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CO_2 Emissions from air transport -

A near-real-time global database for policy analysis[1]

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Abstract

By moving goods and people over large distances, air transport facilitates international trade and tourism and thus contributes to economic growth and job creation. At the same time, it also comes with environmental challenges, largely related to air emissions and their impact on global warming. Air transport has been disproportionately negatively affected by the COVID-19 pandemic with associated reductions in air emissions. However, recent projections show that, in the absence of accelerated technological developments and more ambitious policy measures, aviation-related carbon dioxide (CO_2) emissions will grow again at a rapid pace after the pandemic. This paper describes a new OECD database providing near-real-time and global information on aviation-related CO_2 emissions, with allocations across countries following either the territory or the residence principle. This database provides a public good for both statistical measurement and environmental policy analysis. On the statistical front, it will facilitate the compilation of global Air Emission Accounts according to the System of Environmental Economic Accounting (SEEA), bring granular and timely information on a significant source of CO_2 emissions, and allow tracking their evolution during and after the COVID-19 pandemic. The comparison with official statistics that are available with a significant delay and at lower frequency demonstrates the accuracy of the OECD estimates. On the environmental policy front, it is expected that the OECD database will help monitor the impact of technological developments and policy measures to curb aviation-related CO_2 emissions in the future.

Keywords: Air transport, CO_2 emissions, climate change, COVID-19, environmental-economic accounting, SEEA, UNFCCC inventories, big data (ADS-B).

JEL Classification: L93, Q53, Q56.

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Résumé

En permettant de déplacer des biens et des personnes sur de longues distances, le transport aérien facilite le commerce international et le tourisme et contribue ainsi à la croissance économique et à la création d'emplois. Néanmoins, il pose également des problèmes environnementaux, en grande partie à cause des émissions atmosphériques qu'il génère et de son impact sur le réchauffement climatique. Le transport aérien a été affecté de manière disproportionnée par la pandémie de COVID-19, ce qui a entraîné une réduction des émissions atmosphériques. Néanmoins, les projections récentes montrent qu'en l'absence de progrès technologiques plus rapides et de politiques plus ambitieuses, les émissions de dioxyde de carbone (CO_2) liées au transport aérien vont reprendre leur croissance à un rythme rapide après la pandémie. Cet article décrit une nouvelle base de données de l'OCDE qui fournit une information en quasi-temps réel et au niveau mondial sur les émissions de CO_2 du transport aérien et les allouent entre pays en suivant les principes de territoire et de résidence. Cette base de données est un bien public qui profitera à la statistique et à l'analyse des politiques environnementales. D'un point de vue statistique, elle va faciliter la mise au point de comptes d'émissions atmosphériques conformément au Système de Comptabilité Économique et Environnementale (SCEE), fournir une information détaillée et quasi immédiate sur une source importante d'émissions de CO_2 et permettre de suivre l'évolution de ces émissions pendant et après l'épidémie de COVID-19. La comparaison avec les statistiques officielles qui sont disponibles beaucoup plus tard et à plus basse fréquence démontre la précision des estimations de l'OCDE. Concernant la politique environnementale, cette base de données devrait aider à suivre l'impact des progrès technologiques et des politiques mises en place pour réduire les émissions de CO_2 liées au transport aérien à l'avenir.

Mots-clés : Transport aérien, émissions de CO_2, changement climatique, COVID-19, comptabilité économique et environnementale, SCEE, inventaires CCNUCC.

Classification JEL : L93, Q53, Q56.

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1. Introduction

1. Air transport can quickly move goods and people over large distances, thus facilitating international trade and tourism and contributing to economic growth and job creation. It also provides connectivity that often cannot be easily substituted by land or water transportation (ITF, 2021b).

2. At the same time, the rapid development of air transport over the last decades comes with environmental challenges, largely related to air emissions and their impact on global warming. According to the IPCC (1999, Chapter 6), aircraft emissions in conjunction with other emissions originating from human activity are expected to modify atmospheric composition, radiative forcing[2] and the world's climate. Atmospheric changes related to aviation result from three types of processes: direct emissions of radiatively active substances[3] (e.g. carbon dioxide (CO_2) or water vapour), emissions of chemicals that produce or destroy radiatively active substances (e.g. nitrogen oxides modifying ozone concentration), and emissions of substances that trigger the generation of additional clouds (e.g. condensation trails, also known as contrails).

3. Aircraft engine emissions are composed of about 70% of CO_2, the best-known greenhouse gas (GHG), a little less than 30% of water and marginal quantities of other GHGs and pollutants.[4] Thus, CO_2 emissions constitute the bulk of GHG emissions related to air transport. Admittedly, an assessment of the full contribution of aviation to global warming would need to take into account non-CO_2 emissions, and in particular water vapour emissions and the formation of contrails. Nevertheless, the best way to quantify the impact of non-CO_2 emissions on global warming is uncertain and still under discussion by the scientific community, which is why this paper exclusively focuses on CO_2 emissions.[5]

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[2] Radative forcing is the change in energy flux in the atmosphere caused by natural or anthropogenic factors of climate change. Positive radiative forcing means that the Earth receives more incoming energy from sunlight than it radiates to space. This net gain of energy causes global warming.

[3] Radiatively active substances absorb or emit radiation in some relevant wavelength and therefore influence the radiation budget in the atmosphere.

[4] When it comes to GHGs, little or no nitrous oxide (N_2O) emissions occur from modern gas turbines. Methane (CH_4) may be emitted by gas turbines when they are in idle mode and by older technology engines, but recent data suggest that little or no CH_4 is emitted by modern engines. When it comes to pollutants, carbon monoxide (CO), nitrogen oxides (NO_x), sulphur oxides (SO_x), Non-Methane Volatile Organic Compound (NMVOC), particulates and other trace components including hazardous air pollutants each account for less than 1% of aircraft engine emissions (IPCC, 2006, Section 3.6).

[5] According to Jungbluth and Meili (2019), multiplying CO_2 emissions by a Radiative Forcing Index (RFI) provides a possible shortcut to accounting for all climate change effects of aviation. Nevertheless, these authors acknowledge that the uncertainty around this parameter is very large and that the appropriate RFI for aviation ranges from 1 to 2.7. Dahlmann et al. (2021) argue that accounting for the non-CO_2 effects of aviation on global warming requires detailed information on aircraft trajectory, engine emissions and ambient atmospheric conditions. They propose a bottom-up approach taking into account the distance flown and the geographic region where each flight is operated, and argue that it gives a more precise measure of the non-CO_2 effects of aviation on global warming than multiplying overall CO_2 emissions by a constant RFI. We leave it for further research to investigate how the OECD database could be extended to account for the non-CO_2 effects of aviation on global warming.

4. In 2019, just before the COVID-19 pandemic started, global CO_2 emissions from domestic and international aviation were roughly similar to the total energy-related CO_2 emissions of Japan and accounted for 3% of global energy-related CO_2 emissions. In OECD countries, this share was 5% and was characterised by a rapidly increasing trend, mainly driven by the development of international air transport over the last decades.

5. The COVID-19 pandemic had a disproportionate adverse impact on air transport, with activity and CO_2 emissions dropping by 75% globally in April-May 2020 compared to the corresponding period of 2019. While CO_2 emissions from domestic flights have returned to their pre-pandemic level since March 2021, those from international flights remained around 45% lower in December 2021.

6. Nevertheless, recent projections by the International Transport Forum (ITF) show that, in the absence of accelerated technological developments and more ambitious policy measures, aviation-related CO_2 emissions would be multiplied by 2.5 between 2015 and 2050, largely driven by international air transport (ITF, 2021a). This scenario comes close to pre-pandemic forecasts and suggests that technological development and policy action will be key to curb CO_2 emissions from air transport.

7. In order to track aviation-related CO_2 emissions, the OECD has developed a near-real-time database covering most countries in the world since 2013. It builds on air traffic (ADS-B) data provided by the International Civil Aviation Organisation (ICAO) and a CO_2 emission calculator provided by the European Organisation for the Safety of Air Navigation (EUROCONTROL). It will help track CO_2 emissions during the recovery phase after the COVID-19 pandemic, the impact on CO_2 emissions of technological developments affecting the fleet of aircraft in operation, and the impact of environmental policies such as carbon taxation.

