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Climate policy and the SDGs agenda: how does near-term action on nexus SDGs influence the achievement of long-term climate goals?

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Abstract

The sustainable development goals (SDGs) represent the global ambition to accelerate sustainable development. Several SDGs are directly related to climate change and policies aiming to mitigate it. This includes, among others, the set of SDGs that directly influence the climate, land, energy, and water (CLEW) nexus (SDGs 2, 6, 7, 13, 15). This study aims at understanding the synergies and trade-offs between climate policy and the SDGs agenda: how does near-term action on SDGs influence long-term climate goals? Based on a multi-model comparison, we evaluate three scenarios: (i) reference; (ii) climate mitigation; and (iii) a CLEW nexus SDGs scenario. We find clear positive effects of combining the climate and the sustainable development agendas. Notably, healthier diets, with reduced meat consumption, have strong co-benefits for climate, with positive effects across multiple SDGs: improvements in food security, reductions in air pollution and water stress, and improvements in biodiversity conservation. Such positive outcomes are prominent in the Global South, where regions typically at higher risk of food and energy insecurity and other environmental stresses (e.g. Sub-Saharan Africa, Asia and Latin America) benefit from a shorter term agenda focusing not only on the climate but also on the other sustainable development dimensions. However, trade-offs are also observed (e.g. increases in the prices of food and electricity), especially in the dynamics of land and the food systems, highlighting the importance of exploring policy synergies: if individually applied, some measures can negatively impact other sustainability goals, while taking into consideration the nexus interactions can reduce trade-offs and increase co-benefits. Finally, near-term action on SDGs can help speed up the transition towards the long-term climate goals, reducing the reliance on negative emissions options. In 2100, the SDG scenario in significantly less reliant on carbon dioxide removals both from AFOLU and the energy system.

1. Introduction

In 2015, two sets of ambitious goals were internationally agreed: (1) the Paris Agreement goal to prevent dangerous anthropogenic climate change by limiting global mean temperature increase by 2100 to well below 2 °C and pursue efforts to stay below 1.5 °C (UNFCCC 2015), and (2) the sustainable development goals (SDGs) to accelerate sustainable development across the world (UN 2015). The SDGs agenda, introduced by the 2030 agenda on sustainable development, sets targets regarding poverty reduction, environmental protection, social well-being and (economic) development. Implicit in these combined agendas is the need for a massive transformation across society, in many systems (e.g energy, land use, health) and across different governance scales (cities, countries, regions, and the world). This will also require considerable investments in physical infrastructure systems to support this transformation (Soergel *et al* 2021, Kulkarni *et al* 2022).

Several SDGs, aside from SDG13, on climate action, have significant links to climate change. This includes the set of SDGs related to land (SDG2 related to food, and SDG15 on terrestrial biodiversity, which has strong relations with climate impacts and climate action), water (SDG6 on water) and energy (SDG7 on clean energy). These domains are highly interconnected and dependent on each other, with a range of interactions, also referred to as the energy-land-water-climate nexus (Van Vuuren *et al* 2019, Doelman *et al* 2022).

Developing scenarios can help in exploring how the goals can be achieved. Several studies have focused on developing model-based scenarios to meet the SDGs goals (Bertram *et al* 2018, van Vuuren *et al* 2015, 2018, Fujimori *et al* 2019, 2020, Doelman *et al* 2022), or to meet climate goals, while looking at co-benefits and trade-offs with the sustainability agenda (Hasegawa *et al* 2018, Humpenöder *et al* 2018, Moyer and Bohl 2019, Soergel *et al* 2021, Fujimori *et al* 2023). For instance, Soergel *et al* (2021) developed a sustainable development pathway scenario, aligning different sets of interventions, covering multiple indicators and extending the analysis to proxies of all 17 SDGs, using the REMIND-MAgPIE model (PIK 2023). (Doelman *et al* 2022) conducted a two-model study on the water-food-land-climate nexus, developing a set of scenarios with harmonized assumptions to evaluate different components of this nexus. A scenario exercise with multiple models, looking at SDGs and climate policy connections around the nexus focusing specifically on the climate/SDGs interaction is still missing.

Therefore, this study focuses on the climate and land-energy-water nexus (CLEW) to identify pathways that can achieve the climate goals while simultaneously addressing multiple SDGs, as well as their synergies and trade-offs for meeting such ambitious goals, using the IMAGE and MESSAGEix-GLOBIOM integrated assessment models (IAMs). IAMs are modelling tools that aim at providing a quantitative description of the human and the earth systems, as well as how they interact with each other. In exploring such interactions, IAMs draw on functional relationships in society, the economy and the environment. Most importantly, in this study we aim at understanding the interactions between sustainable development and climate policy and how actions on SDGs in the short term influence the achievement of the long-term Paris climate goals. This means that we explore how climate feedbacks and climate policy can impact the achievement of the SDGs agenda, and how early action on CLEW related topics can impact the climate.

2. Methods

We conduct our scenario analysis using two IAMs: IMAGE 3.2 (PBL 2023) and MESSAGEix-GLOBIOM_1.1 W (Awais *et al* 2024). The use of two IAMs allows to test the robustness of some of the outcomes, also in light of the differences between these models (see model description in the supplementary material), At the same time, both IMAGE and MESSAGEix-GLOBIOM are particularly suitable for this analysis given their detailed representation of the energy, water and land use systems (Van Vuuren *et al* 2019, Doelman *et al* 2022, Vinca *et al* 2023).

