Key findings of IPCC sixth assessment cycle

The role of bio-based Sustainable Aviation Fuels in global climate mitigation pathways

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IPCC mitigation scenarios

The recent UN Intergovernmental Panel on Climate Change (IPCC) Working Group III contribution to the Sixth Assessment Report (hereafter IPCC WG III AR6) reinforces that we are not on track to limiting global warming to 1.5°C by the end of the century. Although last decades marked significant advances in mitigation efforts and more than 20 countries have decoupled economic growth from greenhouse gas (GHG) emissions, a deep reduction of emissions requires major transformations at unprecedented scales in all sectors of the economy (Skea et al., 2022). This is particularly challenging for the aviation sector, as aircraft low-carbon technological strategies have not reached innovation maturity yet and efficiency improvements in air traffic operations present limited mitigation potential (Carvalho et al., 2019; Jaramillo et al., 2022).

According to the evaluation of the submitted and announced NDCs prior to COP26, annual GHG emissions will likely reach 50-53 [47-57] $GtCO_2e$ by 2030, which exceeds 1.5°C during the 21st century and may lead to a median global warming of 2.8 [2.1 to 3.4]°C before 2100 (Skea et al., 2022). An emission gap of 6-16 and 16-26 $GtCO_2e.yr^{-1}$ needs to be closed to stabilise warming to 2°C (>67% likelihood) and 1.5°C (>50% likelihood) levels, respectively (Lecocq et al., 2022). The next few years will therefore be crucial to decline emissions. Closing the 1.5° (>50%) warming gap with no or limited overshoot requires accomplishing three landmarks: (i) reach the peak of global GHG emissions as soon as possible and no later than 2025, (ii) reduce GHG emissions by 43% [34–60%] in the course of the next decade, and (iii) achieve nearly net CO_2 emissions by mid-century (Pathak et al., 2022; Skea, 2022). If we aim at closing the gap to achieve the 2°C (>67% likelihood) warming level, we have a bit more time to reduce CO_2 emissions to net zero by 2070's, but the task is still massive (Riahi et al., 2022).

A wide range of integrated assessment model (IAM) scenarios from the literature were assessed in the IPCC WG III AR6 and made available in the IPCC WG III AR6 scenario explorer and database[1] hosted by IIASA (Byers et al. 2022). More than 2,000 global mitigation scenarios[2] assessed by the report were classified into eight categories according to their degree of climate ambition ranging from narratives that reflect a limit warming to 1.5°C with no or limited overshoot or a warming of 4.0°C by the end of the century

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[1] An opensource database of quantitative scenarios with data on socio-economic development, greenhouse gas emissions, and sectoral transformations across energy, land use, transportation, buildings and industry is available at: https://data.ene.iiasa.ac.at/ar6/#/downloads (Byers et al 2022).

[2] *Mitigation scenarios* are plausible descriptions of how the future may develop based on implementation of policies and measures to reduce GHG emissions consistent with assumptions about key driving forces (e.g., rate of technological change, prices). Scenarios are used to provide scientific sound information to policymakers on views of the implications of certain developments and actions, but by no mean shall be interpretated as predictions or forecasts (Guivarch et al 2022).

(Table 1). Among those, seven scenarios were selected to reflect the key findings of recent emission scenario literature (Figure 1). Two of these pathways are illustrative pathways (IPs) that reflect high (CurPol) and moderate (ModAct) emission trajectories. The CurPol scenario projects emissions based on policies implemented by the end of 2020, while ModAct depicts a pathway compatible with pledges of Paris Agreement NDCs. The five remaining scenarios, referred to as Illustrative Mitigation Pathways (IMPs), describe pathways with deep and rapid emissions reductions. They have a few common features but reflect different combinations of sectoral mitigation strategies. In all IMPs, global warming is limited to below 2°C over the whole century (with >67% likelihood). Furthermore, in IMPs with significant upfront emission reductions (Ren, LD, and SP), warming is limited to 1.5°C at the end of the century after a low overshoot (with >50% likelihood).

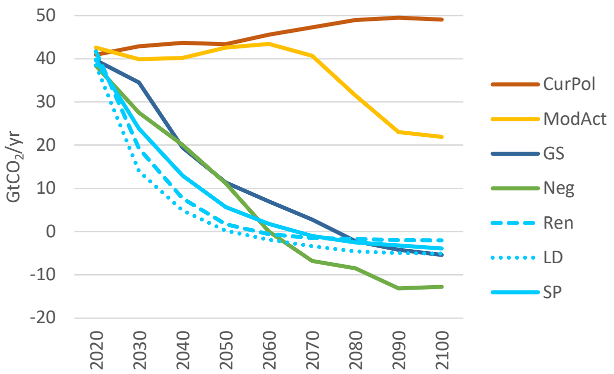

FIGURE 1: Net CO_2 emissions of modelled pathways. Source: Own elaboration based on Byers et al. (2022).