8. The OECD database is freely available online[6] and can be seen as a public good for different types of users, from statisticians involved in the compilation of environmental accounts and statistics, researchers and policy makers, to journalists and the broader public. To facilitate the mapping with the two other official statistical sources on air emissions (Box 1.1), this database records emissions according to two different perspectives: the territory perspective used in air emission inventories provided by the UN Framework Convention on Climate Change (UNFCCC), and the residence perspective used in air emission accounts (AEAs) compiled according to the System of Environmental-Economic Accounting (SEEA, 2012).

9. The OECD database also offers several key advantages as compared with UNFCCC inventories and SEEA AEAs:

- Timeliness and frequency. The information in the OECD database is updated at quarterly frequency and includes monthly information from 2019 onwards. As of February 2022, it includes information up to December 2021. Since UNFCCC inventories and SEEA AEAs are available at annual frequency and published 16 and 12 months after the end of the reference year, respectively, the OECD database offers a substantial gain in timeliness. This will be crucial in tracking the rebound following the COVID-19 pandemic, analysing technological developments and providing timely advice for policymaking.[7]

[6] http://stats.oecd.org/Index.aspx?DataSetCode=AIRTRANS_CO2.

[7] Liu et al. (2020) also provide near-real-time CO2 emissions for a large number of countries and economic sectors during the COVID-19 pandemic. Compared with their results, the OECD database brings several improvements for the aviation sector. First, the OECD estimates are based on a true

- Near global coverage. Whereas only 43 (Annex-I) countries report data on CO_2 emissions to the UNFCCC on an annual basis, and around 40 (mostly European) countries compile AEAs, the OECD database has a near global coverage.
- Consistency across countries for the calculation and allocation of aviation-related CO2 emissions. The estimates included in the OECD database rely on a single methodology and are consistent across countries. In particular, the methodology avoids any double counting of CO_2 emissions across countries.[8] It will thus support the transparent monitoring of progress in reaching emission reduction targets across countries.
- Coverage of both domestic and international aviation. Contrary to UNFCCC inventories where only CO_2 emissions from domestic aviation are accounted for in national inventory totals (Box 1.1), the OECD database covers CO_2 emissions from both domestic and international aviation.
- Granularity. The OECD database includes breakdowns into domestic and international flights, and into passenger and freight flights. Distinguishing domestic and international flights is important because the demand for these types of flights does not grow at the same pace, and because, in the short term, governments have more policy levers to curb the CO_2 emissions from domestic flights than from international flights. Tracking freight flights separately gives the possibility to use this database to monitor international trade developments in different countries and regions.
- Accuracy. The OECD calculates CO_2 emissions from air transport based on granular information on flights and aircraft types. Considering the type of aircraft operating each flight allows tracking of technological improvements made by airlines to increase the fuel efficiency of their fleet over time. From 2019 onwards, the OECD estimates are also based on actual rather than scheduled flights, which further increases their accuracy, especially during the COVID-19 pandemic.

10. The rest of this article is organised as follows. Section 2 discusses the evolution of aviation-related CO_2 emissions over recent decades, the impact of the COVID-19 pandemic and the prospects for future development. It explains how the OECD database will help track aviation-related CO_2 emissions after the pandemic as well as the impact of technological developments and policy measures to curb CO_2 emissions from aviation. Section 3 describes the data sources and the OECD methodology to estimate CO_2 emissions from aviation. Section 4 discusses the accuracy of this estimation methodology by comparing the OECD estimates with official statistical sources on aviation-related CO_2 emissions. Section 5 concludes.

bottom-up approach using information on individual flights and the specific type of aircraft used in each case. Liu et al. (2020) do not have information on aircraft types and assume that the composition of the operated aircraft fleet is the same during the pandemic as in 2019. Moreover, Liu et al. (2020) do not allocate international flights across countries whereas the OECD database includes allocations from two different accounting perspectives: territory and residence.

[8] The correct allocation of production activities across countries in a globalised world is an issue that goes beyond air emission accounting. See Section 3.2.3 for details.

Box 1.1. Existing official statistics on air emissions: UNFCCC inventories and SEEA Air emission accounts

Air emission inventories according to the United Nations Framework Convention on Climate Change (UNFCCC)

All parties to the 2016 Paris Agreement are required to provide regular production-based GHG emission inventories to the UNFCCC, but only the 43 Annex-I countries to the Convention submit inventories every year. They cover the period from the base year (1990) until two years prior the submission year. Hence, the inventories submitted in Spring 2021 do not cover GHG emissions beyond the year 2019. All UNFCCC inventories follow a consistent structure, known as Consistent Reporting Format (CRF), where GHG emissions are broken down into emissions from fuel combustion activities, fugitive emissions from fuels, emissions from CO2 transport and storage, and memo items that are not included in national totals. The allocation of transport-related GHG emissions is very specific. While GHG emissions from domestic aviation are included in GHG emissions from fuel combustion activities, those related to international aviation are accounted for in a specific memo item and thus excluded from national inventory totals. GHG emissions from international aviation are only accounted for in inventory totals at the global level. The distinction between domestic and international aviation in UNFCCC inventories is based on whether departure and arrival airports are located in the same country (territory), and not on the nationality of airlines.

Air emission accounts according to the System of Environmental Economic Accounting (SEEA) 2012

The SEEA, endorsed as an international statistical standard by the UN Statistical Commission (UNSC) in 2012, provides a way to relate air emissions to economic activities. Indeed, SEEA air emission accounts (AEAs) break down air emissions into economic activities and households using the same industrial classification and accounting principles as national (economic) accounts. This alignment allows identifying which industries contribute to air emissions, and decomposing the evolutions over time of air emissions into within-industry changes and reallocations between industries with different emission intensities. In addition, AEAs can be combined with Inter-Country Input-Output (ICIO) tables in order to compare air emissions related to production in a given country (production-based emissions) with those generated all along global value chains in order to meet final demand[9] in this country (demand-based emissions).[10]

[9] Final demand corresponds to the sum of household and government consumption, gross fixed capital formation (i.e. investment) and exports.

[10] The OECD compiles demand-based CO2 emissions from a combination of SEEA air emission accounts, International Energy Agency (IEA) statistics on energy consumption and OECD ICIO tables. These estimates are available at:

https://stats.oecd.org/Index.aspx?DataSetCode=IO_GHG_2019.

When it comes to air transport, it means that all CO_2 emissions generated by an airline that is resident in country A should be allocated to the AEAs of this country, whereas CO_2 emissions generated by non-resident airlines should be allocated to the AEAs of their country of residence, even though some of them are generated over the territory of country A. This might generate substantial discrepancies between residence- and territory-based emissions for some countries (Section 3.2.4). For example, countries with an intense freight or tourism activity in which national airlines only play a limited role will be allocated much higher CO_2 emissions from air transport on a territory than a residence basis.

One major obstacle to the wider use of AEAs is their limited implementation outside the European Union.[11] In order to scale up the compilation of these accounts, the OECD has developed a methodology to estimate them starting from UNFCCC inventories and applied it to some large countries including Japan, Kazakhstan, Russia, Ukraine and the United States (Flachenecker et al., 2018).[12]

The information provided by the OECD database on Air Transport CO_2 emissions is a public good that could feed into the regular compilation process of UNFCCC inventories and SEEA air emission accounts. Beyond being available in quasi-real time, this database ensures a consistent allocation of CO_2 emissions across countries.

2. Stylised facts about CO_2 emissions from air transport

2.1. Before COVID-19, aviation-related CO_2 emissions were increasing at a rapid pace

11. In 2019, just before the COVID-19 pandemic, domestic and international aviation accounted for 3% of energy-related CO_2 emissions globally (Figure 2.1). With around 1Gt of CO_2 emissions in 2019, aviation-related CO_2 emissions were similar to the overall energy-related CO_2 emissions of Japan.