2.1. Scenarios representing climate policy and CLEW SDGs

The scenarios look into: (1) a reference scenario of possible developments without new climate policies (REF); (2) a climate mitigation scenario focusing on achieving the Paris climate goals (CLIM); and (3) a third scenario that implements both a set of policies targeting the CLEW SDGs and climate policies aiming at the Paris goals (SDG). Below, we explain the CLEW SDGs policies and the approaches taken by the different models to implement them and discuss the scenarios in more detail.

2.1.1. Climate policy

Climate policy is implemented in both models in the form of price on CO_2 emissions or a carbon budget that is introduced to meet a determined climate goal—in this case, to reach a radiative forcing of 2.6 W m^{-2} in the 2100, which is consistent limiting global mean temperature rise to 2 °C with greater than 66% likelihood. These scenarios achieve globally concerted climate action until 2100, with a temperature overshoot in the intermediate period (defined as category C3b in the IPCC's scenario classification (IPCC 2022)). The carbon price induces cost-effective measures to meet the goal, including energy efficiency, introduction of renewable energy and nuclear power, the use of carbon-capture-and-storage and reduction of non-CO_2 greenhouse gases.

2.1.2. CLEW SDGs policies

A set of measures has been identified to address the CLEW nexus SDGs. The main criteria for measures to be included are: (i) they should maximally benefit the overall goal (i.e. achieving the SDG targets); (ii) they should be unambiguous and quantifiable. Most measures are implemented in an equal or very similar way in both models, with the main differences in the implementation approach summarized in table 1 (detailed model-specific implementation is described in the supplementary information).

Table 1. Implementation of SDGs measures.

SDG	Measures	
	IMAGE	MESSAGEix-GLOBIOM
SDG2 Zero hunger	1. Changes towards a healthier diet: alternative consumption patterns were implemented based on the definitions of the EAT-Lancet commission (Willett *et al* 2019)[a] 2. Reduce food waste in middle and high-income countries to the lowest level among them in three stages of the supply chain (primary, processing, and consumption)[b] 3. Strong improvements in equity of food availability	1. Developing countries reach minimum total calorie intake levels that limit undernourishment below 1% globally by 2030 (undernourishment calculation based on (Hasegawa *et al* 2018))[c] 2. Developed countries assume that total calorie intake should not fall below 2010 levels in response to the mitigation policy 3. Changes in dietary preferences for livestock products based on the USDA recommendations for healthy diets (USDA 2015)[d] 4. Food waste is reduced by 50% in 2030, in processing, transporting and retail, and consumption
SDG6 Water	1. Variable monthly flow (VMF) method (Pastor *et al* 2014) to constrain the available surface water based on environmental flow requirements for wet and dry seasons 2. Water efficiency improvement assumptions (Pastor *et al* 2014, 2019, Van Vuuren *et al* 2019)[e]	1. Variable monthly flow (VMF) method (Pastor *et al* 2014) to constrain the available surface water based on environmental flow requirements for wet and dry seasons 2. Water efficiency improvement assumptions (Frank *et al* 2021, Pastor *et al* 2019)[f] 3. Wastewater treatment capacity is increased to be able to treat a minimum of half of all the wastewater collection in the infrastructure system (Awais *et al* 2024)
SDG7 Energy	1. Access to electricity is increased to a minimum of 98% of all households per region by 2030[g] 2. Reduction in the use of traditional biomass and increase in the adoption of cleaner cooking and heating fuels (LPG, kerosene, electricity)[h]	1. The MESSAGE-Access-E-USE (end-use services of energy) model is used for the analysis of households' energy access to modern energy services for heating and cooking
SDG15 Life on land	1. Protection of 30% of all terrestrial area per ecoregion, preventing the expansion of agriculture in these areas (Kok *et al* 2023)[i]	1. Doubling the AICHI Biodiversity target 11 (i.e. increase total surface of protected areas to 17% by 2030). 2. UNEP-WCMC Carbon and Biodiversity Report (UNEP-WCMC 2008) is used to identify highly biodiverse areas and prevent their conversion to agriculture or forest management from 2030 onwards[j]
SDG13 Climate action	1. Limit the increase in global temperature to well-below 2 °C in 2100 (forcing target of 2.6 W m^{-1})[b]	

Notes.

[a] Maximum level of 275 kcal/cap/day for animal products; minimum level of 900 kcal/cap/day for vegetables, legumes, vegetable oils and fruits; maximum level of 110 kcal/cap/day for sugars; maximum level of 2100 kcal/cap/day for cereals.

[b] Reductions in food waste for six commodities groups (cereals, roots and tubers, oilseeds and pulses, fruit and vegetables, milk, and meat) based on (FAO 2011).

[c] Once the calorie threshold is reached by 2030, the GLOBIOM model assumes no decrease in the minimum intake levels thereafter for example due to GDP growth.

[d] Animal calorie intake is decreased to 430 kcal/capita/day by 2030 in countries exceeding this threshold.

[e] Per sector (i) agriculture: not included; (ii) industry: 5%; (iii) residential: 26%; and (iv) power generation: 59%.

