

Chapter 4

Mitigation Scenarios for Non-energy GHG



Malte Meinshausen and Kate Dooley

Abstract Presentation of non-energy emission pathways in line with the new UNFCCC Shared Socio-Economic Pathways (SSP) scenario characteristics and the evaluation of the multi-gas pathways against various temperature thresholds and carbon budgets (1.5 °C and 2.0 °C) over time, and additionally against a 1.5 °C carbon budget in 2100, followed by a discussion of the results in the context of the most recent scientific literature in this field. Presentation of the non-energy GHG mitigation scenarios calculated to complement the energy-related CO₂ emissions derived in Chap. 8.

In this section, we present the results for the land-use CO₂ and non-CO₂ emissions pathways that complement the 2.0 °C and 1.5 °C energy-related CO₂ scenarios.

4.1 Land-Use CO₂ emissions

This section presents the aggregate results for the land-use sequestration pathways designed for this study. Figure 4.1 below shows the annual sequestration in the sequestration pathways over time, differentiated into climate domains. The pathways shown are the results of the Monte Carlo analysis described in Table 3.11 in Sect. 3.8.1.5 and the text. We focus on the median values (thick lines in Fig. 4.1). Note that the area under the curve for a given pathway is an indication of the cumulative CO₂ uptake. By far the most important sequestration may result from large-scale reforestation measures, particularly in the subtropics and tropics (see yellow pathways in Fig. 4.1 below). The second most important pathway in terms of the amount of CO₂ sequestered is the sustainable use of existing forests, which basically means reducing logging within those forests. Although effective mitigation is not

M. Meinshausen (✉) · K. Dooley
Australian-German Climate and Energy College, University of Melbourne, Parkville,
Victoria, Australia
e-mail: malte.meinshausen@unimelb.edu.au; kate.dooley@unimelb.edu.au

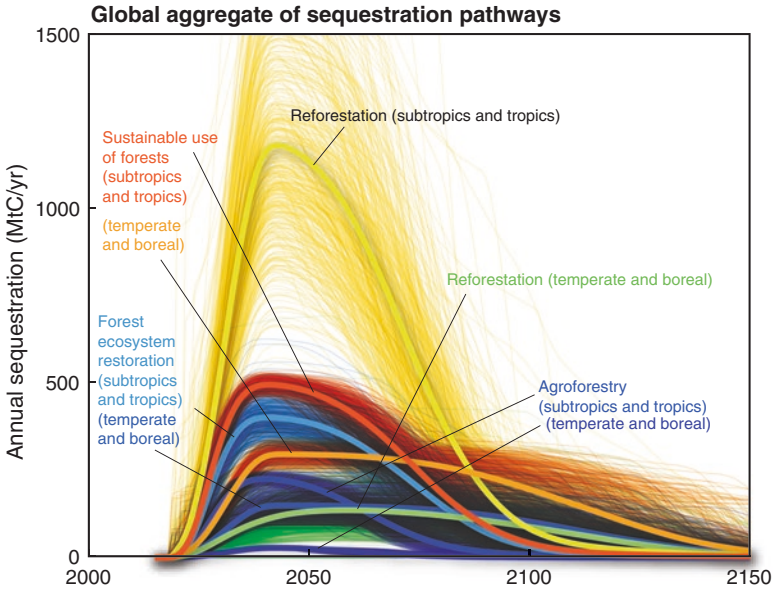


Fig. 4.1 Land-use sequestration pathways showing annual sequestration rates over time

achieved in the tropics (Martin et al. 2015), in the temperate and boreal regions, improved forest management could provide substantial additional carbon uptake over time. The time horizon for this sequestration option is assumed to be relatively long in temperate and boreal regions, consistent with the longer time it takes for these forest ecosystems to reach equilibrium (Roxburgh et al. 2006; Luysaert et al. 2008). The ‘forest ecosystem restoration’ pathway is also important, which basically assumes a reduction to zero in logging rates in a fraction of the forest, allowing these forests to be restored to full ecosystem function, including their carbon stocks and resilience due to biodiversity (Mackey 2014).

Overall, the median of all the assumed sequestration pathways, shown in Fig. 4.1, would result in the sequestration of 151.9 GtC by 2150. This is approximately equivalent to all historical land-use-related CO₂ emissions to date (Houghton and Nassikas 2017; Mackey et al. 2013). The magnitude of these figures indicates the substantial challenges that go hand in hand with these sequestration pathways. Given the competing forms of land use that exist today, the challenge of converting overall terrestrial carbon stocks back to pre-industrial levels cannot be underestimated. There would be significant benefits, but also risks, if this sequestration option were to be used instead of mitigation. The benefits are clearly manifold, ranging from biodiversity protection, reduced erosion, improved local climates, wind protection, and potentially a reduction in air pollution (Mackey 2014). Despite this, terrestrial carbon sequestration is inherently impermanent. However, a future warming climate with an increased fire risk also brings with it the risk of large reversals in sequestered carbon. Similarly, prolonged droughts in some areas could reverse the gains in terrestrial carbon stocks. Although the increased resilience of natural and biodiverse ecosystems compared with that of monoculture plantations can guard against this

risk (DellaSala, 2019; Lindenmayer and Sato 2018), a future mitigation pathway that relies on sequestration *instead of mitigation action* is ultimately always more susceptible to higher long-term climate change, given the risk of ‘non-permanence’. However, in this study, the land-use CO₂ sequestration pathways complement some of the most ambitious mitigation pathways, and should therefore be regarded, not as ‘offsetting’ mitigation action, but as complementary measures to help reduce the CO₂ concentrations that have arisen from the overly high emissions in the past.