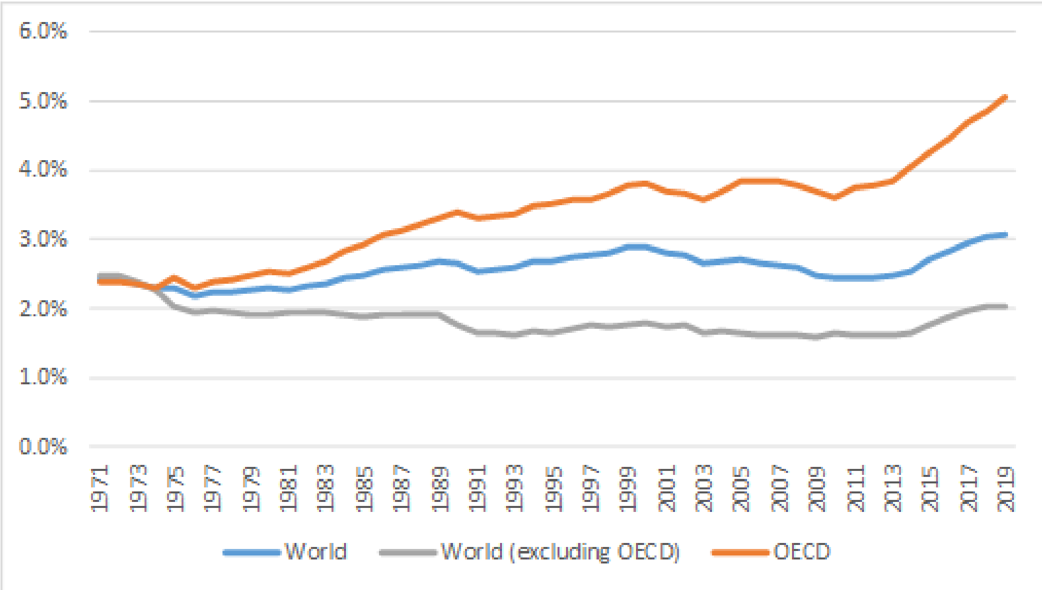
12. Focusing on OECD countries, the share of aviation-related CO_2 emissions in total energy-related CO_2 emissions was well above the global average and reached 5% in 2019. The increase of this share over recent decades reflects the fact that aviation-related emissions increased much faster than other energy-related emissions in OECD countries before the 2008-09 financial crisis, and continued to rise thereafter. The difference between aviation and other emissions widened from 2010, with aviation-related emissions increasing at a faster pace than other energy-related emissions (Figure 2.2). This sustained increase in aviation-related CO_2 emissions in OECD countries is largely related to international aviation, as shown by Figure 2.3.

[11] Outside the EU, the publication of GHG emission accounts is limited to Australia, Canada, Colombia, Iceland, Korea, New Zealand, Norway, Serbia, Switzerland and Turkey. All official AEAs are available at: http://stats.oecd.org/Index.aspx?DataSetCode=AEA.

[12] The corresponding estimated AEAs are available at: http://stats.oecd.org/Index.aspx?DataSetCode=OECD-AEA.

Figure 2.1. In 2019, aviation represented 3% of energy-related CO_2 emissions in the world, and 5% in OECD countries

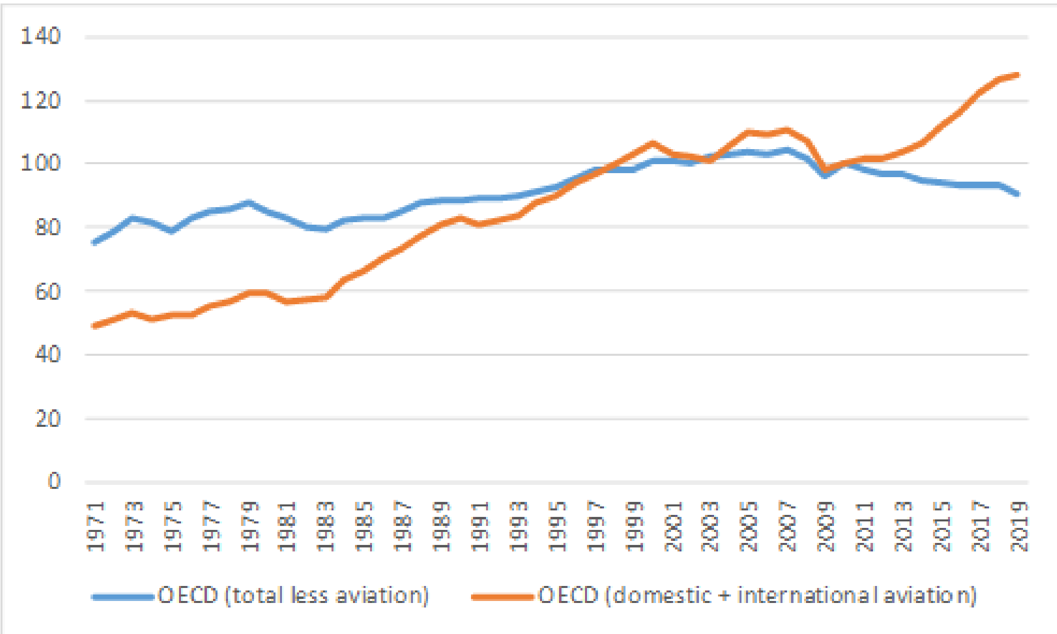
Share of (domestic + international) aviation in total energy-related CO_2 emissions, 1971-2019



Note: CO_2 emissions from international aviation were added to OECD and World (excluding OECD) totals before calculating shares.
Source: International Energy Agency (IEA), authors' calculations.

Figure 2.2. Over the last decades, aviation-related CO_2 emissions increased much faster than other energy-related CO_2 emissions in OECD countries

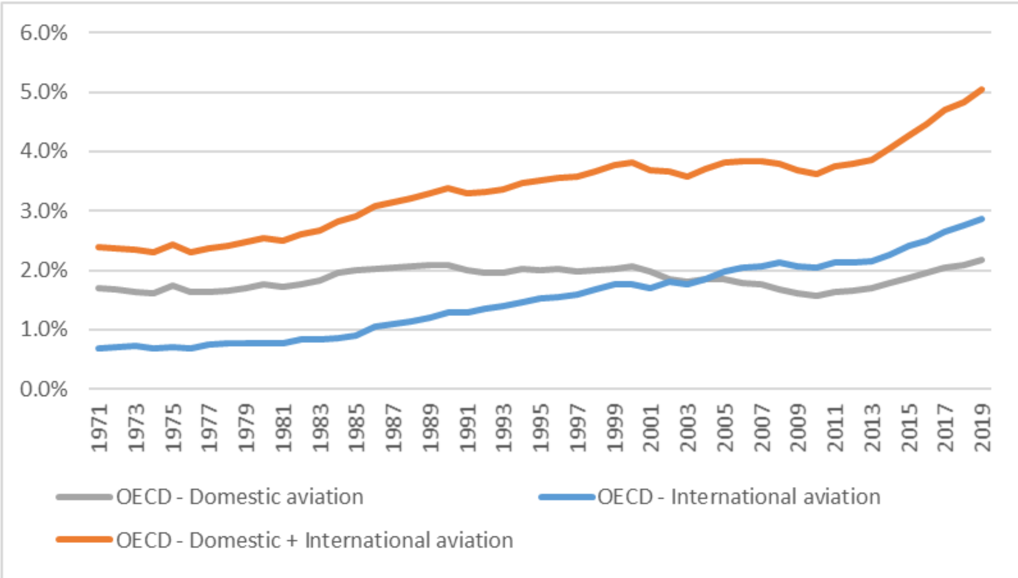
Aviation- and other energy-related CO_2 emissions in OECD countries, 1971-2019, 2010 = 100



Source: International Energy Agency (IEA), authors' calculations.

