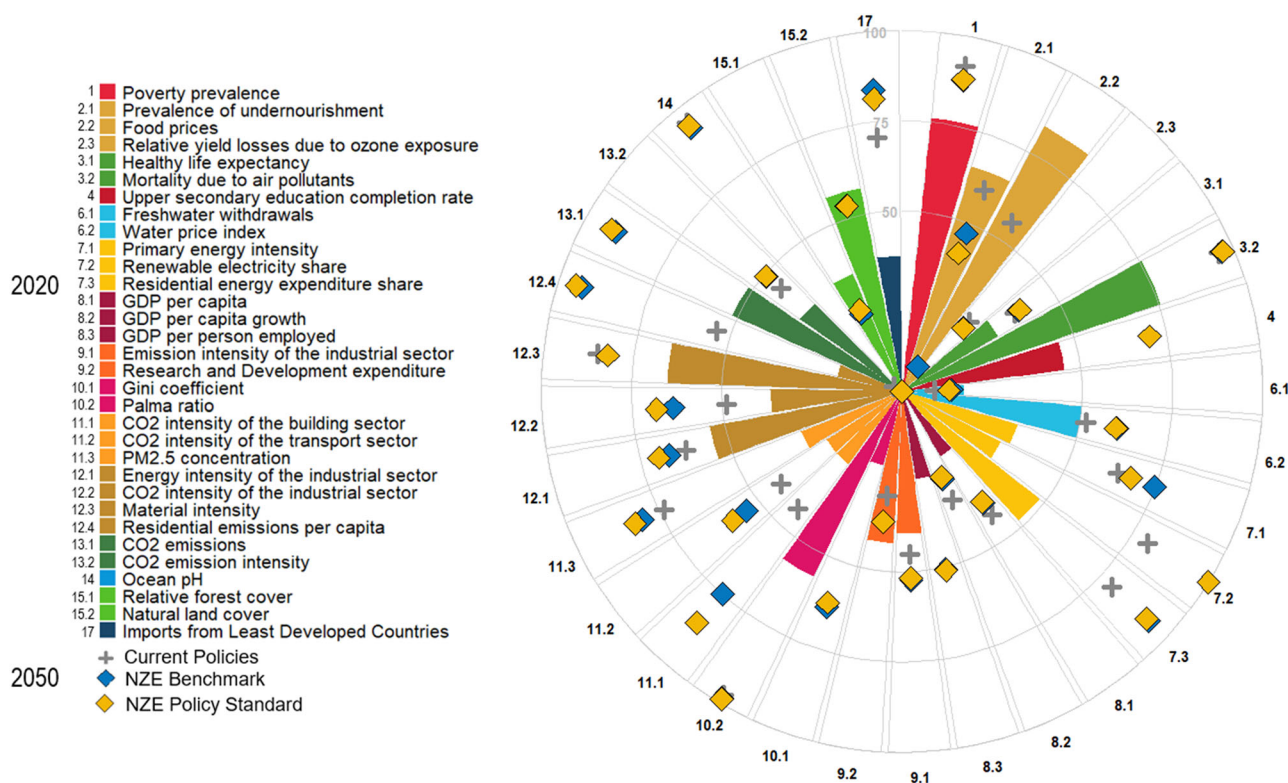
Fig. 2 | SDG indicator performance comparison in the EU+ between the NZE Benchmark, NZE Policy Standard and Current Policies in 2050 against values in 2020. Coloured bars show 2020 results, while grey, blue, and yellow symbols represent 2050 values in the three analysed scenarios. Results are normalised to show comparable goal progress or recession across indicators. Progress toward the value 100 implies getting closer to goal achievement, independently of whether this means an increase or decrease in the absolute value of the specific indicator (see Methods section for further details on benchmark rationale and values). Even though SDGs were conceived to be reached in 2030, only projections for 2050 are shown here, with the aim to focus on the long-term implications of current mitigation pledges.

highlighting that the modest worsening of the prevalence of undernutrition (SDG 2) (from 2.1% in 2020 to 2.4% in 2050 under the Current Policies scenario) is a consequence of a small contraction of the agricultural output caused by an increase agricultural production costs due to mitigation policies in several Member States.

Following an NZE-aligned pathway would result in slightly longer and healthier lives (SDG 3) in the EU+ by 2050 than sticking to Current Policies (from 71.8 to 72.1 years) due to the co-benefits of mitigating local pollutants mitigation[45,46]. Additionally, ocean pH (SDG 14), measuring the ocean uptake of CO_2, would improve from 8.11 in 2020 to 8.04 in 2050 because of the global emissions cuts (acknowledging, however, that the scenarios are mainly focused on EU climate ambition and assuming no additional climate efforts in the rest of the world). Crop yield losses due to ozone exposure (SDG 2) would be reduced from 6.4% to 5.1% in 2050 with respect to 2020 under Current Policies, but NZE scenarios would not be able to further reduce these damages due to more intensive use of bioenergy releasing additional methane and contributing to the formation of ozone.

Our analysis also suggests that more stringent climate policies in NZE scenarios would increase policy costs compared to Current Policies by reducing GDP by around 0.4–0.9% on average for the 2020-2050 period, according to NEMESIS and GEMINI-E3, and even more for ICES-XPS—see Boitier et al.[35] for further quantitative details on socioeconomic impacts with the same model configuration. This drives the decline of SDG 8-relevant economic indicators—acknowledging, however, that capturing economic costs of climate change impacts could alter the costs and benefits of mitigation[47], potentially affecting GDP losses and gains, but this remains beyond the scope of this study. However, our study and its methodology could usefully be combined with a broader assessment of the SDG implications of climate action on the basis of not just EU but also global mitigation efforts. This would allow the derivation of a set of avoided climate damages impacts which could potentially be downscaled to the EU and sub-EU level,

albeit with considerable uncertainties at granular scales. Other socially relevant SDG indicators directly related to economic performance worsen, for example, poverty prevalence (SDG 1), which rises from 0.13% to 0.18% and undernourishment prevalence (SDG 2) from 2.4% to 3.3%, in 2050, in NZE scenarios with respect to Current Policies. Increased land competition resulting from a combination of rising afforestation and increased bioenergy production would also affect food prices. High policy costs assumed in the EU+ would increase imports from least developed countries with respect to 2020 levels (7.5% of total imports) both in Current Policies (14%) and in NZE scenarios (16.5%), thereby generating a positive effect on these countries' welfare (SDG 17).