The thin lines in Fig. 4.1 indicate individual draws in the Monte Carlo analysis. The thick lines are the median values from the ensemble of draws for each sequestration pathway and domain.

We aggregated the four sequestration pathways from our country-level data to the five RCP regions (Fig. 4.2). The country-level data were subject to substantial uncertainties and simplifications because we used climate-domain average uptakes, carbon density caps, and saturation periods. The re-aggregated sequestration rates over the five RCP regions can be considered approximate illustrations of the biome-average sequestration rates if those sequestration pathways were pursued with a range of institutional and policy measures.

For the 1.5 °C Scenario, we assumed the full extent of sequestration shown in Fig. 4.1, whereas for the 2.0 °C pathway, we assumed that only a third of that sequestration will occur. The reference scenario is assumed to follow the SSP2 ‘middle of the road’ reference scenario created by the MESSAGE-GLOBIOM modelling team. As illustrated in Fig. 4.2, the reference scenario does not assume a complete phasing-out of global land-use-related net emissions over the next 20 or 30 years. Instead, it assumes that they are not phased-out until approximately 2080.

The 2.0 °C pathway (brighter blue in Fig. 4.2) aligns relatively well with the SSP1 1.9 and SSP1 2.6 scenarios from the forthcoming CMIP6 model inter-comparison project. The 1.5 °C pathway, with three times the sequestration rates, is consistent with the lower land-use CO₂ scenarios analysed here—with mitigation rates of up to –2 GtC per annum from 2040 to 2050.

Figure 4.2 shows the land-use-related CO₂ emission and sequestration rates of the 2.0°C and 1.5 °C pathways in this study compared with those in the CMIP6 CEDS scenarios (turquoise) and the scenarios from the IPCC SR1.5 database (thin green lines). The global total pathway is the sum of the five regional pathways shown in the lower row of the panels.

4.1.1 Other GHG and Aerosol Emissions

This section examines the other main GHGs (methane and N₂O) and gives examples of some fluorinated gases. The full results, with the species-by-species time series, are provided in a data appendix.

Methane (CH₄) emissions are the second-largest contributor to anthropogenically induced climate change. Our approach, described in the Methods section earlier, derives pathways for the 1.5 °C and 2.0 °C Scenarios that are close to the lower end of the overall scenario distribution. This is mainly because the methane distribution at