Figure 2.3. International aviation-related CO_2 emissions in OECD countries increased over the 50 years preceding the COVID-19 pandemic

Share of domestic and international aviation in total energy-related CO_2 emissions, OECD countries, 1971-2019



Note: The shares of domestic and international aviation (grey and blue lines) sum to the overall OECD share of aviation in energy-related CO_2 emissions (orange line).
Source: International Energy Agency (IEA), authors' calculations.

2.2. COVID-19 has strongly disrupted air transport, in particular international air transport

13. Before the outbreak of the COVID-19 pandemic, air transport was expected to continue growing at a fast pace. According to the 2019 forecast by the International Civil Aviation Organisation (ICAO), in the absence of technological and operational improvements, energy use and CO_2 emissions from international aviation are set to triple between 2015 and 2050 (ICAO, 2019).

14. Since these forecasts were made, air transport has been strongly disrupted by the COVID-19 pandemic. The OECD database, based on ICAO data (Section 3.1), allows tracking aviation-related CO_2 emissions at monthly frequency since the outbreak of the pandemic. At the height of the crisis, in April-May 2020, global emissions were 75% lower than in the corresponding period of 2019.[13] They have progressively increased since then, still in December 2021, global emissions remained around 30% lower than in December 2019 (Figure 2.4). Similar patterns hold when focusing on OECD countries.

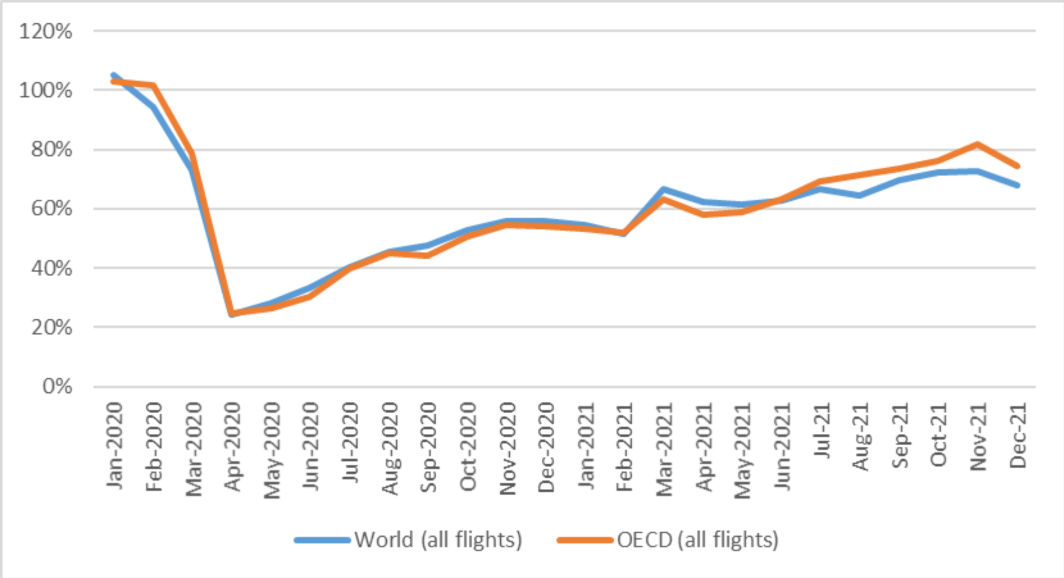
15. Nevertheless, this overall drop in CO_2 emissions hides large differences between domestic and international flights. While global CO_2 emissions from international flights were around 45% lower in December 2021 than in December 2019, those from domestic flights returned to their pre-pandemic level in March 2021 (Figure 2.5). Here again, similar patterns hold when focusing on OECD countries.

[13] Since air traffic is seasonal, comparisons between current CO_2 emissions and those recorded in the same month in 2019 allows controlling for seasonal fluctuations.

16. Zooming in on international flights, it appears that the pandemic only had a marginal impact on the overall activity of freight flights and related CO_2 emissions (Figure 2.6. It mostly affected international passenger flights. However, these produce most of the CO_2 emissions from international flights (94% globally in 2019).

Figure 2.4. In December 2021, aviation-related CO_2 emissions were significantly below their pre-pandemic level

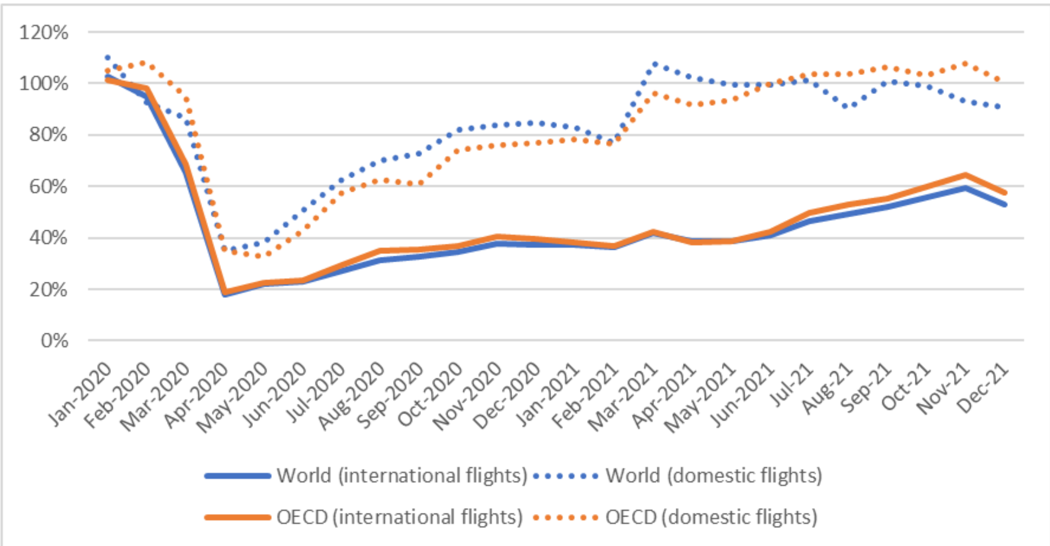
CO_2 emissions relative to the same month of 2019, World and OECD countries, January 2020 – December 2021



Source: [OECD database on Air Transport CO2 emissions](), authors' calculations.

Figure 2.5. In December 2021, CO_2 emissions from domestic flights had returned to their pre-pandemic level, while CO_2 emissions from international flights remained significantly lower

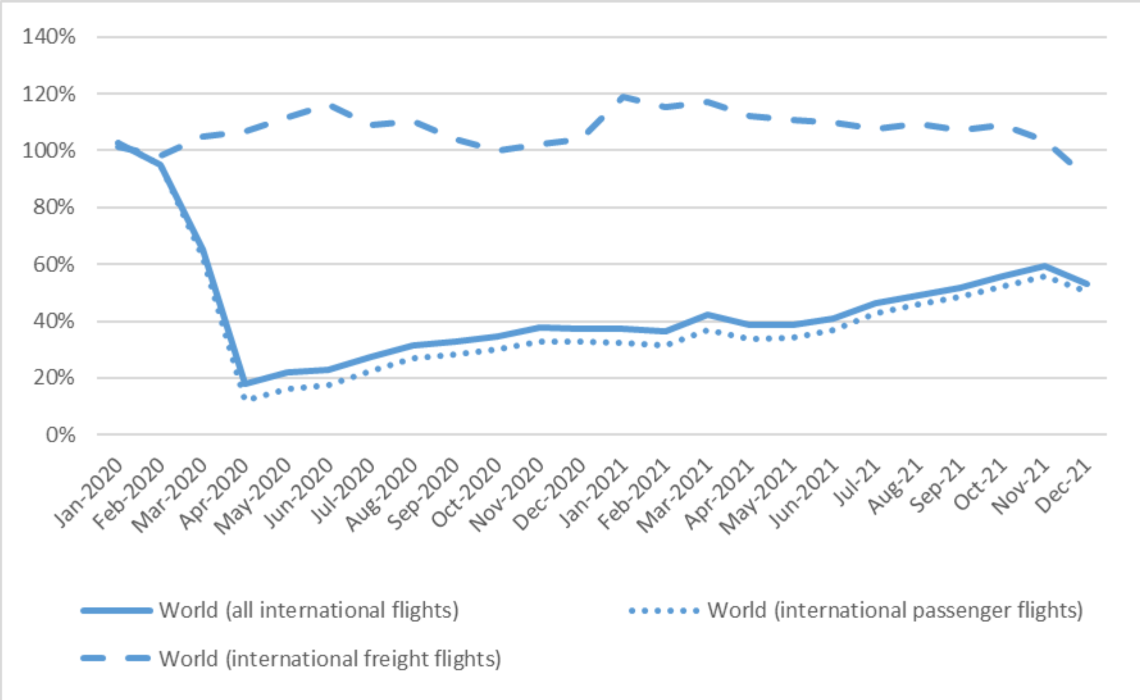
CO_2 emissions relative to the same month of 2019, World and OECD countries, January 2020 – December 2021



Source: [OECD database on Air Transport CO2 emissions](), authors' calculations.