Small differences can be observed between NZE Benchmark and NZE Policy Standard scenarios; however, Benchmark outperforms Policy Standard in indicators heavily influenced by policy costs, such as poverty, while cost-efficient abatement allocation in Benchmark would also imply higher use of natural resources leading to worse performance in air pollution, energy, and emission intensity. Benchmark assumes a larger contribution from land use, land use change, and forestry (LULUCF); therefore, Policy Standard would imply more pressure on other sectors, notably showing deeper decarbonisation needs for the industrial (5 vs. 9 g CO_2 MJ^{-1}), transport (33 vs. 39 g CO_2 MJ^{-1}), and residential (100 kg CO_2 per capita vs. 140 kg CO_2 per capita) sectors compared to Benchmark, which is aligned with conclusions from other studies[48]. More stringent sectoral emission cutbacks in Policy Standards would also account for the improved results in mortality due to air pollution (58 years of life lost per 100,000 people vs. 65 in Benchmark).

Model variance
Regarding indicators assessed by several models, we find the largest variabilities in water prices, renewable electricity shares, per capita GDP growth rates, and CO_2 intensities in the transport sector (Fig. 3). These are caused by
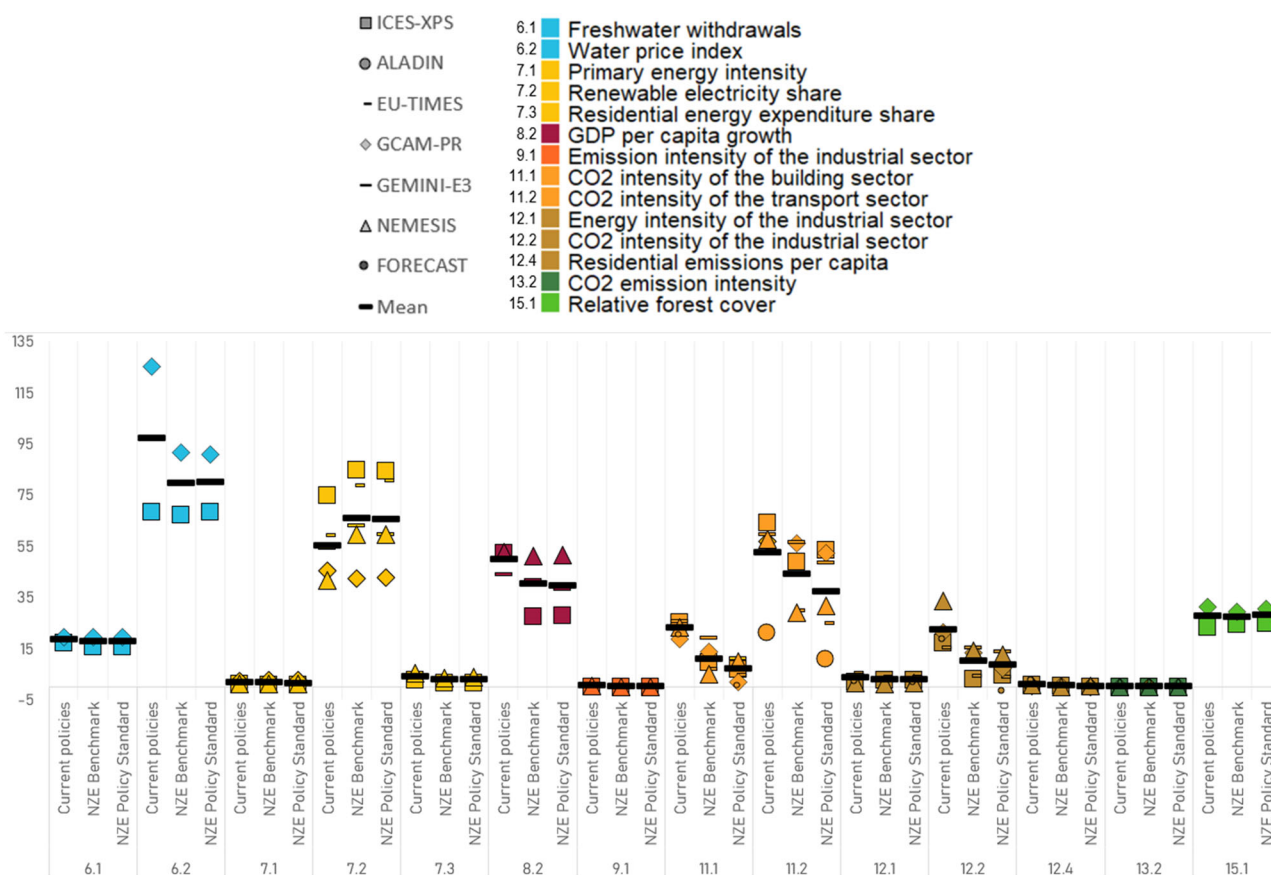
Fig. 3 | Raw value distribution across models for the EU+ in 2050 for 14 out of the 16 SDG indicators obtained by more than one model for the Current Policies, NZE Benchmark, and NZE Policy Standard scenarios. *Y*-axis units vary for each indicator and are detailed in the column "Units" in Supplementary Table S1 in Methods. Since these are not normalised values, larger values do not necessarily imply being closer to SDG achievement. Per capita GDP and CO_2 emissions were left out of the figure for the sake of clarity in the visualisation. In any case, they are among the indicators with the lowest variability across models (see the section with detailed results of those two indicators in Supplementary Information for further details). The units of each indicator are the ones detailed in Supplementary Table S1.

model choices driven by their structures and available technology options. For instance, GCAM relies strongly on bioenergy in NZE scenarios with two to three times as much bioenergy consumption by 2050 compared to other models. This is in line with previous model intercomparison where GCAM stands out in this regard[3,14]. This higher reliance on bioenergy explains the rise in water prices in Current Policies and offsets water demand reductions from the cutback of traditional crops. Variability is reduced in NZE scenarios due to the penetration of other abatement technologies. Contrary to GCAM's reliance on bioenergy in the previous example, biomass is unavailable in ICES-XPS, resulting in a declining trend in price projections with respect to 2020. Along the same lines, ICES-XPS, GCAM, and GEMINI-E3 only feature a basic representation of the transport sector that does not allow for stringent sectoral decarbonisation policies even in net-zero scenarios (51 g CO EJ^{-1} in the EU+ by 2050 compared to 30 g CO_2 EJ^{-1} in EU-TIMES and NEMESIS or 10 g CO_2 EJ^{-1} in the sector-specific model ALADIN). Featuring basic representation and limited development of specific mitigation technologies (e.g., carbon capture and storage), ICES-XPS projects the highest policy costs driving down per capita GDP growth and increasing the variance across models.