[f] Per sector: (i) agriculture: 2% per decade; (ii) power generation: not included.

[g] The electrification rate and the associated costs are determined using the methodology of (van Vuuren *et al* 2021).

[h] This is implemented by changing the preference factors by means of adding a 'perceived cost' to traditional biomass (Daioglou *et al* 2012).

[i] Protected areas are allocated as follows: (i) current protected areas retrieved from the World Database on Protected Areas (WDPA) are assumed to remain protected; (ii) key biodiversity areas and intact forest landscapes are protected up to 2050; (iii) additional remaining natural land, where areas with higher range size rarity index are allocated first.

[j] Areas where three or more biodiversity priority schemes overlap are considered highly biodiverse.

Table 2. Included climate impacts and underlying approach/data.

Climate impact	Approach	IMAGE[a]	MESSAGEix-GLOBIOM[b]
Renewable energy supply (wind, solar, hydro, bioenergy)	Changes in renewable energy potentials are calculated through time on 0.5 × 0.5 grid and aggregated to regional cost-supply curves (Byers *et al* 2018, Gernaat *et al* 2021)	Yes	Hydropower only[c]
Heating and cooling demand	Changes in grid-level daily air surface temperature HDD/CDD (0.5 degree), aggregated and population-weighted to country and region (Byers *et al* 2018, Gernaat *et al* 2021)	Yes	Yes
Water availability	Runoff and groundwater recharge from LPJmL & CWatM for IMAGE & MESSAGEix-GLOBIOM, respectively, calculated at 0.5 × 0.5 grid (Burek *et al* 2020, Schaphoff *et al* 2018)	Yes	Yes
Crop yields	IMAGE: crop yield change due to climate change calculated in LPJmL on 0.5 × 0.5 grid (Schaphoff *et al* 2018) MESSAGEix-GLOBIOM: crop yields from (Müller *et al*, 2014) are used in GLOBIOM	Yes	Yes

[a] IMAGE uses IPSL-CM5A-LR.
[b] MESSAGEix-GLOBIOM uses the multi-model average: GFDL-ESM2M, IPSL-CM5A-LR, MIROC5 (for water availability), UKESM1-0-LL (for crop yields), HadGEM2-ES (for heating/cooling demand).
[c] As impacts on renewable energy supply are found to be relatively small (Byers *et al* 2018, Gernaat *et al* 2021), the exclusion of non-hydro renewables in MESSAGEix-GLOBIOM is not expected to lead to large discrepancies between the models.

Table 3. Scenarios.

Scenario	Climate target ($W m^{-2}$, in 2100)	Additional SDGs measures	Climate impacts
REF	6.0	No additional effort	Climate impacts included in all scenarios, consistent with the warming pathways (specified in the climate target)
CLIM	2.6	No additional effort	
SDG	2.6	Additional measures to achieve food/water/energy/biodiversity targets	

Note: an additional scenario focusing on achieving the SDGs except for the climate targets is not relevant given that climate action is part of the SDGs agenda (SDG 13).

2.2. Climate feedback and impacts

Climate feedback and impacts are implemented in both IAMs for consistency with the emissions pathways (table 2). Data is based on the Inter-Sectoral Model Intercomparison Project (Frieler *et al* 2017), to ensure internal consistency across the different indicators and across models. Where relevant, models can differ in terms of impact modules and default climate patterns (e.g. in IMAGE, data from the IPSL global climate model is used, while MESSAGEix-GLOBIOM uses the mean of a multi-model ensemble). With an intended focus on sectoral biophysical impacts, the impacts on labor productivity and GDP are not included in this assessment.

2.3. Scenario analysis

For the scenario analysis, the scenario set-up uses different assumptions across three dimensions: SDGs measures, climate policy and climate impacts. The scenarios are based on SSP2, from the Shared Socioeconomic Pathways, assuming middle-of-the-road development for all relevant parameters (O'Neill *et al* 2017) (summarized in table 3).

3. Results

First, the effectiveness of the measures on CLEW SDGs in the short term (2030) are explored and compared with the mitigation case (CLIM). Then, we evaluate the benefits and trade-offs of simultaneous actions on CLEW SDGs and climate policy, for both mid-term (2050) and long-term (2100) strategies.

3.1. Effectiveness of implemented CLEW SDGs measures

Figure 1 shows the effectiveness of the implemented CLEW SDGs measures, comparing them with the mitigation case across multiple indicators, for the short term (2030).