Figure 2.6. International freight flights were largely unaffected by the pandemic

CO_2 emissions relative to the same month of 2019, January 2020 – December 2021



Note: The pattern is very similar for OECD countries.
Source: OECD database on Air Transport CO2 emissions, authors' calculations.

2.3. Technological developments and policy measures will be key to curb aviation-related CO_2 emissions

17. The International Transport Forum's (ITF) 2021 Transport Outlook (ITF, 2021a) includes three scenarios describing possible post-pandemic trajectories for air transport. These scenarios combine policy decisions, technological evolutions and potential long-term impacts of the pandemic:

- The *Recover* scenario assumes a return to pre-pandemic flying behaviour, coupled with policies agreed or planned in spring 2021.
- The *Reshape* scenario also assumes a return to pre-pandemic flying behaviour, but with adoption of more ambitious policy measures incentivising a reduction of CO_2 emissions and faster technological development and adoption.
- The *Reshape+* scenario assumes a long-term impact of the pandemic on flying behaviour, such as reduced business travel, and assumes an accelerated adoption of emission mitigating policies and technologies as compared with the *Reshape* scenario.

18. The *Recover* scenario is consistent with the aviation sector's resilience to prior crises and shocks. It shows that, in the absence of accelerated technological developments and more ambitious policy measures, aviation-related CO_2 emissions would be multiplied by 2.5 between 2015 and 2050, largely driven by further increases of international air transport. This scenario comes close to pre-pandemic forecasts.

19. Under the *Reshape* and *Reshape+* scenarios, global aviation-related CO_2 emissions in 2050 would be slightly below the level recorded in 2015, but still around 600Mt per year. It means that, in order to achieve net zero emissions globally by mid-century, even these ambitious aviation scenarios would require compensations (i.e. *negative* net emissions) by other sectors of the economy. Moreover, they would necessitate the implementation of ambitious policy measures and the development and adoption of Sustainable Aviation Fuels (SAF) and new types of aircraft (hydrogen-based, hybrid-electric and, to a lesser extent, fully electric aircraft).

20. Countries have a range of policy instruments to encourage emission reductions, such as emission pricing, performance standards and regulation. Among the policies that would help decarbonise air transport, carbon taxation is one option. Indeed, most CO_2 emissions from international aviation are currently not priced. This situation is related to the existence of numerous bilateral and multilateral agreements, known as Air Services Agreements (ASAs), that have been signed by countries since the end of the Second World War These ASAs exempt the purchase of fuel for international flights from taxation (Teusch and Ribansky, 2021; ITF, 2021b).

21. In order to start pricing CO_2 emissions from international aviation at the global level, a market-based mechanism known as Carbon Offsetting and Reduction Scheme for International Aviation (CORSIA) has been negotiated under the auspices of ICAO. Nevertheless, its aim is currently limited to *offsetting* the *growth* (not the level) of CO_2 emissions from international aviation after 2019, and some large countries including Brazil, Russia and China are not participating in its pilot phase.

22. As the International Transport Forum recently emphasised (ITF, 2021b), the climate emergency and the difficulty of reaching international agreements necessitate putting in place a range of policies at various geographical levels in order to start decarbonising air transport in the short- to medium term:

- At regional level, the European Union Emission Trading System (EU ETS)[14] applying to the fuel purchased for all flights taking place within the European Economic Area,[15] Switzerland and the United Kingdom provides a good example of coordinated policy action.
- At national level, there are no legal obstacles preventing governments from taxing the fuel purchased for domestic flights. Such taxes already exist in over 40 countries, including some with significant domestic aviation markets such as Brazil, Canada, India, Japan and the United States.
- In addition or as a substitute to carbon taxation, governments can also apply ticket taxes to both domestic and international flights.
- Policies supporting the development and the uptake of low-carbon aviation fuels, such as low-carbon fuel standards, can either be implemented on their own or as complementary measures to carbon pricing.
- Similarly, regulations on aircraft fuel efficiency and financial support to research and innovation can accelerate the development and the uptake of more fuel-efficient aircraft.

[14] More information on the EU ETS and its coverage for aviation can be found here: https://ec.europa.eu/clima/eu-action/transport-emissions/reducing-emissions-aviation_en.

[15] The European Economic Area comprises all 27 EU Member States, plus Iceland, Liechtenstein and Norway.

2.4. The OECD database will help track the impact on CO_2 emissions of technological developments and environmental policies such as carbon taxation

23. Looking ahead, the OECD database on Air Transport CO_2 emissions will allow tracking of aviation-related CO_2 emissions during the recovery phase after the COVID-19 pandemic, as well as the impact of technological developments affecting the fleet of aircraft in operation and the impact of environmental policies such as carbon taxation on CO_2 emissions.

24. The calculation of aviation-related CO_2 emissions by the OECD follows a bottom-up approach and takes into account the type of aircraft used for each flight (Section 3), it will be possible to keep track of any changes in the fleet of aircraft operated by airlines. These changes may occur either because the pandemic speeds up the retirement of older and less efficient aircraft (ITF, 2021a), or because new types of aircraft (e.g. hybrid/electric aircraft) are progressively developed and adopted.

25. Assuming that the necessary information on carbon taxation in different locations is available, the statistical infrastructure underlying the OECD database will allow tracking of the actual price of carbon paid by each country's resident airlines, taking into account their actual flight routes around the world.

26. Since it is likely that carbon taxation will only be implemented gradually across countries, differences across countries and over time could probably be exploited to assess the impact of carbon taxation on flights and on the resulting CO_2 emissions using econometric techniques.

27. At the same time, a progressive implementation of carbon taxation also means that there is a risk that carbon leakage may reduce the impact of taxation on global environmental performance. Carbon leakage refers to the displacement of CO_2 emissions occurring when economic activities move across jurisdictions to take advantage of less stringent environmental policies. In particular, if airlines were confronted by significantly different carbon prices in different countries, they may decide to increase their fuel tankering practices, redeploy their fleet or relocate hubs (Teusch and Ribansky, 2021; Dray and Doyme, 2019):

- Tankering is the practice whereby aircraft take on more fuel than is needed for a flight in order to avoid taking on more expensive or lower quality fuel at the next airport. There are limits to tankering, because taking on more fuel reduces the amount of cargo that can be carried and increases the fuel consumption of aircraft.
- If confronted by different carbon prices along different routes, airlines may redeploy less efficient aircraft to routes where carbon prices are lower or lease out older aircraft in their fleet. This practice is known as fleet swapping.
- Relocating hubs means that airlines would adjust their flight routes to concentrate as many flights as possible between countries where carbon prices are lower.

28. Admittedly, the extent of fuel tankering would be challenging to assess since the statistical infrastructure does not include information on fuel purchase locations. This issue would deserve further research. Nevertheless, airline strategies to redeploy their fleet and relocate hubs would be fully accounted for in the OECD database since information on all operated flights and aircraft types is available to the OECD (Section 3).