SDG performance at the Member State level
By averaging normalised indicators within each SDG and then averaging across SDGs for each country, we compute national SDG indices. As illustrated in Figs. 4, 5, specific indicators, such as poverty prevalence in Poland, research and development expenditure in Sweden, or relative forest cover in Finland, show moderate performance drops. This is a result of the increased

mitigation costs reducing available public expenditure and increased consumption of forestry products. However, averaged SDG results suggest that national decarbonisation pathways would reduce SDG progress gaps in 2050 with respect to 2020. Notably, despite remaining progress gaps in 2050, countries among the worst SDG performers in 2020 (Hungary, Spain, Poland) would display some of the highest SDG improvements by 2050, mainly driven by mitigation co-benefits for reduced air pollution levels, improved energy and CO_2 intensities in the transport, industry, and building sectors, increased renewable electricity shares, and reduced within-country inequalities. On the other hand, countries already performing well (e.g., France, Finland, Sweden) are projected to display the slowest progress in the selected indicators in the next three decades. Mostly benefitting current laggards, mitigation policies therefore have the potential not only to drive overall SDG progress but also to bridge SDG performance gaps between countries within the bloc. While the three countries with the lowest SDG scores in 2020 would show an increase of 20 percentage points in their progress in 2050 in the NZE scenarios, in the case of the three countries with the highest SDG scores in 2020, this progress would only amount to 13 percentage points.

Most EU+ countries would also benefit from more ambitious mitigation policies with respect to their current policy framework. Substantial progress is observed in Hungary and Bulgaria, due to the large gap between current and required mitigation policies aimed at reducing sectoral emissions and increasing renewable electricity shares. Once again, only small differences can be observed between the NZE Benchmark and NZE Policy Standard, with the latter showing more ambitious sectoral decarbonisation
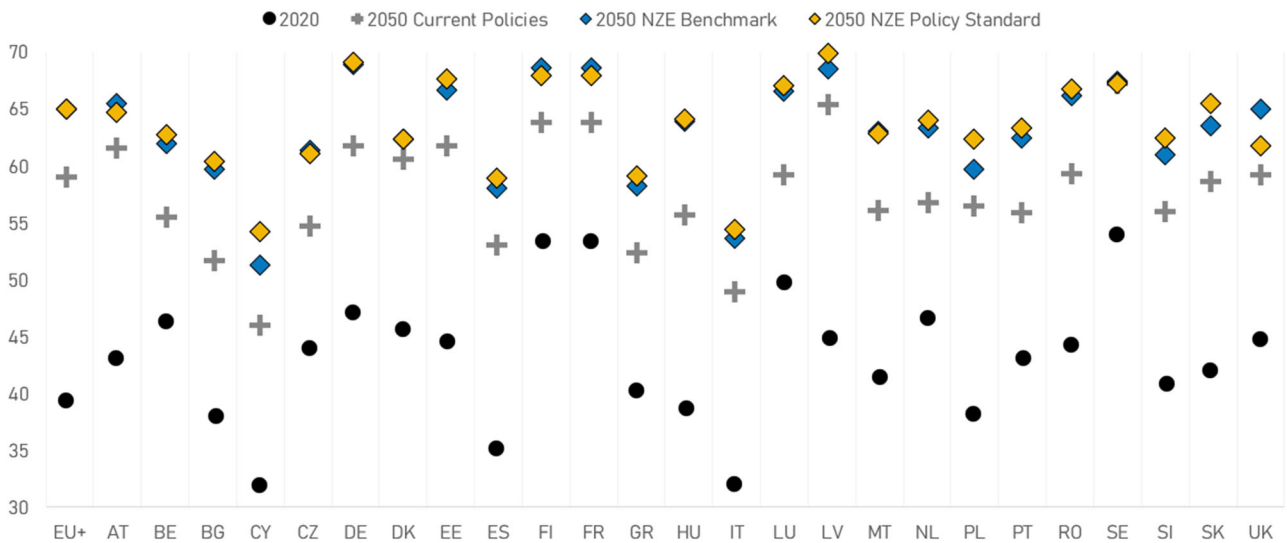
Fig. 4 | SDG scores across all indicators for EU+ countries in NZE Benchmark, NZE Policy Standard and Current Policies in 2050 and scores in 2020. Normalised values were averaged within each SDG and then across SDGs to obtain the final score. Higher values imply getting closer to SDG achievement. The results for some Member States are based on nationally aggregated indicator results captured by the models, while others are imputations from regionally aggregated results; further details on this are given in Supplementary Table S2.
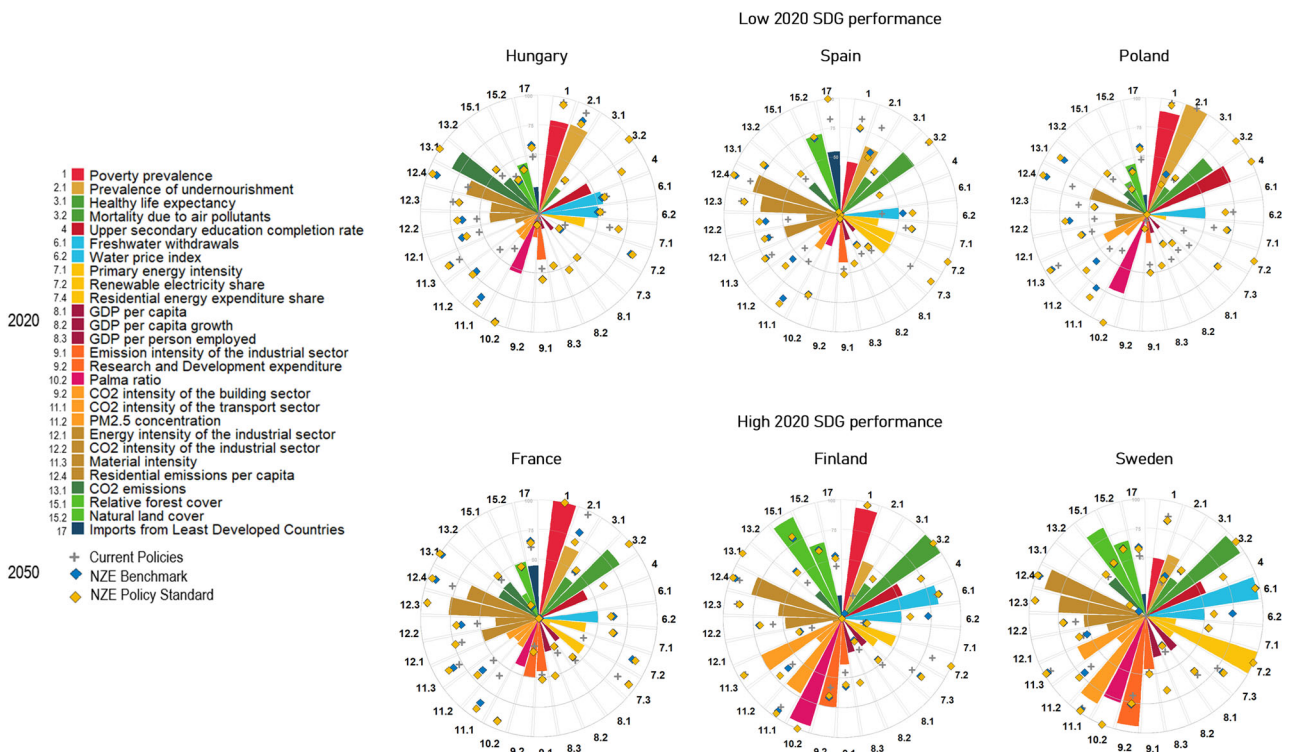
Fig. 5 | SDG country profiles of Hungary, Spain, Poland, France, Finland, and Sweden. Coloured bars show 2020 results, while grey, blue, and yellow symbols represent 2050 values in the three analysed scenarios. Comparison of normalised values between 2020 and 2050 values achieved in current policies and net zero scenarios. Results are normalised to show comparable goal evolution across indicators. Values closer to the circle midpoint refer to lower performance (most negative or least positive side-effects), while values closer to the outer circle boundaries refer to good performance (most positive or least negative side-effects). Food prices, relative yield losses due to ozone exposure, Between-country Gini coefficient and ocean pH were left out for this analysis since they don't have national disaggregation.