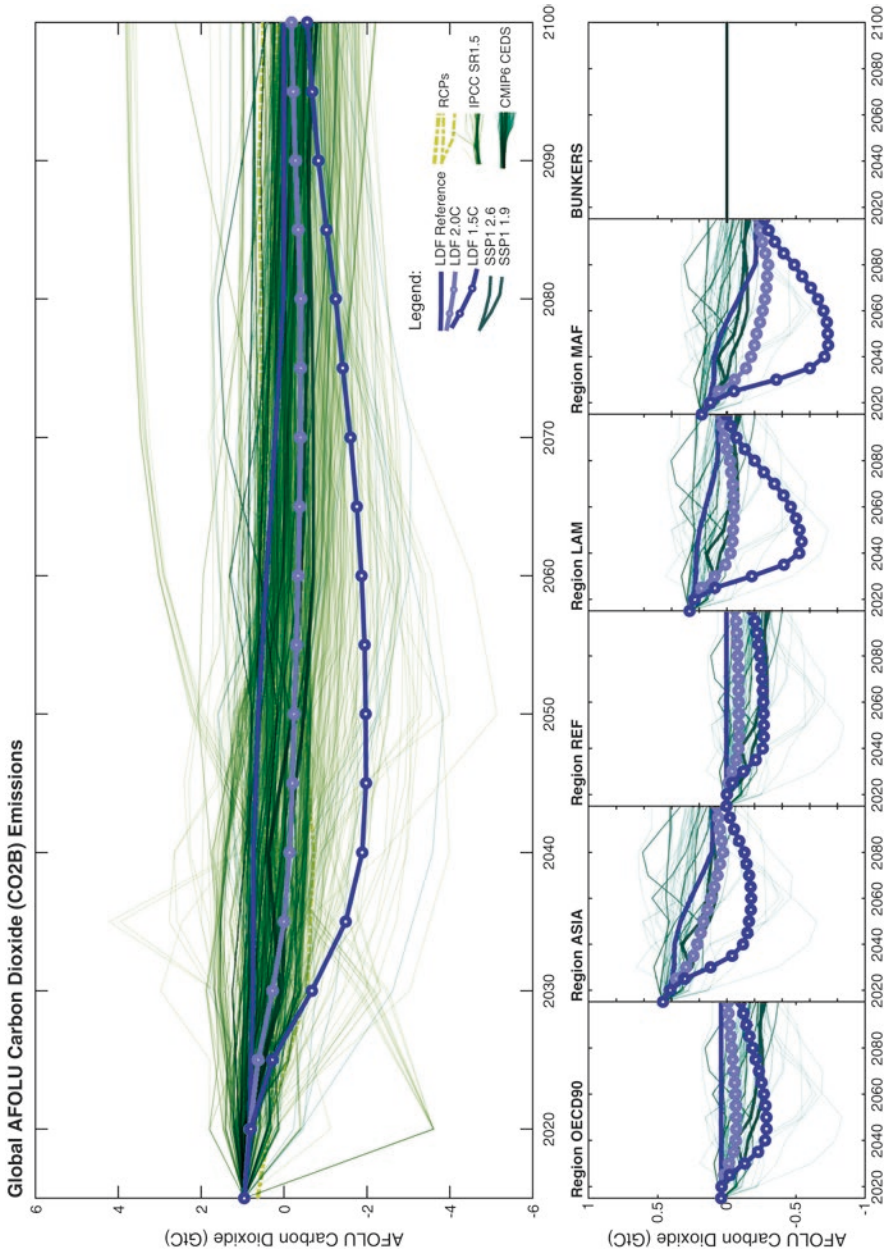


Fig. 4.2 Land-use-related CO₂ emission and sequestration rates

the lower end of the fossil fuel CO₂ emissions is relatively narrow, and there is a strong correlation between the fossil CO₂ and total CH₄ emissions in the scenarios in any given year (see top-left methane panel in Fig. 3.14). As with almost all literature-reported scenarios, a lower plateau of methane emissions is associated with agricultural activities required to feed the world's population. Our quantile regression method resulted in long-term methane emission levels that are quite similar to those in the two lower SSP scenarios, SSP1 1.9 and SSP1 2.6 (Fig. 4.3). The derived CH₄ pathways for 1.5 °C and 2.0 °C track towards the lower of the scenario distributions.

Nitrous oxide (N₂O) is one of the longer-lived GHGs, although the overall amounts in the atmosphere are much smaller than those of methane or CO₂. The relatively high plateau of global emissions, around 5 MtN₂O-N for N₂O, are reflected in the SSP1. 1.9 and SSP1 2.6 scenarios (dark green lines in Fig. 4.4) and in the quantile regression results for the 2.0 °C and 1.5 °C scenarios in this study. This plateau of emissions is related to agricultural activities, mainly the use of fertilizers, and combined with the long lifetime of N₂O, it means that the N₂O concentrations are projected to increase further over the course of the century, even for the lower 1.5 °C and 2.0 °C pathways.

The derived methane pathways for 1.5 °C and 2.0 °C track towards the lower of the scenario distributions.

Halocarbons and fluorinated gases are another group of important GHGs. Recently, some of these gases, such as HFCs, were also subjected to control under the Montreal Protocol, with clear phase-out schedules. Some of the halocarbons and fluorinated gases (such as tetrafluoromethane, CF₄) are only produced and emitted in relatively small quantities—largely for industrial purposes in the semi-conductor industry. Some also have applications in the agricultural sector, including methyl bromide, which is used for soil fumigation. SF₆ is one of the strongest GHGs on a per mass basis. It is controlled under the Kyoto Protocol and included in the nationally determined contributions (NDCs) by many countries under the Paris Agreement. Our applied quantile regression method practically phases-out many of the halogenated species over the course of the next 10–20 years, although some small background emissions remain. The full results for 40 halocarbons, HFCs, PFCs, and SF₆ are provided in a data appendix (Figs. 4.5 and 4.6).

Aerosols have an important temporary masking effect on GHG-induced warming. The most important anthropogenically emitted aerosol coolant in the climate system is sulfur dioxide or SO_x. With higher fuel standards and concerns about local air pollution, future SO_x emissions are projected to be substantially lower than current levels. In fact, most emission inventories assume that SO_x emissions peaked in the 1990s. Therefore, even in the most high-fossil-fuel-emitting reference scenarios, SO_x emissions are projected to decrease. Asia produces by far the most SO_x emissions of any continent because of the coal-fuelled power plants in China and India. In the 2.0 °C Scenario, our quantile regression method sets sulfate aerosol emissions at levels in between those in the SSP1 2.6 and SSP1 1.9 scenarios, whereas in the 1.5 °C Scenario, the level is even lower.

Similarly, the projected emissions of NO_x, which is largely a by-product of fossil fuel burning, are highest in Asia. In the derived 1.5 °C and 2.0 °C Scenarios, NO_x