3. Data sources and estimation methodology underlying the OECD database on air transport CO_2 emissions

3.1. Data sources

29. The main source of information used by the OECD for the estimation of CO_2 emissions from air transport is a database compiled by the International Civil Aviation Organisation (ICAO) which includes most of the passenger and freight flights taking place around the world. For each flight, this database includes information on the departure and arrival airports, the operating airline, and the type of aircraft used. More than 1 000 different aircraft types are considered in this database. For each airline, the database also has information on which country has delivered its Air Operator's Certificate (AOC).[16]

30. Up to 2018, the information provided by ICAO relates to scheduled flights, and from 2019 onwards, it relates to flights actually taking place, based on information from the Automatic Dependent Surveillance-Broadcast (ADS-B) system.[17] Whereas the difference between scheduled and actual flights is limited under normal circumstances, accessing information on actual flights is a prerequisite to accurately monitor air traffic and the related CO_2 emissions during the COVID-19 crisis, in 2020 and beyond.

31. Beyond the possibility to track actual flights, the move to the ADS-B technology brings two additional benefits:

- It allows a better coverage of flights. While general aviation (e.g. agricultural planes and private jets) is not covered by the ICAO source data until 2018, most of it is included in the ICAO database and in the estimated CO_2 emissions provided by the OECD from 2019 onwards.[18] Helicopters and military aviation remain out of scope for all years.
- It allows measurement of the actual distance covered by aircraft, which depends on airspace constraints and meteorological conditions when flights take place. Until 2018, only the (great-circle) distance[19] between origin and destination airports can be taken into account.

[16] An Air Operator's Certificate is the approval granted by a national aviation authority to an aircraft operator allowing it to use aircrafts for commercial purposes. The exact name may vary from one country to the other. For example, it is referred to as an Air Carrier Operating Certificate in the United States, and as an Air Operator Certification in New Zealand.

[17] ADS-B is a surveillance technology in which an aircraft determines its position via satellite navigation or other sensors and periodically broadcasts it, thus enabling to be tracked. The information can be received via air traffic control ground stations or by other aircraft to provide situational awareness and allow self-separation.

[18] Prior to 2019, it is only for the US that general aviation is included in the estimated CO2 emissions. The corresponding information is sourced from the US UNFCCC inventories. CO2 emissions from general aviation cannot be separately identified in the inventories of the other Annex-I countries to the UNFCCC. Therefore, they cannot be accounted for in the estimated CO_2 emissions provided by the OECD.

[19] The great-circle distance is the shortest distance between two points on the surface of a sphere.

3.2. Estimation methodology

32. Taking the United Kingdom as an example, Figure 3.1 identifies all possible cases, depending on whether flights are operated by British or non-resident airlines, and where these flights take place. It shows which ones correspond to territory- or residence-based CO_2 emissions. Note that, in this paper, bridging items are defined in the same way as in Eurostat's Manual on AEAs (2015). These bridging items relate AEA totals with UNFCCC totals for *domestic* aviation.[20] *International* aviation is treated as a memo item, and thus excluded from UNFCCC totals (Box 1.1). Nevertheless, in order to fully assess the accuracy of our estimation methodology, territory-based total estimates are compared with UNFCCC totals for both domestic and international aviation in Section 4 and Annex B.

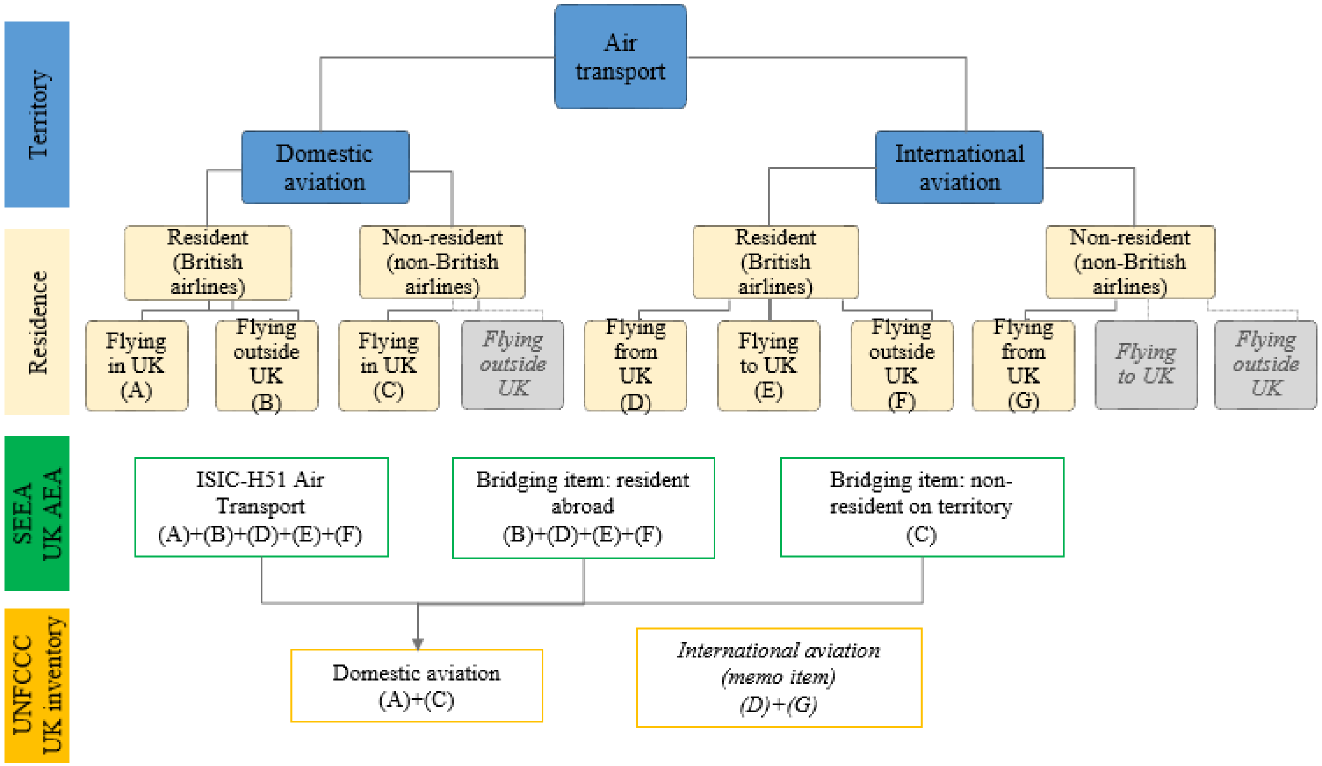
33. To estimate CO_2 emissions related to each flight, the flight information provided by ICAO is linked with a CO_2 emission calculator provided by the European Organisation for the Safety of Air Navigation (EUROCONTROL).[21] Given an aircraft type equipped with a specific type and number of engines and a specific distance travelled, this tool calculates a flight trajectory, a quantity of fuel burnt and a quantity of CO_2 emitted. Additional details are available in EUROCONTROL (2016). This method corresponds to a sophisticated Tier-3A methodology in the 2006 IPCC Guidelines for national GHG inventories.[22]

[20] In line with IPCC (2006), we define domestic aviation as civil passenger and freight air traffic that departs and arrives in the same country. This includes flights between the mainland and the overseas territories of a country.

[21] Additional details are available at: www.eurocontrol.int/publication/eurocontrol-method-estimating-aviation-fuel-burnt-and-emissions.

[22] See IPCC (2006), p. 61. "[…] Tier 3A takes into account cruise emissions for different flight distances. Details on the origin (departure) and destination (arrival) airports and aircraft type are needed to use Tier 3A, for both domestic and international flights. In Tier 3A, inventories are modelled using average fuel consumption and emissions data for the [Landing/Take-Off] LTO phase and various cruise phase lengths, for an array of representative aircraft categories. The data used in Tier 3A methodology takes into account that the amount of emissions generated varies between phases of flight. The methodology also takes into account that fuel burn is related to flight distance, while recognising that fuel burn can be comparably higher on relatively short distances than on longer routes. This is because aircraft use a higher amount of fuel per distance for the LTO cycle compared to the cruise phase. […]".