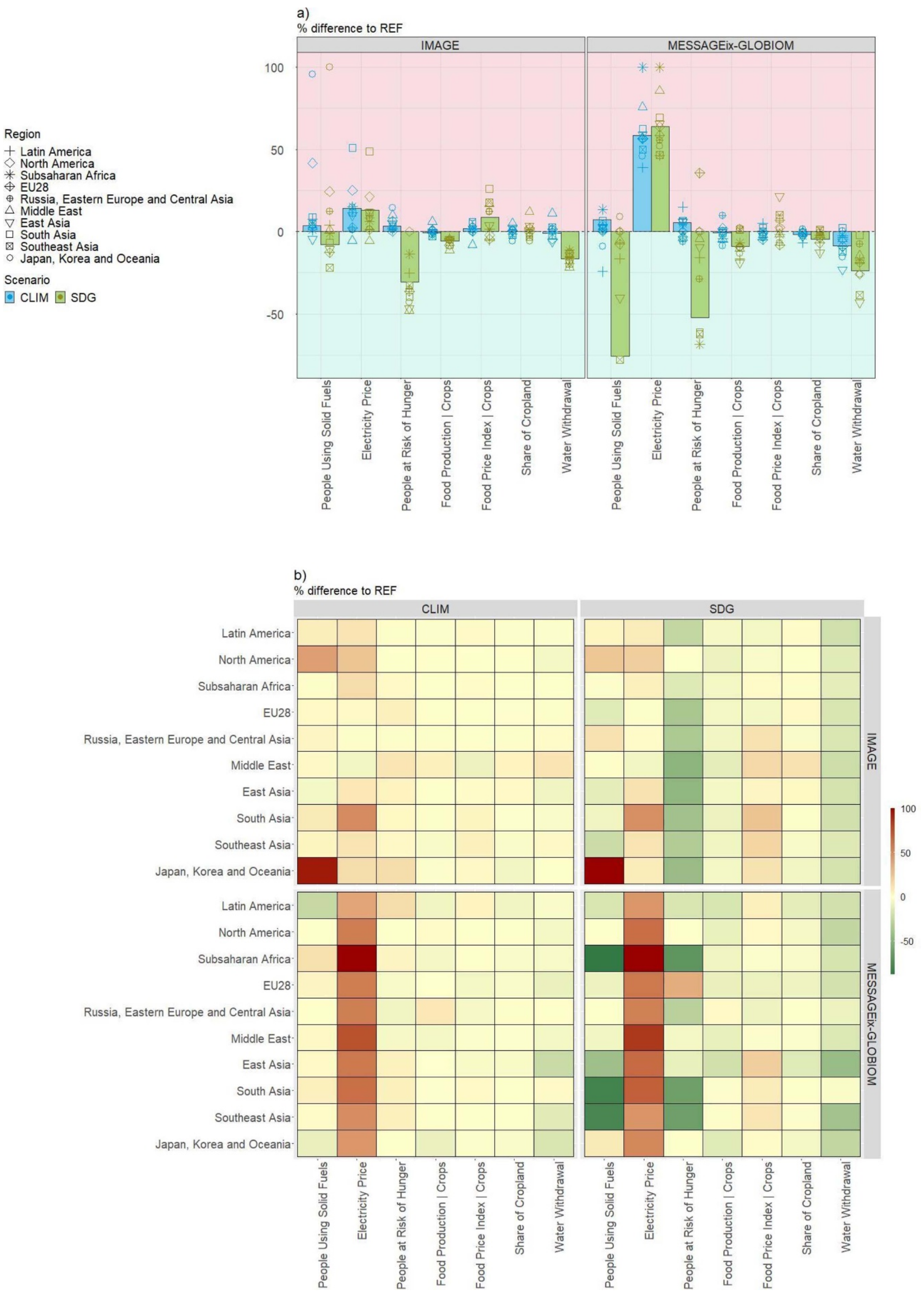

Figure 1. Effectiveness of implemented SDGs measures, per region, per model (2030), in % difference when compared to the reference scenario. (a) Bars represent global results, and points represent different regions; (b) heatmap showing regional results. High increase of people using solid fuels in Japan, Korea and Oceania, in both CLIM and SDG scenarios result from showing % change compared to REF, when in fact absolute change is not too large (approximately 1 million people in total, due to increase in costs for cleaner energy).

3.1.1. *Energy*

In the energy sector, both models indicate an increase in electricity prices for both scenarios, when compared to the reference scenario. MESSAGEix-GLOBIOM shows larger increases in electricity prices: globally, prices increase by 57% in CLIM and 44% in SDG. Regionally, notable increases are observed in the Middle East (89% in CLIM and 60% in SDG) and in Sub-Saharan Africa (over 100% for both scenarios). In IMAGE, most regions show increases in prices by 2030, as high as 51%–49% in South Asia, and 25%–21% in North America, for the CLIM and SDG scenarios, respectively. Traditional solid fuels (e.g. collected wood or dung) have no formal price attached to them. In the models, such fuels are used by households for free. Therefore, a switch to electricity results in an increase in their expenditures. The additional increases in electricity prices result from the increase already taking place in the baseline, due to a combination of overall population growth and economic activity, as well as resource depletion (both fossil and renewable), and the response to climate policies (carbon capture and storage and carbon pricing/taxing of remaining fossils). For MESSAGEix-GLOBIOM, the policies implemented in SDG tend to increase the prices when compared to CLIM. In IMAGE, while in both cases overall prices of electricity tend to increase, when compared to the reference scenario, taking into account the need for expanding the access to clean energy goals (SDG) results in more affordable electricity.

Simultaneously, there are substantial reductions in the population relying on solid fuels, such as the use of traditional biomass and coal for cooking and heating in the SDG scenario. In both models, there is slightly higher population relying on solid fuels in the CLIM scenario due to higher energy prices for mitigation (140 million people in IMAGE and 177 million people in MESSAGEix-GLOBIOM), compared to substantially less in the SDG scenario, worldwide (315 million and 1.8 billion fewer people, in IMAGE and MESSAGEix-GLOBIOM, respectively) and in most regions. The combined effects of maximizing the access to electricity and access to cleaner fuels (SDG7), has direct benefits for the climate (SDG13). This trend globally, and more prominently in South and Southeast Asia, and Sub-Saharan Africa, which are regions where large investments needs towards access to clean cooking fuels are estimated (Dagnachew *et al* 2020, 2023).