and air pollution reductions. Additionally, the NZE Policy Standard also achieved better SDG performance in countries with lower SDG progress in 2020 (Bulgaria, Cyprus, Spain, Greece, Italy, and particularly, Poland), while the NZE Benchmark performed slightly better in those countries with higher initial SDG scores (Austria, Finland, France, and UK). Regional and national result disaggregation is detailed in Supplementary Information.

Socioeconomic vs. environmental trade-off patterns

Finally, a trend shared across many EU+ countries when comparing net zero outcomes with respect to Current Policies is that, although many environmental indicators display remarkable progress (particularly those related to decarbonisation in countries with currently low climate performance, which offset moderate SDG 15 declines due to increased demand for

forestry products), other sustainability dimensions show negligible gains, notably with certain socioeconomic indicators such as per capita GDP, food prices, poverty, and undernourishment prevalence rates even slightly worsening. These impacts observed in NZE scenarios with respect to Current Policies are driven by increased mitigation costs reducing growth rates, and increasing land competition and inequalities. Rather than setting sectoral emission reduction targets, NZE Benchmark explores cost-efficient net zero scenarios; as a result, it slightly mitigates the economic impacts with respect to Policy Standards.

This trade-off between socioeconomic and environmental goals should not come entirely as a surprise as targeted mitigation policies pursue mainly environmental outcomes without necessarily exhibiting synergistic behaviours with other sustainability dimensions[49]. However, the use of potential carbon tax revenues to support different economic agents or activities has the potential to reduce the social and economic impacts of climate change mitigation[50].

Discussion

Analysis of the selected SDG indicator trajectories in EU+ mitigation pathways under existing climate policies and under longer-term targets offers insights into mitigation co-benefits but also highlights certain trade-offs or side-effects that policymakers must carefully consider and attempt to avoid or mitigate through corrective policy packages.

Considering progress at the EU+ level, all analysed environmental indicators are projected to improve alongside climate efforts whilst also yielding some socioeconomic co-benefits. NZE scenarios would reduce crop yield losses due to ozone exposure (SDG 2), contribute to longer and healthier lives (SDG 3), and enhance access to clean water (SDG 6). Results also suggest that the countries benefitting the most in SDG terms from ambitious climate policies would be the ones currently lagging in SDG performance.

On the other hand, we also find that, in the absence of countermeasures, the cost of mitigation policies may have a negative impact on economy-related metrics (SDG 8) as well as implications for food prices, poverty, and undernourishment prevalence (SDGs 1 and 2). These trends would hint that no country manages to achieve all SDGs, not even in 2050 according to our projections. These trade-offs should, however, not slow down the implementation of stringent climate policies; they rather call for coupling mitigation efforts with other development priorities or corrective packages—e.g., by implementing redistributive policies such as using revenues from carbon taxes to compensate low-income households[11,51] or by providing financial support to low-carbon technology research and development to decrease mitigation costs[52]. Corrective policies like this would allow countries to reduce their SDG achievement gaps, as evidenced in our projections while pursuing climate objectives. The integration of models of backcasting approaches compatible with full SDG achievement could be a useful tool in the future to assess SDG-aligned sustainable pathways.

Our results also indicate that Paris Agreement goals are still achievable, although targeted policies supported by ex-ante analysis must be implemented to counteract potential trade-offs between mitigation policies and the SDG Agenda.

It should not be taken for granted that SDG attainment will come along with climate mitigation policies. Reducing GHG emissions will have synergies with other environmental objectives since their achievement is being severely jeopardised by climate change. This set of models is not suitable to quantify climate change impacts on SDG attainment; however, it would be useful to combine climate change impacts and mitigation assessments in the future[53]. Nonetheless, even in the absence of this damage quantification, climate policy implications on SDG achievement should be anticipated and tackled to counteract potential trade-offs affecting social dimensions of the SDG Agenda, ensuring that a sustainable future comes along with a fair transition.

Notably, in our analysis of performance in socioeconomic indicators with respect to the currently implemented policies, we do not consider the cost of climate change impacts that mitigation policies can reduce. Previous quantitative assessments of these damages conclude that these can be several times greater than the mitigation costs[54–56]. Due to model limitations, only costs are considered in this study, while benefits of increased abatement are not. Therefore, we acknowledge the potential underestimation of SDG outcomes in NZE scenarios and overestimation in Current Policies with respect to scenarios of low climate ambition and high climate change impacts.