Figure 3.1. From territory to residence: Allocation of flights from a UK perspective



Note: Bridging items in this Figure link CO_2 emissions related to domestic and international aviation on a residence basis (SEEA air emission accounts) to CO_2 emissions related to domestic aviation on a territory basis (UNFCCC inventories, excluding the international aviation memo item). Any additional flight category in the *Residence* section that is not relevant to the UK air emission accounts or inventories is shown in grey (e.g. a domestic flight outside the United Kingdom by a non-resident airline is neither accounted for in the UK air emission accounts nor in the UK inventories). Categories (B) and (F) correspond to flights operated by airlines that are resident in the United Kingdom but taking place outside of the United Kingdom. For example, a British Airways' flight between Paris and Nice would be recorded under category (B) and a British Airways' flight between Paris and Rome would be recorded under category (F).
Source: OECD own elaboration.

3.2.1. Territory-based emissions

34. The purpose of the UNFCCC inventories is to record CO_2 emissions related to the combustion of the jet fuel and the aviation gasoline sold in a given country.[23] The OECD estimates assume that airlines optimise their purchases of fuel at origin airports to be the quantities of fuel needed for the upcoming flight (i.e. no bunkering occurs). Territory-based emissions for a given country correspond to the emissions generated by all flights taking off from this country during the reference period. This estimation method is able to replicate in near-real-time the information on aviation emissions that official UNFCCC inventories provide with a lag of around 16 months (see Section 4 and Annex B).

3.2.2. Residence-based emissions

35. The rationale for adopting the residence-based principle in the SEEA is the ability to relate CO_2 emissions to the underlying production (and factors of production) used to generate value added, as recorded in the national accounts.

36. For most economic activities, identifying the residence of the firm (or the institutional unit) providing an economic activity is relatively straightforward. The 2008 System of National Accounts (SNA, Chapter 4), the 2010 European System of Accounts (ESA, Chapter 18) and the Balance of Payments and International Investment Position Manual (BPM6, Chapter 4) define the residence of an institutional unit as "the economic territory with which it has the strongest connection, expressed as its centre of predominant economic interest".

37. More precisely, paragraph 4.11 in the 2008 SNA states that:

> *"An institutional unit has a centre of predominant economic interest in an economic territory when there exists, within the economic territory, some location, dwelling, place of production, or other premises on which or from which the unit engages and intends to continue engaging, either indefinitely or over a finite but long period of time, in economic activities and transactions on a significant scale. The location need not be fixed so long as it remains within the economic territory. Actual or intended location for one year or more is used as an operational definition; while the choice of one year as a specific period is somewhat arbitrary, it is adopted to avoid uncertainty and facilitate international consistency."*

3.2.3. Multi-territory enterprises

38. For airlines operating and providing services across a number of economic territories, determining residence is necessarily more complex than the simple case described above. Even though an institutional unit is usually resident in only one country, the 2008 SNA (paragraph 4.13) makes an exception for multi-territory enterprises such as airlines operating across countries.

39. In the simplest case where airlines have branches (e.g. establishments) with a full set of accounts in the different countries where they have a "centre of predominant economic interest", residence can be assessed at the branch level.

40. For multi-territory enterprises without well-identified branches however, determining residence is non-trivial, and in such cases international statistical guidelines

[23] See IPCC (2006) guidelines, Section 3.6.1.5.

recommend creating "notional units" in each of the economic territories where these enterprises operate.[24]

41. An additional difficulty arises from the fact that hardly any global coordination mechanism exists to ensure that the accounting treatment of multi-territory enterprises is consistent across countries and does not lead to any double (or multiple) counting. For example, national accountants in different countries may have opposing views on whether the production of a multi-territory enterprise outside the territory of its head office is "substantial", or they might use different apportionment factors to split this enterprise. As a result, country A may consider that the economic activity and CO_2 emissions related to the flights operated by its national airline and its foreign branches should be recorded in country A's accounts, whereas country B may consider the branches of country A's national airline operating on its territory as resident companies, and record the corresponding economic activity and CO_2 emissions in country B's accounts.

42. In part to avoid introducing global inconsistencies, and also for the sake of simplicity and transparency, the country of residence of an airline is determined based on its AOC. For example, Air France has a French AOC and it is thus considered as a French resident company.

43. The only exception to this standard approach is for Scandinavian Airlines (SAS) because national accountants in Denmark, Norway and Sweden have agreed on a coordinated accounting treatment of this company, based on the relative share of equity that each country owns in the SAS Consortium. In order to ensure a consistent treatment with national accounts, the residence-based CO_2 emissions of SAS are allocated to Denmark, Norway and Sweden following the approach by national accountants (see Box 3.1).

44. Countries that would prefer to have another accounting treatment in this exercise, e.g. because they consider that some airlines with a foreign AOC have resident branches in their country, or the opposite, should contact the OECD (SDD.SEEA@oecd.org). The OECD will then set up bilateral discussions between these countries and the country of origin of the airlines, in order to agree on a coordinated accounting treatment that can be reflected in the OECD database on Air Transport CO_2 emissions, as well as in the national accounts and air emission accounts of these countries.

[24] These guidelines are reflected in the 2008 SNA (paragraph 26.35), BPM6 (paragraphs 4.25-4.28), UNECE (2015, Chapter 8). Note that BPM6 calls notional units "artificial institutional units". UNECE (2015), which gives the most precise and up-to-date guidelines to tackle this issue, recommends splitting multi-territory enterprises into different countries by creating notional units whenever possible, provided that these enterprises meet the three following criteria:

- They have substantial production in a territory outside that of their head office.

- The operations in different countries can be separated (e.g. by using appropriate enterprise-specific indicators of the proportion of operations in each territory).

- They have a complete set of accounts, including a balance sheet, or it is possible and meaningful to compile these accounts if required.

Box 3.1. Specific allocation of CO_2 emissions from Scandinavian Airlines in the OECD database

Scandinavian Airlines (SAS) is a specific case because its operations are so closely tied to three countries (Denmark, Norway and Sweden) that it would be meaningless to allocate all its resident CO_2 emissions to a single country (e.g. Sweden, the country delivering the AOC).

The national accountants of Denmark, Norway and Sweden have agreed on a coordinated treatment of SAS, based on the relative share of equity that each country owns in the SAS Consortium: 2/7 for Denmark, 2/7 for Norway, and 3/7 for Sweden. [25] In the national accounts and balance of payments of these three countries, turnover and capital stocks are pro-rated to the three countries in accordance with their ownership shares.

Table 3.1. Allocation of SAS CO_2 emissions across countries – Example of a SAS-operated flight from Stockholm to Copenhagen

	Denmark	Norway	Sweden
Territory	No emissions allocated to Denmark	No emissions allocated to Norway	All emissions allocated to Sweden, under international aviation (memo item in UNFCCC inventories)
Residence	- 2/7 of emissions allocated to category E (resident airline flying to Denmark)	- 2/7 of emissions allocated to category F (resident airline flying outside Norway)	- 3/7 of emissions allocated to category D (resident airline flying from Sweden) - 4/7 of emissions allocated to category G (non-resident, Danish and Norwegian, airlines flying from Sweden to another country)
	<u>Implications for Danish AEAs</u>: - 2/7 of emissions allocated to H51 - 2/7 of emissions recorded under Bridging Item – Emissions from residents abroad	<u>Implications for Norwegian AEAs</u>: - 2/7 of emissions allocated to H51 - 2/7 of emissions recorded under Bridging Item – Emissions from residents abroad	<u>Implications for the Swedish AEAs</u>: - 3/7 of emissions allocated to H51 - 3/7 of emissions recorded under Bridging Item – Emissions from residents abroad

In order to ensure a consistent treatment with national accounts, the OECD applies the same logic as national accountants to allocate the SAS-related CO_2 emissions to Denmark, Norway and Sweden on a residence basis. More precisely, the CO_2 emissions of each SAS-operated flight are considered as emanating from three different airlines: a Danish-resident airline (for 2/7), a Norwegian-resident airline (for 2/7), and a Swedish-resident airline (for 3/7). Then the same allocation principles apply as for any other airline.[26] The allocation of the corresponding CO_2 emissions on a territory basis also follows the same logic as for all other airlines. On a territory basis, the emissions of a given flight are simply allocated to the country of departure.