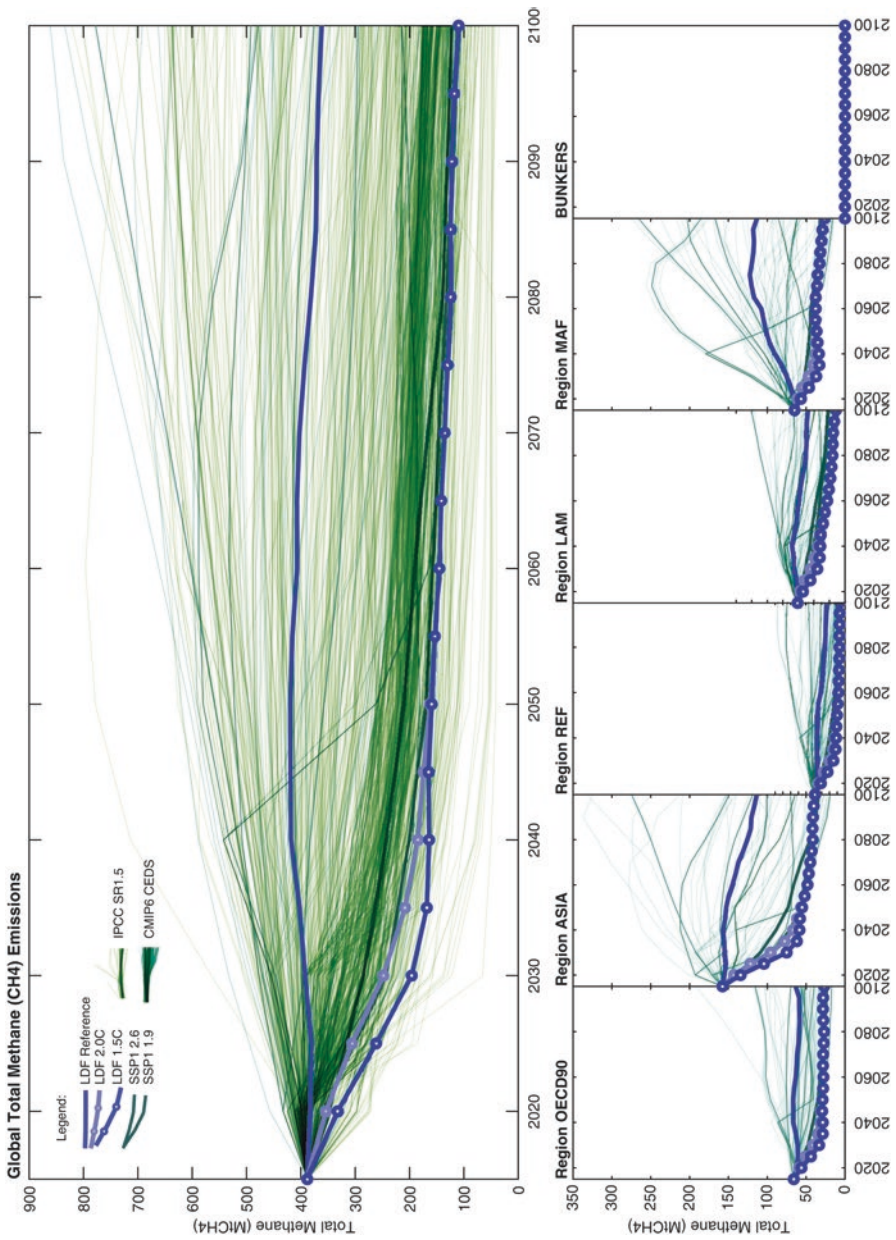


Fig. 4.3 Global and regional methane emissions from fossil, industrial, and land-use-related sources