TABLE 1: Temperature categories and their relationship with the IMPs.

Categories	Description	IPs/IMPs
C1	Limit warming to 1.5°C with no or limited overshoot	LD, Ren, SP
C2	Return warming to 1.5°C after a high overshoot	Neg
C3	Limit peak warming to 2°C	GS
C4	Limit warming to 2°C	–
C5	Limit warming to 2.5°C	–
C6	Limit warming to 3.0°C	ModAct
C7	Limit warming to 4.0°C	CurPol
C8	Exceed warming of 4.0°C	–

Decarbonisation of the aviation sector

Among all IMPs, the aviation sector is considered a hard-to-abate sector given its dependency on fossil jet-A fuel and long timescale infrastructure turnovers. Figure 2 presents mitigation scenarios for travel demand and carbon dioxide emissions of the aviation sector up to 2100 under different global warming assumption categories[3]. Although there is much uncertainty related to post-Covid19 pandemic recovery, scenarios without firm commitments to meet long-term temperature targets (C7) indicate a nearly six- and 12-folded increase in travel demand by 2050 and 2100, respectively, which suggests CO_2 emissions rise by a factor of six in 2050 and eight in 2100, over 2020 levels. In more stringent scenarios to limit warming to 2°C (>67% likelihood) (C3) and 1.5°C (50% likelihood) with no or limited overshooting (C1), aviation energy demand still rises, but in a lower level and travel demand peaks around 2080-90's. In terms of CO_2 emissions, the sector could reach net zero CO_2 emissions (C1) or stabilise emissions at 1470 $MtCO_2$ emissions yearly (C3), a 37% decline compared to a current policy scenario (C7).

To speed up mitigation strategies in the aviation sector, the IPCC WG III AR6 report highlights six major strategies to reduce emissions in the sector, namely: (i) Technology options for engine and airframe, (ii) Operational improvements for navigation, (iii) Bio-based, synthetic, and liquid hydrogen-based sustainable aviation fuels, (iv) Technological and operational trade-offs between CO_2 and non-CO_2 effects, (v) Market-based offsetting measures, and (vi) Modal shift to High-Speed Rail. Among these, bio-based sustainable aviation fuels (hereafter bio-SAF) present the highest potential and technology readiness level (TRL), varying from TRL5 for alcohol-to-jet (ATJ) routes and TRL9 for hydro-processed esters and fatty acids (HEFA) synthesis (Portugal-Pereira et al., n.d.). Bio-SAFs also have a high potential to support mitigation

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[3] Selected scenarios were based on IMAGE model results (Byers et al. 2022).

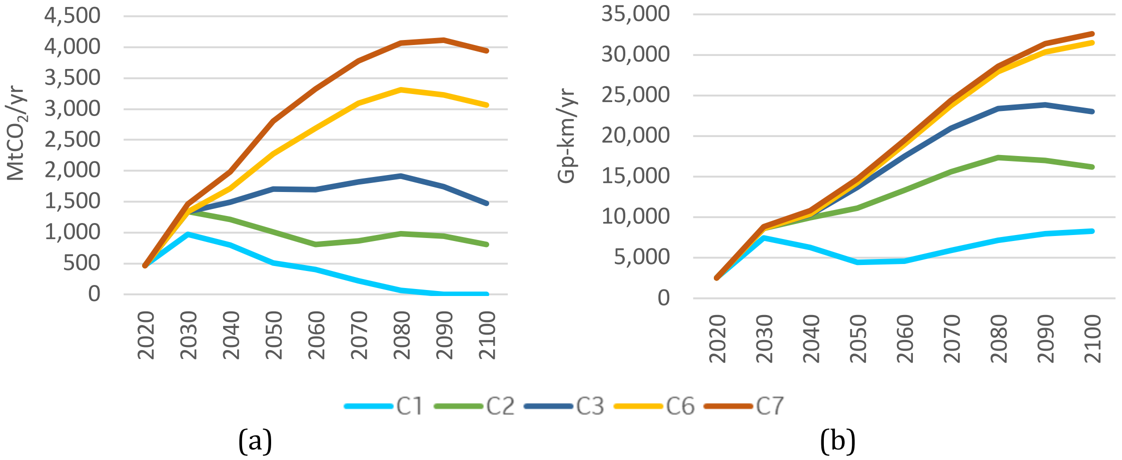

FIGURE 2: The aviation sector in selected mitigation scenarios from the IPCC WG III AR6: (a) CO_2 emissions (million tonnes per year) and (b) passenger aviation demand (billion passenger-kilometre per year).
Source: Own elaboration based on Byers et al. (2022).