The explored SDG-relevant indicators included the contribution of all employed models able to represent them. Relying on an ensemble of models allowed us to, on the one hand, absorb structural and parametric uncertainties and biases arising from models' theory and assumptions and, on the other, enhance the coverage of SDG dimensions. Robustness was also pursued by harmonising our model inputs and drawing from parameters from recent studies. However, we acknowledge that using model ensembles is only one way to enhance confidence in model outputs[57] and that more can be done with respect to maximising robustness—for example, by defining robustness criteria across key performance metrics[58], employing sensitivity analysis[59], or using portfolio theory[60,61], which has also been used in the context of SDG analysis based on IAMs[24,62].

Both the multi-model approach to increasing goal coverage and the national deep-dive into EU+ countries fill a relevant gap in the SDG-oriented IAM literature. Nonetheless, our framework can be enhanced by refining the modelling methods and covering a broader set of SDG dimensions in line with the identified IAM target space[10] and, critically, by accounting for climate change impacts. This development is a crucial step toward supporting sustainability policymaking with more realistic scenarios. Finally, a broader set of scenarios capturing more SDG-related policies would also enhance current policy representation and further increase the reliability of our results.

Methods
Model descriptions
Building on recent single-model studies exploring interactions of mitigation with part[22,62,63] or the broad spectrum[15] of SDGs, we use a diverse ensemble of 7 models to cover a wide range of SDG outcomes and focus on national performances of selected EU countries (Fig. 1). This ensemble includes one partial equilibrium model (GCAM) and two computable general equilibrium models (GEMINI-E3, ICES-XPS) at global level, as well as one macroeconometric model (NEMESIS), one energy system model (EU-TIMES), and two sector models covering the building, industry (FORE-CAST) and transport (ALADIN) sectors in Europe; GCAM is further coupled with one atmospheric model for air quality and short-lived climate pollutants (TM5-FASST) and a global climate carbon-cycle model (Hector).

GCAM is a global, partial equilibrium IAM that represents human-Earth dynamics by exploring the behaviour and interactions between the energy system, agriculture and land use, the economy and climate to model GHG emissions, energy use, energy prices, and trade patterns[64,65]. It operates by looking for cost-efficient energy system solutions in a specific period and then moves on to the next time period to repeat the optimisation exercise. GEMINI-E3 is a recursive, general equilibrium model that simulates carbon taxes, marginal abatement costs and prices of tradable permits, abated emissions, welfare loss, macro-economic indicators, exchange and interest rates[66]. It assumes perfectly competitive domestic and international markets except for foreign trade, where the same goods can have different characteristics depending on their exporting country. This open-access model is available at https://github.com/JGCRI/gcam-core/releases. ICES-XPS is a recursive-dynamic, general equilibrium model capable of assessing climate change mitigation impacts on the economy, including both regional and international market flows[38,39]. It assumes market equilibrium across all sectors and regions and is linked to a post-processing module capable of modelling several SDG indicators. NEMESIS is a sectoral macroeconomic model used to simulate climate mitigation policies for all European countries focused on economic instruments and long-term impacts on, among others, market competitiveness, employment, and public accounts[67,68]. EU-TIMES is a European version of TIMES model and analyses the necessary

impact and deployment of energy technologies and innovation to comply with European energy and climate change objectives[69]. It includes representation of EU Member States as well as neighbouring countries and can assess the impacts on the entire energy system, specific sectors, or clusters of specific technologies. FORECAST is a bottom-up technology-detailed simulation model that incorporates socioeconomic and technology dynamics to project energy demand and emissions in the industry, residential and tertiary sectors at both the national level and the EU[70]. ALADIN is an agent-based simulation model projecting until 2050 purchasing decisions of alternative fuel (passenger and heavy-duty) vehicles in Europe. It projects ownership costs for different vehicles under specific conditions based on datasets of user-driving behaviour[71,72]. More information about these models can be found on the I²AM PARIS platform here: https://www.i2am-paris.eu/detailed_model_doc. TM5-FASST is an air quality model able to model air pollutant concentrations and their related impacts on human health, and agricultural crop production[73]. GCAM outputs on GHG emissions and agricultural production are used to feed a TM5-FASST simulator in R, rfasst (accessible at https://github.com/JGCRI/rfasst) to estimate pollutant concentrations and human health and agricultural effects derived from the exposure to these concentrations. Finally, Hector, a climate model used to run together with IAMs[74] was fed with GCAM GHG emission outputs to estimate changes in global temperature and in ocean pH.

Model harmonisation

The harmonisation process on which the multi-model approach of this study is built is based on Giarola et al.[36]. Harmonisation was tailored to include the partial and general equilibrium and macroeconometric models mentioned in the previous section. This transparent process comprised harmonisation of socio-economic parameters (GDP, population, and working population) sourced from the 2018 Ageing Report[75], along with historical emissions, techno-economic parameters in the power, transport, buildings, and industry sectors (projected costs, efficiencies, and lifetimes of key technologies) and climate policies from the recent literature (see Giarola et al.[36] for additional sources of the harmonised parameters). The structure and coverage of each of the applied models differ significantly (see Table 2); therefore, harmonisation was limited to those variables that are input in each of the models. Model outputs were not fed back into the other models for further calibration. This applies, for example, to the GDP. The general equilibrium (ICES-XPS) and macro-econometric (NEMESIS) models calibrate harmonised GDP projections in the baseline scenario without climate policy. However, GDP is an endogenous output of these models in the climate mitigation scenarios. Similarly, food price outputs by GCAM were not fed back as inputs for ICES-XPS to derive results on undernourishment. By doing this, it is likely that we are under-estimating undernourishment because the additional food price increases derived from climate impacts could suppress demand for food further than indicated. The study allowed us to reduce intermodel outcome divergences compared to previous multi-model harmonisation processes and present an updated climate policy database for further multi-model analyses.