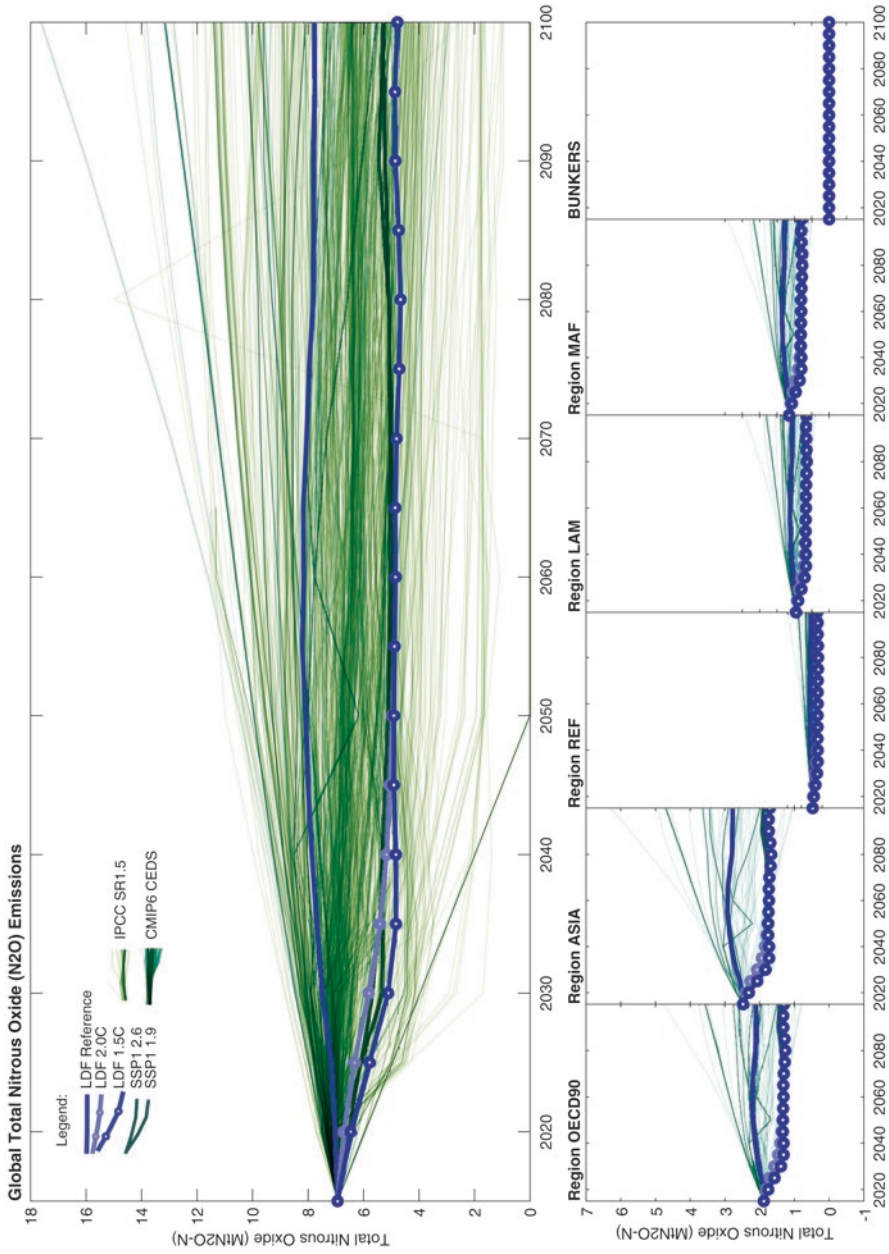


Fig. 4.4 Global and regional methane emissions from fossil, industrial, and land-use-related sources

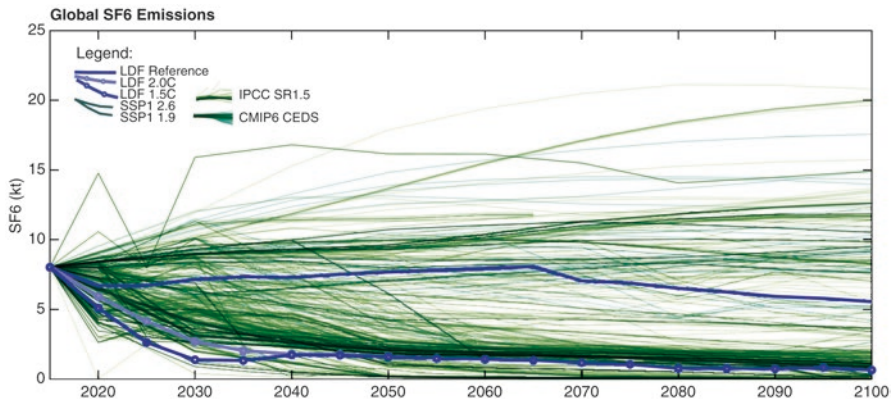


Fig. 4.5 Global SF₆ emission levels from literature-reported scenarios and the LDF pathways derived in this study

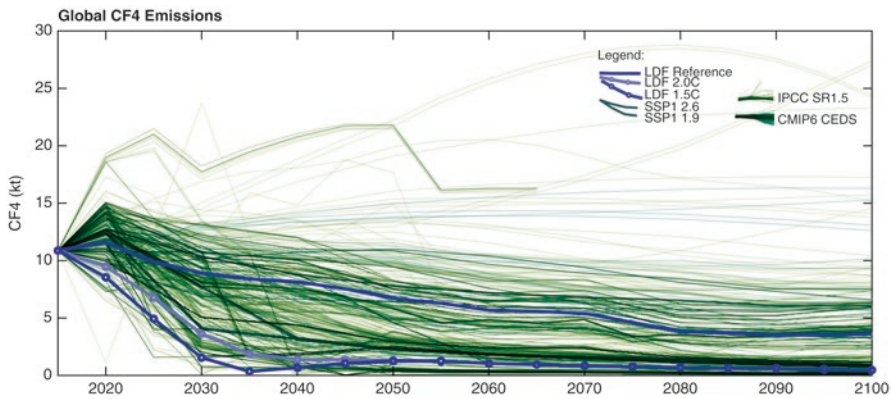


Fig. 4.6 Global tetrafluoromethane (CF₄) emissions from the collection of assessed literature-reported scenarios and the LDF pathways derived in this study

levels are between the levels in the SSP1 2.6 and SSP1 1.9 scenarios for most of the twenty-first century (Figs. 4.7 and 4.8).