3.1.2. Food

For food crops, CLIM shows a slight decrease in global production (approximately −1% in both models, when compared to the REF scenario). This is a result of the competition with land-based mitigation. There are, however, large differences between regions. While production decreases in most regions, it is expected in regions that are less influenced by land-based mitigation production might increase (given comparative advantages): North America, Western and Central Europe, Russia, Eastern Europe and Central Asia, and the Middle East. For the SDG scenario, the production of food crops decreases in all regions (globally −6% in IMAGE and −10% in MESSAGEix-GLOBIOM). This is due to the policies assumed (dietary changes involving less meat, improved food distribution and reduction in food waste). For both models, we observe a shift in the trend of increasing population with risk of hunger in the CLIM scenario towards a substantial decrease in the SDG scenario. The regions that benefit the most from this increase in food security are South, Southeast and East Asia, Sub-Saharan Africa, and Latin America.

In terms of prices, MESSAGEix-GLOBIOM results indicate that food prices remain globally stable in both scenarios, with larger regional variations in SDG. On a different trend, IMAGE results indicate an increase in food prices globally (+2% in the CLIM scenario and +8% in the SDG scenario) due to increased pressure on the land system. In the SDG scenario this is a result of the counteracting impacts of measures that reduce available land for agriculture (e.g. forest protection and afforestation) and measures that increase potentially available land (e.g. diet change). For both models, the most affected regions are South and Southeast Asia. In IMAGE, the Middle East, Japan, Korea, and Oceania are also significantly affected by higher food prices in the SDG scenario, suggesting that these regions would otherwise benefit from unsustainable land use practices as in the reference scenario.

3.1.3. Land and biodiversity

In both models, the effects of protection of natural lands and lower pressures on land use for agriculture (due to dietary changes and the reduction of food waste) lead to increases in the share of natural lands, of +5% in IMAGE and +3% in MESSAGEix-GLOBIOM, globally, for SDG. Regionally, the largest increases in natural land shares are observed in Latin America (+12% in IMAGE and +8% in MESSAGEix-GLOBIOM) and South Asia (+10% in MESSAGEix-GLOBIOM). On the other hand, the dietary and food waste measures lead to reductions in the share of cropland globally (−6% in MESSAGEix-GLOBIOM), and regionally (−5% in Japan, Korea and Oceania, and −3% in Southeast Asia, in IMAGE). The trade-off between natural lands and croplands has implications for food security. Implicit assumptions concerning crop yields, crop management and fertilizer use, as well as the enforcement of ancillary policies are critical to protect the food system.

3.1.4. Water

Overall, changes in global water withdrawals in both models are negligible in the CLIM scenario, given the reduction of thermal cooling needs but also the lower climate change impacts on water availability than in the REF scenario, although regional and sectoral shares vary. When SDGs measures are included, water withdrawals decrease in all regions for both models, reaching −17% globally in IMAGE and −16% globally in MESSAGEix-GLOBIOM, in 2030. This result reflects the strict limits on water withdrawals to respect environmental flow requirements as well as the higher efficiencies of water use in industry, agriculture, and the power sector.