Indicator coverage

Most of the SDG indicators do not have an agreed quantitative target, therefore, to be able to assess indicator achievement gaps, results were normalised on a 0–100 scale using benchmarks derived from EU+ policy targets (e.g., emissions, renewable electricity shares, etc.) or previous SDG quantitative studies or progress reports (e.g., food prices, research and development expenditure, etc.). Wherever this was not possible, we normalised indicators using upper and lower bounds stemming from the value distribution of each indicator across years and scenarios of simulation (e.g., water price index, the energy intensity of industrial production, etc.). Once the upper and lower bounds were defined, indicator values were normalised using a 0–100 scale by applying the following formula (Eq. (1)):

$$NV = \frac{V - LB}{UB - LB} * 100 \qquad (1)$$

where V stands for the raw indicator value, LB for the lower bound, UB for the upper bound, and NV for the normalised value. Indicator units, model coverage, normalisation benchmarks and their sources are detailed in the Supplementary Information (Supplementary Methods; Supplementary Tables S1 and S2). This method also allows us to make the 32 indicators comparable among each other and understand which ones would face larger gaps towards goal achievement. To obtain SDG indicator outcomes, normalised values are then averaged across all models covering them. Similarly, individual country SDG scores are obtained by averaging first across indicators within each SDG and finally averaging across SDGs.

The following paragraphs go through all the indicators by SDG, explaining how they were calculated. Some indicators are built directly using output variables obtained from models' endogenous calculations. Others are supplemented with indicators stemming from the ICES-XPS SDG module, which combines empirical estimates and ICES-XPS modelling results. For the latter, their initial values are historical (from WDI or UN) up to 2018, and then they are projected considering the output of the ICES-XPS model. Whenever the calculation of an indicator is explicitly given as a formula, it means it has been empirically estimated on historical values and projected using the model's results in the ICES-XPS module. If no formula is given, then the results are directly obtained from the models through endogenous computations.

Essentially, the benchmarking procedure followed in this study is a normalisation method combining existing benchmarks in the literature and simulated results from the model, which are applied to a set of indicators to bring them all into the same unit of measure and therefore make them all comparable. This comparability needs to be ensured not only to establish rankings but also to compare performance across indicators and scenarios. Since only a few SDGs have quantitative targets (e.g., SDG1), the normalisation procedure often relies on benchmarks derived from best-performing and worst-performing countries. While this does not allow us to quantify the gap in achieving the SDG targets in absolute terms, it can be used to quantify the gap in achieving the SDG targets given a certain set of scenarios and compare countries' SDG achievement performance. This normalisation methodology is common practice compared to the use of historical indicators. It was first used in Campagnolo et al.[76]. and regularly thereafter in the yearly Sustainable Development Reports[77] as detailed in Schmidt-Traub et al.[43]. Contrary, establishing absolute quantitative targets based on historical data in the SDG framework would lead to a misleading setting of bounds and therefore performances, since it would fail to capture the tendency of all countries to progress towards higher levels of sustainability. The benchmark procedure needs to account for the evolution of indicators; therefore, we have opted for the use of simulation data for the normalisation procedure rather than actual historical data.

SDG 1 — No poverty. The definition of the poverty prevalence indicator is taken from the World Bank: poverty headcount ratio below the poverty line at 1.90 2011$ PPP a day. Considering the existence of this threshold in the SDG definition, this metric was elected for consistency with the benchmarking process described. An additional threshold could have been taken (potentially more relevant in the EU context), but this choice would have been limited to just this one indicator based on an additional source and would constitute a deviation from the established methodology, which would consequently be difficult to justify, especially with respect to the differentiated treatment vis-a-vis the other indicator. Literature suggests that the determinants of poverty prevalence are, mainly, the growth of average per capita income[78], followed by income distribution[79–81] and region-specific sectoral growth[82,83]. Drawing from these conclusions, our analysis relies on Campagnolo and Davide[11] to estimate the poverty prevalence $POV_{i,t}$ as a function of average per capita income (GDP PPP 2011 per capita) and the Palma ratio (further details on how the Palma ratio was obtained are provided in the 'SDG 10' paragraph of this section) for the income distribution. Running a panel data regression with country fixed effect (c_i), we use Eq. (2) including

Table 2 | Main model features, including type, team, version, EU geographical representation, and sectoral granularity

		ALADIN	EU-TIMES	FORECAST	GCAM	GEMINI-E3	ICES-XPS	NEMESIS
Type of model		Bottom-up sector perspective	Energy system model	Bottom-up sector perspective	Partial equilibrium	General equilibrium model	General equilibrium model	Macro-econometric
Research team (see also authors' affiliations)		Fraunhofer ISI	E4SMA s.r.l.	Fraunhofer ISI	BC3	EPFL	CMCC	SEURECO
Version		–	E4SMA-EU-TIMES 1.0	–	GCAM-PR 5.3	GEMINI-E3 7.0	ICES-XPS 1.0	NEMESIS 5.1
EU geographical disaggregation		30 regions: EU27 (each Member State individually), United Kingdom, Norway, Switzerland	30 regions: EU27 (each Member State individually), United Kingdom, Norway, Switzerland	30 regions: EU27 (each Member State individually), United Kingdom, Norway, Switzerland	2 regions: EU15 (Sweden, Finland, Ireland, United Kingdom, Denmark, Netherlands, Spain, Belgium, Portugal, France, Germany, Austria, Italy, Greece), EU12 (Estonia, Lithuania, Latvia, Poland, Czechia, Slovakia, Hungary, Slovenia, Romania, Bulgaria, Cyprus)	1 region (entire EU-27, United Kingdom)	12 regions: Germany, Benelux (Belgium, Holland, Luxembourg), Italy, Greece, Finland, Czechia, France, Spain, Poland, Sweden, United Kingdom, Rest of EU (Estonia, Latvia, Lithuania, Denmark, Ireland, Portugal, Austria, Slovakia, Hungary, Slovenia, Croatia, Romania, Bulgaria, Cyprus)	30 regions: EU27 (each Member State individually), United Kingdom, Norway, Iceland
Sectoral granularity	Macroeconomic	No	Exogenous (as drivers)	Exogenous (as drivers)	Exogenous (as drivers)	Yes	Yes	Yes
	Agriculture	No	Energy requirements only	No	Detailed	As an economic activity with non-CO_2 emissions	As an economic activity	As an economic activity
	Energy supply	No	Very detailed	No	Very detailed	Detailed for power generation	Detailed for power generation	Detailed for power generation
	Industry	No	Detailed	Very detailed	Detailed	As economic activities	As economic activities	As economic activities
	Transportation	Very detailed	Detailed	No	Detailed	As economic activities and household expenditures	As economic activities and household expenditures	As economic activities and household expenditures
	Buildings	No	No	Very detailed	Detailed	As economic activities and household expenditures	As economic activities and household expenditures	As economic activities and household expenditures
	Land uses	No	No	No	Yes	No	No	No

ICES-XPS projections, to obtain scenario-specific projections of poverty prevalence.

$$\ln\left(\text{POV}_{i,t}\right) = \beta_0 + \beta_1 \ln\left(\text{GDPPPPpc}_{i,t-1}\right) + \beta_2 \ln\left(\text{Palma}_{i,t-1}\right) + c_i + \varepsilon_{i,t}$$

$$(2)$$

Supplementary Table S3 reports the coefficients of this regression (lagged variables have here the prefix L.); the GDP PPP pc and the poverty prevalence indicator (POV) derive from WDI database (World Bank), the Palma ratio from the regression described below for SDG10.