Black and organic carbon emissions are also accruing substantially in the Middle East and Africa, largely from biomass burning (Figs. 4.9 and 4.10). Similar to other aerosol emissions, black and organic carbon emissions are projected to decrease. Although black carbon is a substantial warming agent, organic carbon is a net coolant. Because both species are often co-emitted, the net effect of policies to reduce black carbon do not have as large a mitigation benefit as might be initially assumed. This is because a reduction in the processes and activities that produce black carbon emissions will also lead to lower organic carbon emissions, partially offsetting both the warming and cooling effects. The emissions projected as part of the IMAGE model SSP1 2.6 and SSP1 1.9 scenarios are very low compared with those in other studies. Furthermore, the correlation between fossil CO₂ emissions and black or

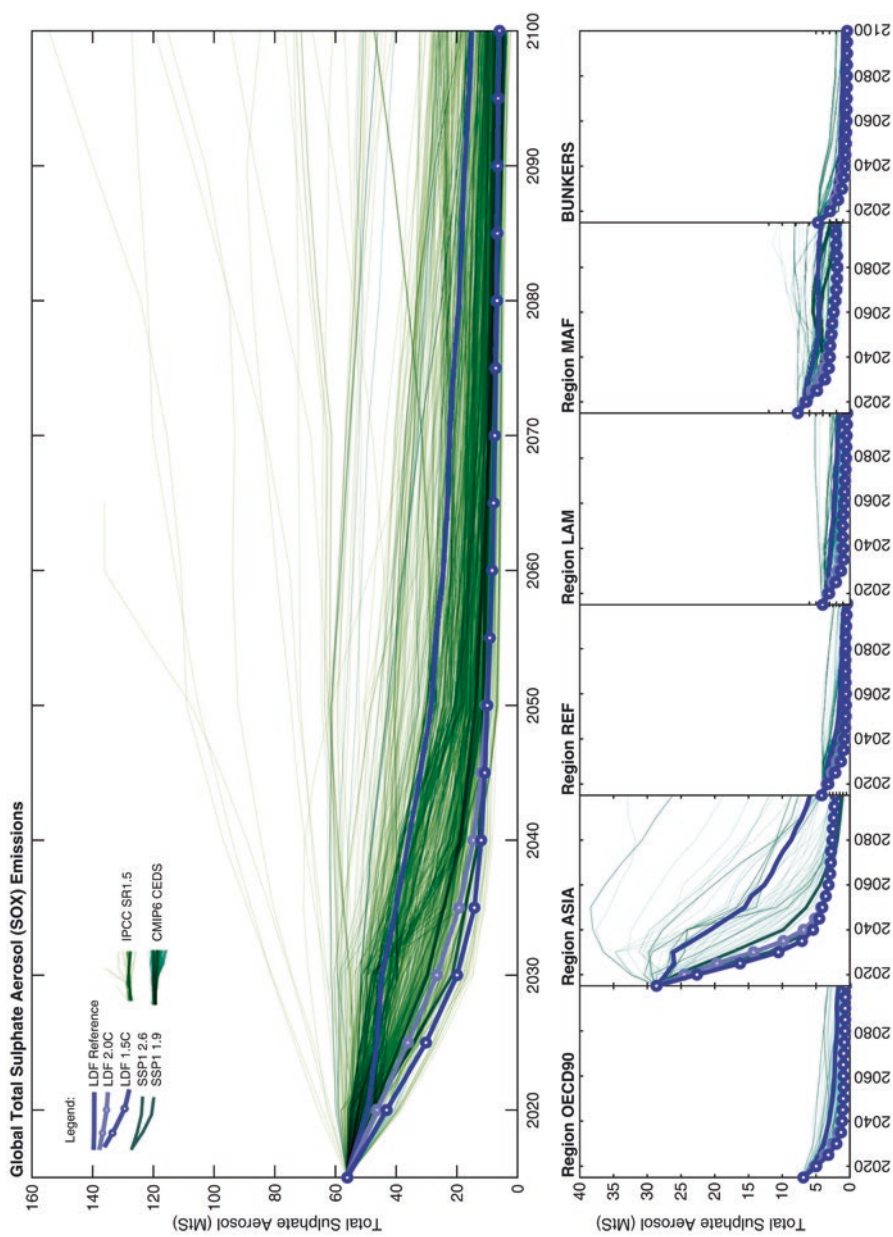


Fig. 4.7 Global and regional sulfate dioxide (SO_x) emissions in the literature-reported scenarios considered and the LDF pathways derived in this study