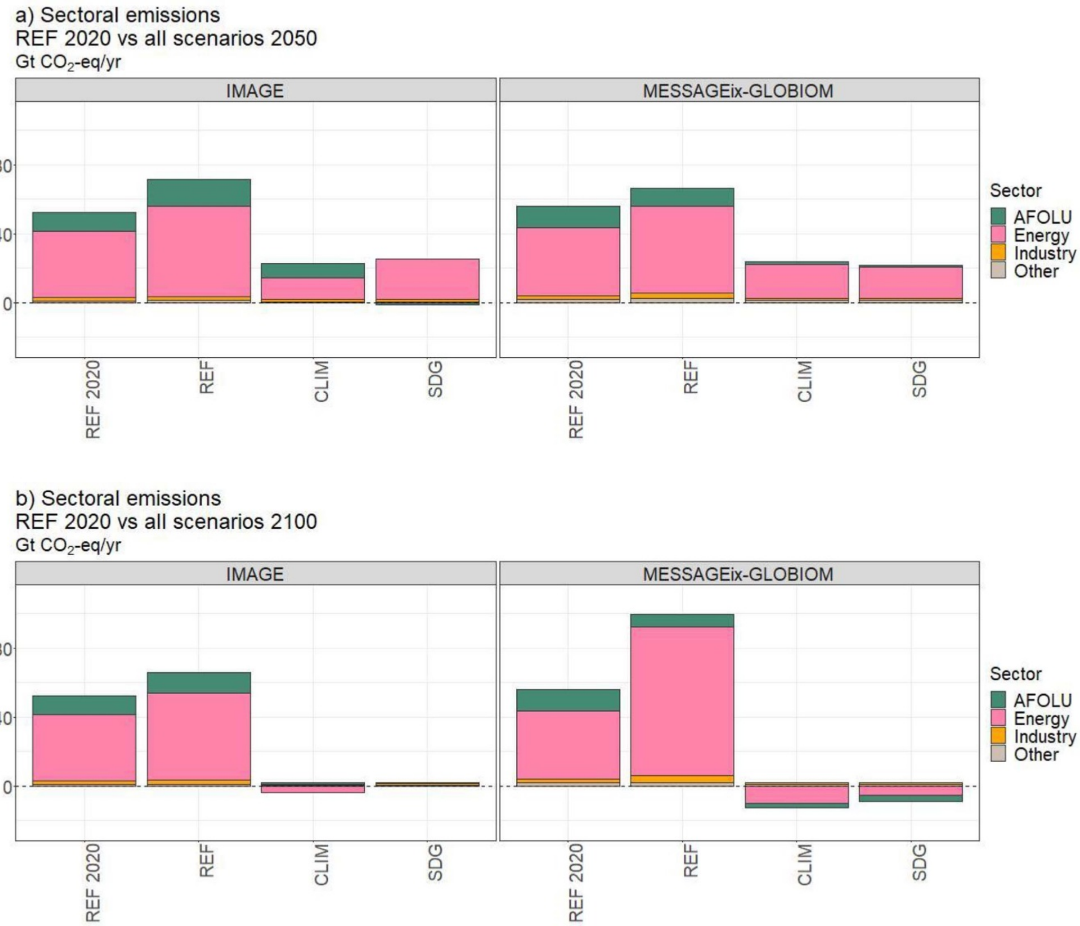

Figure 2. (a) GHG emissions per sector for the REF scenario in 2020 and in 2050, and for the CLIM and SDG scenarios in 2050; (b) GHG emissions per sector for the REF scenario in 2020 and in 2100, and for the CLIM and SDG scenarios in 2100.

3.1.5. Synergies in the CLEW nexus

Measures focused on the CLEW nexus result in improvements for all indicators and related SDGs, with co-benefits for climate mitigation. Shifting diets towards lower consumption of meat, higher consumption of vegetables and lower calorie intake, as well as reducing food wastes and ensuring more equity in food availability, resulted in a considerable increase in food security (SDG2) with co-benefits for multiple SDGs. For instance, diet changes and the overall increase in food security have synergies with the protection of natural lands and biodiversity (SDG15), and water availability, correlating the reduction in the share of croplands and the efficiency gains in water use for agriculture (SDG6).

3.2. Sustainable development and climate policy

Figure 2 shows sectoral GHG emissions for all scenarios, comparing them with the REF scenario in 2020. Having the same climate target, CLIM and SDG have similar emissions trajectories, with both CLIM and SDG scenarios indicating reductions in GHG emissions in all sectors. However, action on SDGs results in less negative emissions required in the longer term. In the CLEW nexus space, this outcome is mostly driven by changes in the food system. Changes in diet and the distribution of food leads to the contraction of pasture lands and lower non-CO_2 GHG emissions and allows the expansion of forests (figure 3(c)), resulting in a reduction in AFOLU emissions. For IMAGE, the CLIM scenario goes net-negative in 2100, with important contributions from the energy sector, while the SDG scenario stays closer to net-zero (positive emissions mostly from industry). For MESSAGEix-GLOBIOM, the system goes net-negative at the end of the century in both scenarios. Nonetheless, the SDG scenario shows a reduction in negative emissions coming from the energy sector.

Figure 3 presents the developments in the energy and land systems, for all scenarios.

In terms of the energy system, our results show a similar behavior for the mitigation scenarios, with a strong reduction in the use of fossil fuels, especially in the shares of coal. Both models still deploy a considerable amount of natural gas in 2050, with