SDG 2—Zero hunger. A cross-country panel regression with country fixed efforts was also used to estimate the prevalence of under-nourishment as shown in Eq. (3). Undernutrition prevalence is reduced with increased per capita GDP and food production[84,85] and reduced inequalities[86].

$$
\begin{aligned}
\text{UnNur}_{i,t} = \;&\beta_0 + \beta_1 \ln\left(\text{GDP\_PPP\_pc}_{i,t-1}\right) \\
&+ \beta_2 \ln\left(\text{GDP\_PPP\_pc}_{i,t-1}\right)^2 + \beta_3 \ln\left(\text{Palma}_{i,t-1}\right) \\
&+ \beta_2 \ln\left(\text{Agri\_prod\_pc}_{i,t-1}\right) + c_i + \varepsilon_{i,t}
\end{aligned}
$$

$$(3)$$

Supplementary Table S4 reports the coefficients of this regression (lagged variables have here the prefix L.); all explanatory variables are in the WDI database apart from the Palma ratio estimated in the regression presented below under SDG 10.

The other two indicators included in SDG 2 (food prices and relative yield losses due to ozone exposure) are direct outputs from the models and consider land competition dynamics arising from the energy and water modules integrated into the models and emissions from industrial processes resulting in ozone concentrations affecting agricultural productivity.

SDG 3—Good health and well-being. According to the World Health Organisation (WHO), the healthy life expectancy at birth (HALE) measures how many equivalent years of full health on average a newborn baby is expected to have, given current age-specific mortality, morbidity and disability risks. We obtained projections for this indicator based on a cross-country panel regression where we identified three main drivers: access to health care services (proxied by both population size and public and private health care expenditure), education expenditure[87] and PM2.5 concentration levels[88] (Eq. (4)).

$$
\begin{aligned}
\ln(\text{HALE}_{i,t}) = \;&\beta_0 + \beta_1 \ln(\beta_2 + \beta_3 \ln(\text{Pop}_{t-1}) + \beta_4 \ln(\text{Health\_exp\_pc}_{t-1}) \\
&+ \beta_5 (\text{PrivHealth\_exp\_sh}_{t-1}) + c_i + \varepsilon_{i,t}) \\
&+ \beta_6 \ln(\text{Edu\_exp\_pc}_{t-1}) + \beta_7 (\text{PM2.5\_conc}_{t-1}) + c_i + \varepsilon_{i,t}
\end{aligned}
$$

$$(4)$$

Supplementary Table S5 reports the coefficients of this regression (lagged variables have here the prefix L.); all explanatory variables are in the WDI database.

The mortality due to air pollutants indicator considers both the frequency of deaths and the age at which it occurs, measuring the effects of outdoor and indoor air pollution in terms of years of life lost.

SDG 4—Quality education. The secondary education completion rate above 25 years was proxied by per capita public expenditure (endogenously in ICES-XPS) and urbanisation level (exogenous assumptions), and it was also computed through a country-specific panel regression (Eq. (5))

$$\text{SEdu\_rate}_{i,t} = \beta_0 + \beta_1 \ln\left(\text{Edu\_exp\_pc}_{i,t-1}\right) + \beta_2\left(\text{Urban\_sh}_{i,t-1}\right) + c_i + \varepsilon_{i,t}$$

$$(5)$$

Supplementary Table S6 reports the coefficients of this regression (lagged variables have here the prefix L.); all of the explanatory variables used in the regression are in the WDI database.

We assumed that government expenditure maintains the same path across scenarios in the ICES-XPS model, as we are not linking government expenditure to tax revenues. Education is only one of the possible destinations of government expenditure, therefore, only small variations of education expenditure per capita can be observed across different mitigation scenarios, which are driven by small price differentials across other goods/services that the government can purchase. Consequently, the evolution of the indicator on secondary education completion rate remains very similar across scenarios.

SDG 6—Clean water and sanitation. Water pressure and sustainable use of water resources are captured by an indicator on freshwater withdrawal share, defined as the percentage of the total freshwater abstracted annually from water sources, compared to the total available renewable resources (flow of rivers and recharge of aquifers generated from precipitation).

Volumes of water withdrawals are the ones necessary to balance the needs for the agricultural and industry sectors considering the water requirements of the different available technologies. This demand balance also defines the water price, which is used as an indicator to capture the accessibility or affordability component.

SDG 7—Affordable and clean energy. Generating energy sustainably means reducing the pressure on primary energy sources, in particular, the fossil ones whose stock is limited and whose combustion generates GHG emissions and causes global warming. We used an indicator on primary energy intensity and another on renewable electricity shares to capture the reliance of EU countries' economies on energy sources and the contribution of renewable sources to sustain energy needs. The energy access component of SDG 7 was only partially covered due to model limitations through the affordability component with an indicator of expenditure share dedicated to energy in the residential sector.

SDG 8—Decent work and economic growth. Per capita GDP, its growth and the GDP per person employed were used to assess the economic performance of EU+ countries. While some of the models use these figures as inputs for their computations, the results presented here are the GDP output figures obtained by the macroeconomic models ICES-XPS and NEMESIS.

SDG 9—Industry, innovation and infrastructure. The decarbonisation of the economy also means sectoral decarbonisation. Concerning SDG 9, this is translated into a reduction in the emission intensity of the industry sector measured as CO_2 emission generated for each currency unit of sectoral value added. Another relevant indicator for SDG 9 is the GDP share dedicated to both private and public research and development due to its contributing role to national income and labour intensity. Like in the case of education expenditure explained previously in SDG 4, public expenditure projections are adjusted based on government revenues and other government expenditure shares obtained with ICES-XPS. However, these are not directly impacted by climate policies but rather by small price differentials across other goods/services that the government can purchase.