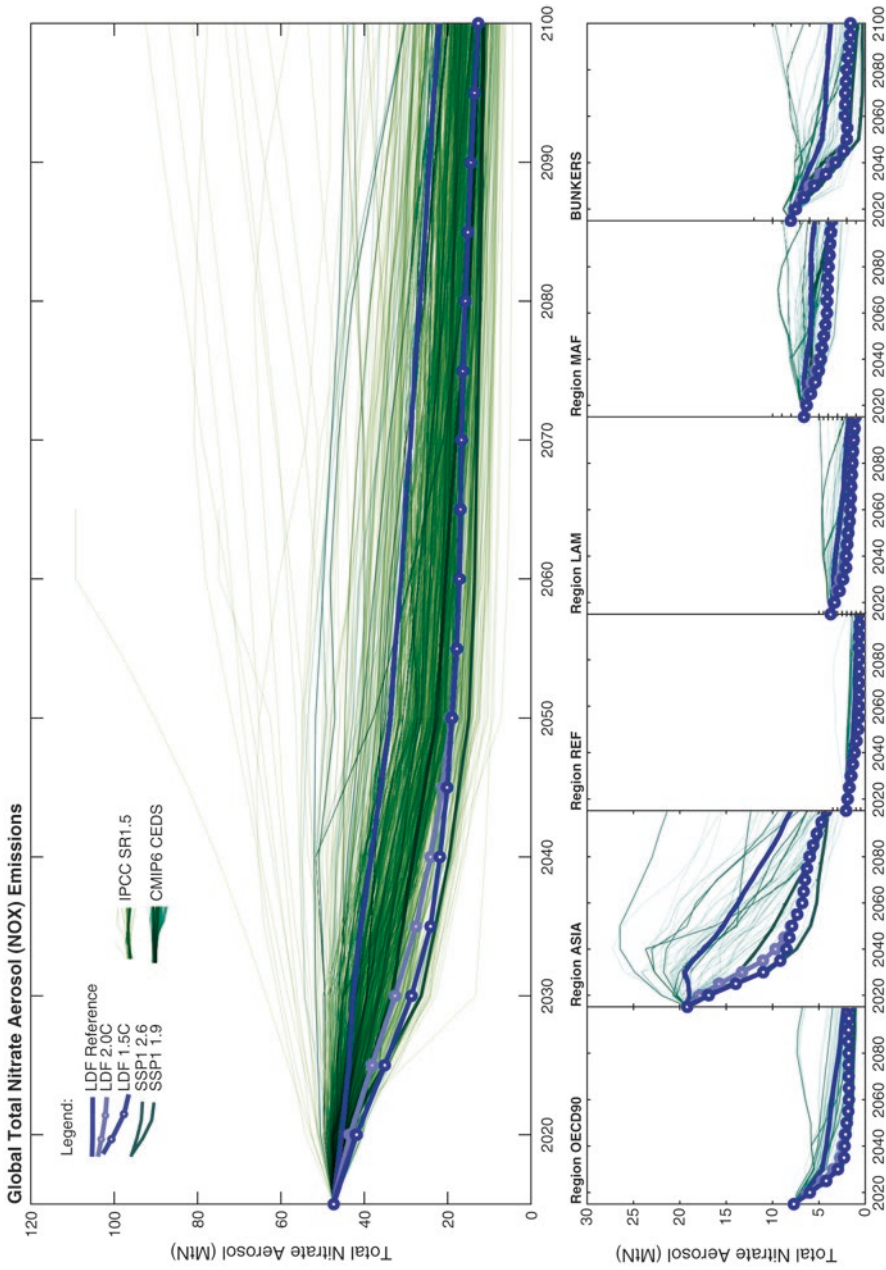


Fig. 4.8 Global and regional nitrate aerosol (NO_x) emissions in the literature-reported scenarios considered and the LDF pathways derived in this study