scenarios in the short- and mid-term and to keep up with the projected growing demand for air traffic passengers and cargo. Further, bio-SAF conversion units may be coupled with carbon dioxide capture and storage (CCS) units, which could result in negative emission technologies. Thus, the IPCC WG III AR6 suggests that the deployment of bio-SAF is a leading strategy to coping with expected growing demand of aviation without increasing CO_2. As of October 2021, the American Society for Testing and Materials (ASTM) has certified nine conversion processes of bio-SAF with blends ranging between 5 and 50%.

Bio-SAF can be produced from a high range of biomass feedstocks, including cultivated sugar, starch, oily, and lignocellulosic feedstock crops, algae biomass, agricultural crop residues, municipal solid waste, waste fats, wood products and forestry residues (Carvalho et al., 2019). The production potential entails high uncertainty, but recent literature assessed in the IPCC Special Report on Climate Change and Land (hereafter IPCC SRCCL) consider that sustainable production of bioenergy could vary between 100 and 170 EJ (Calvin et al., 2021; Creutzig et al., 2015; Frank et al., 2021; Wu et al., 2019).

Benefits and potential adverse-side effects of bio-SAFs

While an important strategy in the mitigation of the aviation sector, the bio-SAF life cycle has variable carbon footprints due to various production methods, methodological approaches and associated land-use change. Estimations suggest that bio-SAF can reduce life cycle GHG emissions by 2-70% compared to conventional fossil jet-A under a wide range of scenarios (Jaramillo et al., 2022). However, large-scale production of bioenergy may result in significant land use changes and adverse side-effects for food security and terrestrial ecosystem services (de Coninck et al., 2018; Smith et al., 2019).

The magnitude of co-benefits and adverse side effects depends on a variety of factors, including the feedstock, management regime, climatic region, other demands for land, and scale of deployment (Calvin et al., 2021; Smith et al., 2019). Generally, the use of waste feedstocks and planting dedicated crops on degraded land result minimises competition for land and results in low GHG emissions, but land-related footprint increases when considering large-scale bioenergy supply scenarios.

The IPCC SRCCL draws attention to the potential adverse effects of bioenergy production on food security. The use of food crops for bioenergy, or cultivation of energy crops on high-quality arable land, can displace food production, leading to increased food prices and land use changes to meet demand for displaced food crops (IPCC, 2019; Mbow et al., 2018; Smith et al., 2019). Moreover, the production of bioenergy may have negative impacts on water resources. Reporting of water impacts on ecosystems caused by the implementation of modern bioenergy systems varies significantly (Neary, 2018). While some assessments include only active human uses such as irrigation and water used in biofuels conversion processes, others include hydrologic processes such as evapotranspiration, infiltration, runoff, and baseflows, which are natural ecosystem processes influenced by human activity (Neary, 2013).

Finally, bioenergy production for bio-SAFs can affect wild and agricultural biodiversity in a positive way, if applied in restoration of degraded lands, but may also have negative impacts, for example when natural forestry landscapes are converted into energy cropland or peatlands are drained (IPBES, 2019; IPCC, 2019; Pathak et al., 2022). In general, wild biodiversity is threatened by loss of habitat when the area under crop production is expanded, whereas agricultural biodiversity is vulnerable in the case of large-scale monocropping, unsustainable fertilizer usage, and limited genetic variety.

In conclusion, IPCC WG III AR6 mitigation scenarios suggest that bio-SAFs are the most competitive strategy in the short- and mid-term to cope with stringent mitigation scenarios compatible with keeping global warming to 1.5°C and 2°C by the end of the century. However, large-scale deployment of bioenergy may compete for biomass and land, increasing pressure on terrestrial ecosystem services and other sustainable development dimensions beyond climate mitigation. The magnitude of adverse side effects and risks are local and context specific, but tend to be severe to food security, land tenure, water resources, soil quality and biodiversity, if institutions and weak governance fail in protecting natural ecosystem services and the most vulnerable people dependent on land-based activities.

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