SDG 10—Reduced inequalities. The between-country Gini coefficient indicator is able to capture the spreading of the per capita income among countries and can be directly computed from some of the model outputs through Eq. (6)

$$\text{WGini}_t = \frac{2}{n^2 \overline{\text{GDPpc}_t}} \sum_{i=1}^{n} i * \left(\text{GDPpc}_{i,t} - \overline{\text{GDPpc}_t}\right)$$

$$(6)$$

To capture the within-country income inequality we used the Palma ratio, defined as the ratio of the GDP share held by the richest 10% of the population and the share held by the poorest 40%. The literature identified several explanatory variables related to labour productivity differences

between agricultural and non-agricultural sectors, education rates, sectoral wage differences and labour market reforms[89–91]. Following Campagnolo and Davide[11], building on Ferreira et al.[82], we focus on nominal income (not adjusted for reduced purchasing power due to price changes) and measure how this income is distributed instead of focusing on inflation to capture the inequality trends, acknowledging that energy and food prices, albeit important, are more related to the material poverty measures. The Palma ratio (Eq. (7)) was consequently estimated as

$$
\begin{aligned}
\ln(\text{Palma}_{i,t}) = &\ \beta_0 + \beta_1 \ln(\text{PEduExp\_pc}_{i,t-1}) + \beta_2 \ln(\text{AgriVA\_sh}_{i,t-1}) \\
&+ \beta_3 \ln(\text{hIndVA\_sh}_{i,t-1}) + \beta_4 \ln(\text{CorruptCtrl}_{i,t-1}) \\
&+ \beta_5 \ln(\text{Unempl}_{i,t-1}) + t + c_i + \varepsilon_{i,t}
\end{aligned}
$$

$$(7)$$

where $\text{PEduExp\_pc}_{i,t-1}$ stands for per capita public education expenditure; $\text{AgriVA\_sh}_{i,t-1}$ $\text{hIndVA\_sh}_{i,t-1}$ for the shares of value added from agriculture and heavy industry; $\text{CorruptCtrl}_{i,t-1}$ for the corruption control perception and $\text{Unempl}_{i,t-1}$ for the unemployment rate. Additionally, a dummy variable was included to distinguish between consumption and income distribution ($d\_c\_i_{i,t}$), a time trend (t) and country (c_i) and year (y_t) fixed effects. Supplementary Table S7 reports the coefficients of this regression (lagged variables have here the prefix L.).

SDG 11—Sustainable cities and communities. Two other sectoral decarbonisation indicators are comprised in SDG 11: CO_2 intensities of the building and of the transport sectors, as both these sectoral emission reductions are crucial for climate change mitigation in urban areas. Finally, an additional indicator is considered to include the impacts of outdoor air pollution, as it causes over 4 million premature deaths every year[88] by increasing the risk of stroke, heart disease, lung cancer, and both chronic and acute respiratory diseases. We assessed these impacts through an indicator of exposure to fine particulate matter (PM2.5). A reduction of this exposure is achieved hand in hand with GHG emission reductions.

SDG 12—Responsible consumption and production. The sustainability on the supply side is captured through an indicator of energy intensity and another of CO_2 intensity, both referred to in the industrial sector. Energy intensity is defined as the energy required to generate a dollar of added value in the industrial sector. Additionally, we also deemed it relevant to monitor the CO_2 emissions generated per unit of energy used to analyse the decarbonisation rate in the industry sector. To cover the sustainability of the demand sector and include an indicator of sustainable lifestyles, we opted for an indicator of residential emissions per capita accounting only for the direct emissions generated by each individual but not the indirect ones embedded in the consumed products. Finally, an indicator of material intensity was included to capture the reliance on raw materials to generate economic value in the industrial sector.

SDG 13—Climate action. The overall decarbonisation is assessed by comparing the emissions levels at each simulated timestep with respect to the baseline year 1990.

In addition, an indicator of CO_2 emissions intensity was also analysed to reflect on the capacity of countries to decouple economic performance from emissions generation.

SDG 14—Life below water. The assessment of SDG 14 is done through an indicator of the ocean pH. It measures how far the uptake of CO_2 by the oceans is able to chemically alter its superficial layers.

SDG 15—Life on land. The absence of natural land cover is a driving factor for biodiversity loss[92]. We, therefore, included an indicator on the share of natural land cover, including land used for the forest, shrubland, grassland, barren land, and wetland (excluding agriculture and developed land) not necessarily in good conservation state or preserved by human interference.

The key role of forests in climate change mitigation is captured through an indicator of the share of land covered by forest. A reduction of forest-covered areas is related to the release of previously stored carbon into the atmosphere and a reduced capability to absorb carbon dioxide emissions in the future.

SDG 17—Partnership for the goals. The level of partnership and solidarity among countries to foster sustainable development was captured through an indicator of imports share from Least Developed Countries (LCDs) with respect to total imports. The type of goods exported, their value-added, or the social and environmental qualifications of their value chain are also relevant factors when analysing the support of LCDs through trade. Due to model limitations, only the share traded with these countries was used in this study as a proxy to measure the contribution of advanced economies to the economies of LCDs through trade. These resources can be taken as an indirect source of well-being for these countries as they can be used to support their economies.

Data availability
The raw data produced and examined in the present research can be accessed from a public repository (https://zenodo.org/doi/10.5281/zenodo.10072816).

Code availability
The code availability for the specific models used in the study varies, and so interested parties should reach out to the respective modelling groups. The GCAM model is available for download from: https://github.com/JGCRI/gcam-core.

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Author contributions

J.M., L.C., B.B., A.N., A.G., and D.V. coordinated the study design and scenario protocol. All authors were involved in the model analysis, with notable contributions from A.C., M.G. (EU-TIMES), B.B., P.M. (NEMESIS), A.H., K.A.-D., Ş.A., F.N. (ALADIN, FORECAST), D.V., M.G.-E. (GCAM), L.C., E.D. (ICES-XPS), S.P., M.V. (GEMINI-E3), J.M., L.C., A.N., K.K., H.D. (SDG benchmarking and normalisation). J.M. and L.C. compiled and analysed the results and created the figures, with feedback from all other authors. J.M. coordinated the conception and writing of the paper with notable contributions from L.C., B.B., A.N., K.K. and feedback and contributions from all other authors.

Competing interests

The authors declare no competing interests.

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Additional information

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