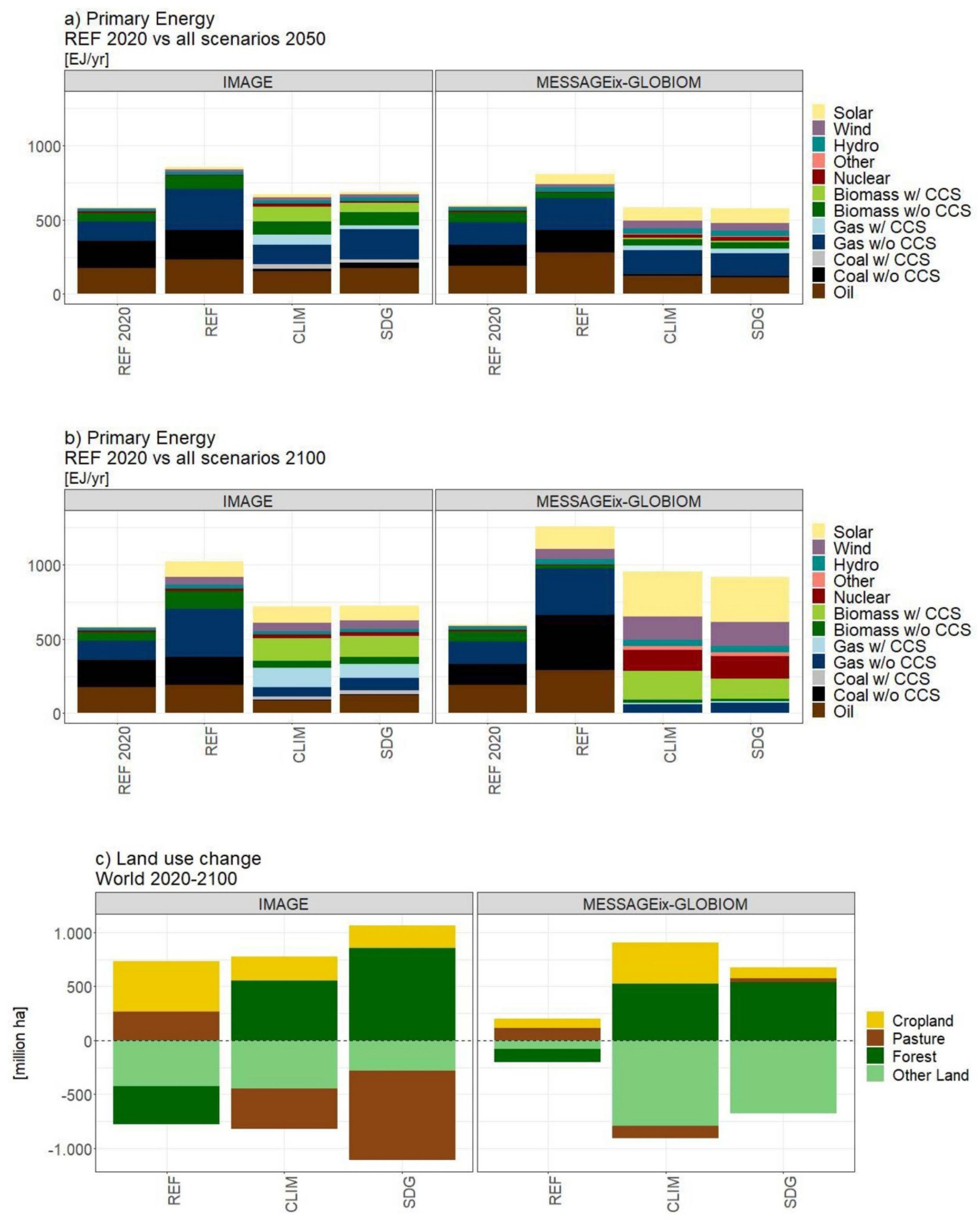

Figure 3. (a) Primary energy, per model, for REF in 2020, and for the REF, CLIM and SDG scenarios in 2050 and (b) in 2100 (direct method for reporting renewable energy); (c) Land cover[5] and land use change (bottom), for REF in 2020, and for REF, CLIM and SDG scenarios in 2100 (when compared to REF in 2020).

IMAGE showing a stronger preference for coupling natural gas with CCS and for bio-based fuels in 2100, while MESSAGEix-GLOBIOM relies on the deployment of non-biomass renewables, and a higher share of nuclear energy. Moreover, it is worth noting that for both models the SDG scenario shows less use of CCS in general (fossil or bio-based). In terms of land, a large increase in forest area is observed, especially for IMAGE, where afforestation takes a prominent role in land-based mitigation. Particularly for IMAGE is also the increase in the 'other land' category, because for IMAGE it includes other types of natural land. Moreover, for IMAGE, the SDG scenario shows a stronger reduction in pasture lands and croplands, in line with the changes assumed for the food systems.

[5] For context, the share of natural land (forests and other land) in 2020 equals approximately 62% of total land cover.

4. Discussion

In the analysis, we have used two different IAM system to look into a similar question—i.e. the possible relationships between specific SDG relates measures and climate policy. As part of the discussion, we would like to highlight four topics: (1) the differences between the two models, (2) the interpretation of results, (3) the representation of adaptation and (4) the need for more systematic studies on SDG achievement. The differences between the models implied that we have chosen to allow the models to analyze each measure in a way that best fit that specific system. The models differ in terms of solution method (e.g. simulation vs. optimization) and sectoral detail (e.g. representation of land use and the land system, food groups and coverage of food crops, heterogeneity of households and different regional aggregation). For instance, for water, the implementation slightly differs given model differences. The strength of IMAGE is that the LPJmL sub-model simulates the global hydrological cycle coupled to natural vegetation dynamics, crop production and land-use allocation. Water demand for agriculture and energy are linked to endogenous processes (crop and energy production, climate), except in case of water limitations. In MESSAGEix-GLOBIOM, the focus is more on targets for reaching sustainable water consumption across all sectors. The capacity of the water infrastructure system for integrating water access and quality targets is constrained and the connection and treatment rates are endogenized in the withdrawals and wastewater collection. The SDG6 narrative on access to clean water and sanitation is incorporated by applying supply and demand side development across the water system. The supply side measure includes constraints on available surface water as environmental flows. This method implies that water withdrawals cannot exceed the residual available supply after environmental flows are considered.