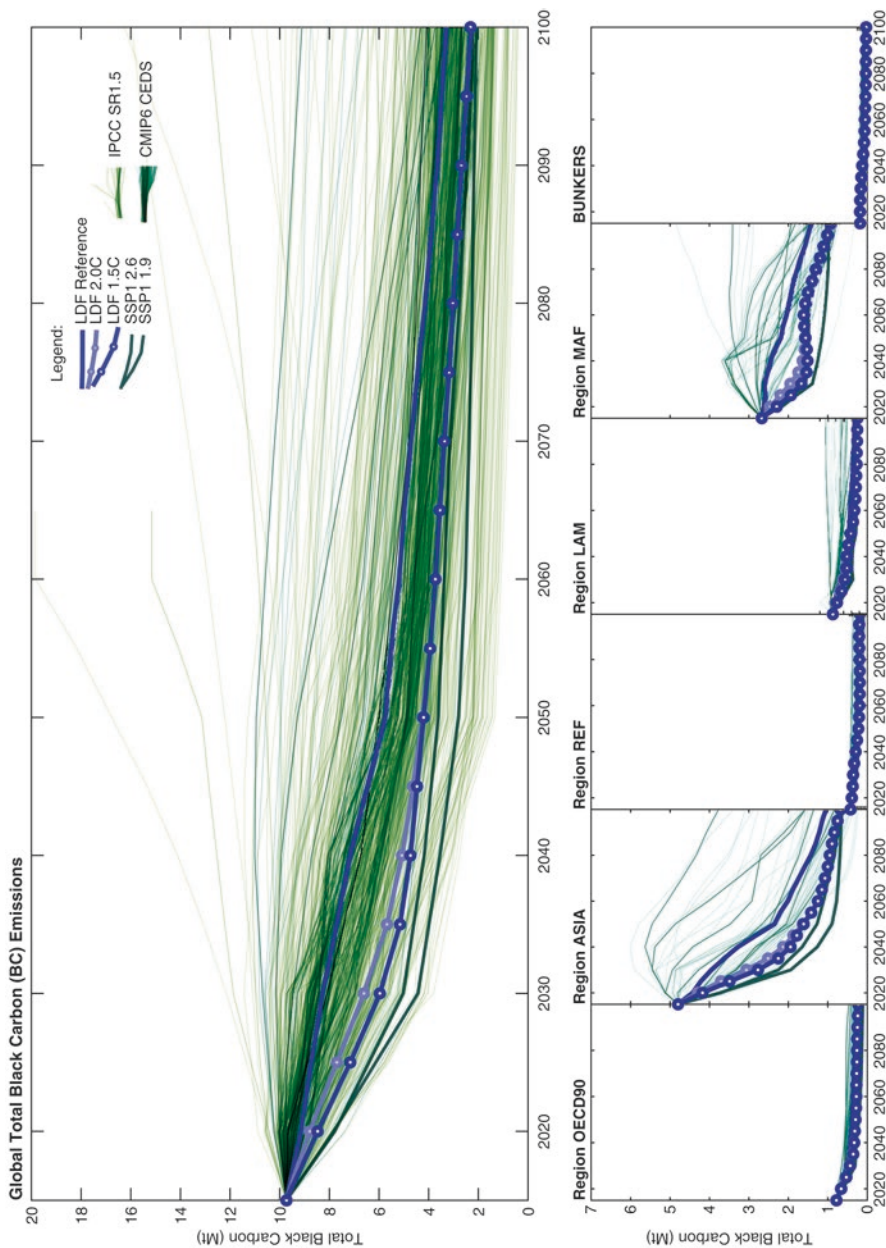


Fig. 4.9 Global and regional black carbon BC emissions in the literature-reported scenarios considered and the LDF pathways derived in this study

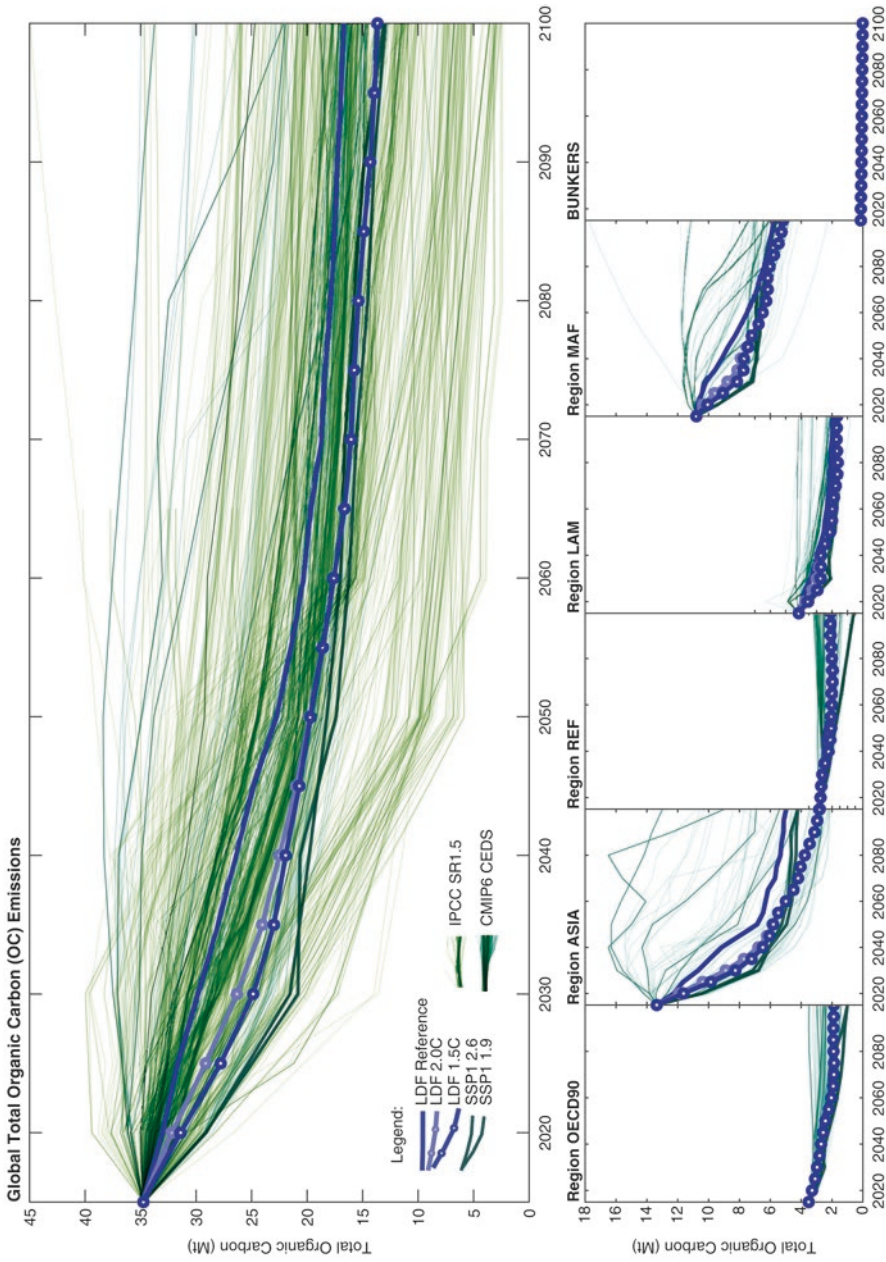


Fig. 4.10 Global and regional organic carbon OC emissions in the literature-reported scenarios considered and the LDF pathways derived in this study

organic carbon is less pronounced than the correlations of fossil CO₂ with other aerosols, such as NO_x and SO_x, partly because it results from biomass burning, which is not related to the burning of fossil fuels. Therefore, with our quantile regression method, the black carbon and organic carbon emission pathways are not as low as those found in the lower SSP scenarios (see Figs. 4.9 and 4.10).

For Tabular overview of three scenarios see Annex

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