For agriculture, the finding of both models that food prices increase as a result of climate policy needs to be put in context. This represents a possibly important trade-off, mainly due to competition for land from land-based mitigation. It should be noted that the impact also depends on the way policies are implemented. The models represent climate policy by a carbon tax on agriculture that thus increases food prices via remaining non-CO_2 greenhouse gas emissions. Other methods to implement policy could prevent such strong impact on prices, such as direct regulation. Moreover, also ancillary policies, such as food access policies, can also be implemented. These might have additional costs, trade implications and effects on logistics. A similar dynamic holds for energy and for policies aiming at expanding (clean) energy access. In mitigation scenarios, climate policies lead to a substitution in electricity sources (including more costly technology options such as carbon capture and storage) and carbon prices/taxes for remaining fossil use. The upward forces driving electricity prices up are stronger than the downward forces, such as decreases in prices via learning. Furthermore, from a market perspective, consumers see the marginal price, i.e. the price of the most expensive generator—thus while costs of individual electricity generators may be lower, the final price consumers see is that of the most expensive generator. An additional element that must be considered is that in principle a carbon tax collected by governments can, via different possible schemes, be recycled to the consumer (Emmerling *et al* 2024). However, revenue recycling is not conducted in this study.

In this context, an important message from our scenarios is that a combination of policies is required to maximize benefits and minimize trade-offs. It is worth noting that this transition is extremely challenging and needs to be assessed in a broader set of dimensions, including the economic, social, political and institutional aspects that might influence its feasibility. One issue to note is that adaptation is still poorly represented in most IAMs (van Maanen *et al* 2023). Depending on the sector, adaptation is either included in a stylized manner and only to a certain extent (e.g. temperature-dependent cost-supply curves for newly installed renewable energy technologies, land optimal allocation for agriculture based on regional temperature and precipitation patterns) or excluded regardless of climate impacts. Adaptation measures also connect with different dimensions of sustainable development, with potential synergies and trade-offs (Fuso Nerini *et al* 2019, Fuldauer *et al* 2022). In our scenario framework, we include climate impacts on the agricultural, energy and residential systems but the implementation of adaptation measures is still limited. Climate impacts are included in IAMs in coarse time scales (annual, at best), while adaptation measures are designed for high impact weather events that tend to have shorter time frames. Nonetheless, having a more detailed sectoral representation, IAMs provide a unique opportunity for better representation of climate adaptation and its relation to climate mitigation (van Maanen *et al* 2023) and sustainable development.

Similarly as to Doelman *et al* (2022), highlights that measures related to diet changes and changes in the food system have multiple co-benefits for the other nexus dimensions, such as improving biodiversity, reducing emissions from land, reducing water withdrawals and improving water environmental flows. However, differently from Doelman *et al* (2022), Soergel *et al* (2021), this study shows that not only climate policy but also measures focusing on meeting the sustainable development agenda put pressure on the land system, leading to increases in food prices. Finally, this study focuses on the CLEW nexus related SDGs and a specific set of indicators, not covering the SDG space completely and thus the need for a more comprehensive exercise. For instance, the community would highly benefit from a model intercomparison project focused on improving modeling of SDGs, not only within IAMs but also a broader group of models (e.g. agent-based models, economic models) and scenarios, with the ultimate goal of better integrating the multiple dimensions that connect sustainability aspects and better inform the sustainable development agenda.

5. Conclusions

There are clear positive effects of combining the achievement of climate targets with the SDGs agenda. Overall, the SDG scenario results show significant reductions in population at risk of hunger and population relying on solid fuels. The preservation of natural lands and water bodies (and consequently, biodiversity), as well as access to and affordability of electricity, are also improved. Notably, combining a more equal distribution of food with shifting diets towards healthier, less carbon-intensive diets, as well as reducing food waste, has positive impacts over multiple SDGs in most regions, increasing food security (SDG2), the protection of natural lands and biodiversity (SDG15), and the climate goals (SDG13), with synergies to sustainable water management (SDG6). These positive outcomes are especially evident in the Global South (notably Sub-Saharan Africa, South/Southeast Asia, and Latin America), with significant benefits from the implementation of measures that go beyond climate towards sustainable development in its multiple dimensions, reducing the amount of people at risk of hunger, people suffering from air pollution related to the use of solid fuels, and other environmental risks such as water stress and biodiversity loss.

However, even though strong synergies and benefits can be derived from this modeling exercise, trade-offs exist and should be taken into careful consideration. Increases in food prices due to pressures in the land system can be observed in multiple regions, and more prominently in the SDG scenario due to a stronger enforcement of natural lands protection. Furthermore, shifting towards less carbon-intensive diets without ensuring that food is distributed more equally could, in fact, lead to higher food insecurity. In terms of water availability and the management of water bodies, the assumption on environmental flow requirements strongly limits water withdrawals, especially in the Middle East, Northern Africa, and Central Asia. If implemented without other measures, this assumption could also have negative effects on food security in those regions. Finally, it should be noted that this transformation is an enormously challenging transition, from multiple (economic, political, social and cultural) perspectives.

Combining climate policies and the SDGs agenda results in a smaller temperature overshoot and consequently less need for negative emissions by the end of the century to meet global warming targets. This reflects the synergies between the two types of policy goals, with short-term action on SDGs helping achieve the long-term climate goals in a more sustainable way. Ultimately, our results indicate that focusing on sustainable development in the short term helps speed up the transition towards the long-term climate goals, smoothing the transformation of the system and reducing the reliance on strong, and at times controversial, assumptions regarding the future availability of technologies and mitigation options to deal with delayed climate action.

Data availability statement

The data that support the findings of this study are openly available at the following URL/DOI: https://zenodo.org/doi/10.5281/zenodo.10655235 (Tagomori *et al* 2024).

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