Table 3.1 provides an example of how the CO_2 emissions of a SAS-operated flight from Stockholm to Copenhagen are allocated across countries. The same notations and allocation principles apply as in Figure 3.1. The same method is applied to all SAS-operated flights in the world.

3.2.4. Territory and residence bases compared

45. In practice, switching from the territory to the residence perspective may have a significant impact. Figure 3.2 shows that for around half of OECD countries there is a gap of over 25% between emissions measured on the different bases.

46. Costa Rica, Greece, Lithuania and Italy, are the four OECD countries for which residence-based emissions were less than half territory-based emissions in 2019, meaning that the CO_2 emissions generated by their resident airlines are much lower than the emissions generated by all flights taking off from their territory. The OECD database is a unique source of information for Costa Rica which is not an UNFCCC Annex-I country and does not compile official AEAs. For Lithuania and Italy, Annex B shows that the OECD estimates are very close to UNFCCC inventories and SEEA AEAs. Hence for these two countries, official statistics reflect similar differences between territory- and residence-based CO_2 emissions as OECD estimates. In the case of Greece, the OECD territory-based estimates are close to official statistics but residence-based estimates are higher, which means that the ratio between residence- and territory-based estimates for Greece is even lower in official statistics than in OECD estimates.

47. Ireland and Hungary are the two OECD countries on the other end of the spectrum. For these two countries, resident airlines generate much more (five times as much) emissions than the flights taking off from their territory. Both official statistics and OECD estimates provide a similar diagnostic (Annex B). For these two countries, the large difference between residence- and territory-based emissions is related to low-cost airlines which are resident in Ireland and Hungary but operate flights abroad.

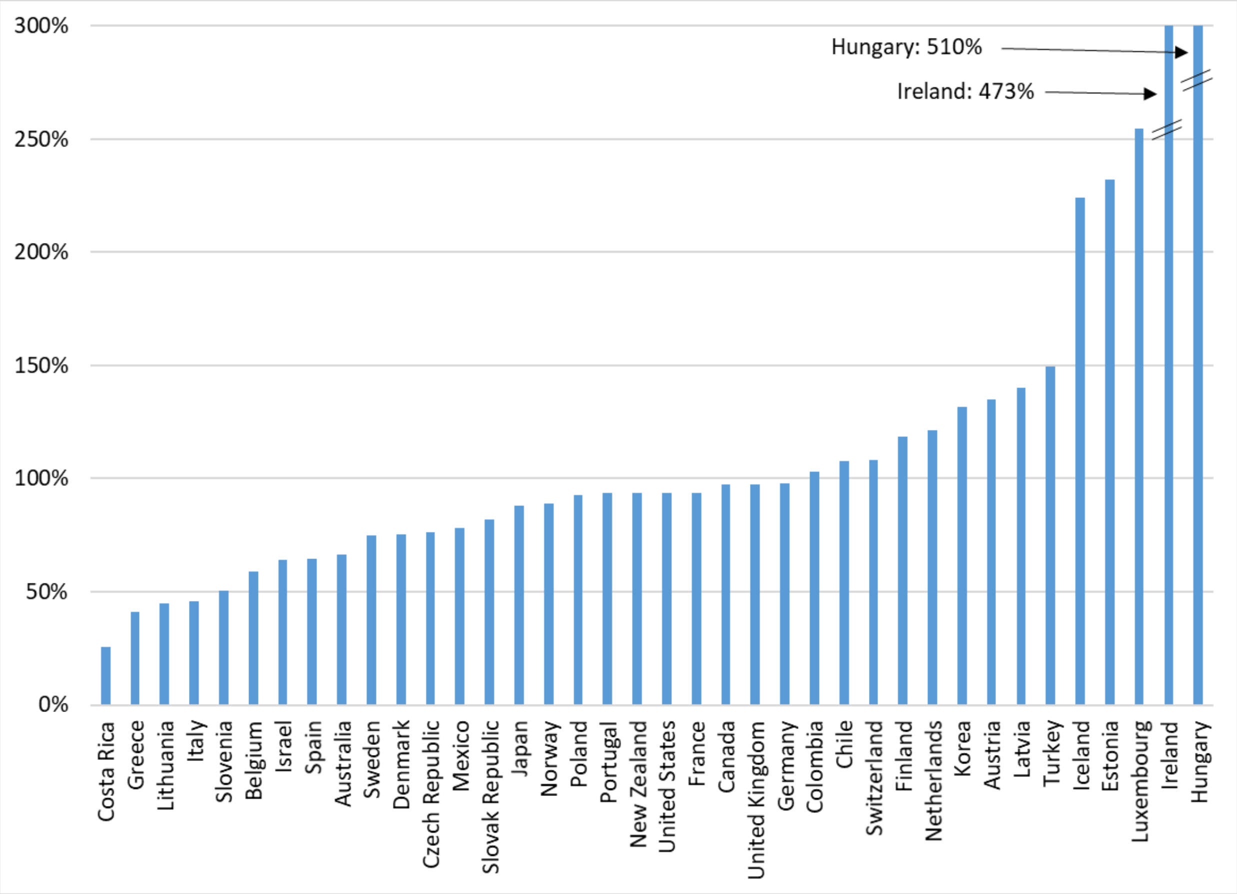
48. In between these extreme cases, half of OECD countries, among which all G7 countries except Italy, have a more limited gap (below 25%) between resident- and territory-based emissions. In such cases, territory-based emissions by non-resident airlines roughly compensate emissions by resident airlines taking place abroad.

[25] See for instance the 2019 financial report of the SAS Consortium which clearly shows that the Consortium is entirely owned by three shareholding companies, SAS Denmark A/S (2/7), SAS Norge AS (2/7), and SAS Sverige AB (3/7): www.sasgroup.net/files/documents/Corporate_governace/annual-reports/sas-consortium-fy-2019-english-january-30-2020.pdf.

[26] Note that, from an IT perspective, this solution is easy to implement and therefore not prone to errors. Once each SAS flight has been split into three different flights, operated by Danish, Norwegian and Swedish airlines, each responsible for 2/7, 2/7 and 3/7 of the CO_2 emissions of the original flight, respectively, the same computer code as for all other airlines can be used.

Figure 3.2. Residence- and territory-based emissions may be significantly different

Ratio of residence- and territory-based emissions, OECD countries, 2019



Note: Residence-based emissions are those generated by resident airlines, wherever they occur in the world. Territory-based emissions are those generated by domestic and international flights taking off from a given country.
Source: OECD database on Air Transport CO2 emissions, authors' calculations.

4. Accuracy of the estimation methodology

49. In order to assess the accuracy of the OECD estimation methodology, estimates are compared with the information included in the inventories of Annex-I countries to the UNFCCC, and in SEEA AEAs for countries compiling these accounts. More precisely, the territory-based CO_2 emissions estimated by the OECD are compared with those reported under items 1.A.3.a.i (International civil aviation) and 1.A.3.a.ii (Domestic civil aviation) in UNFCCC inventories, and the residence-based CO_2 emissions estimated by the OECD with the corresponding information in official AEAs.[27]

50. Two data gaps in the information provided by ICAO prior to 2019 could potentially contribute to the difference between OECD's estimates and officially reported CO_2 emissions in UNFCCC inventories and AEAs up to 2018:

- The information provided by ICAO up to 2018 relates to scheduled flights, as opposed to flights actually taking place in a given year. Nevertheless, looking at scheduled flights under the normal circumstances that prevailed before the COVID-19 pandemic, i.e. before 2020, likely creates no systematic bias.
- The information provided by ICAO up to 2018 does not include general aviation (e.g. agricultural planes and private aircraft). Among UNFCCC Annex-I countries, it is only for the United States that specific information on the corresponding CO_2 emissions for general aviation is included in UNFCCC inventories. According to the US National Inventory Report (US EPA 2019, Table 3-13), these emissions largely occur in domestic territory. For convenience, it is assumed that they are only caused by resident units and thus do not affect bridging items.

51. The information provided by ICAO does not include military flights, for any year, but this does not affect the comparison with UNFCCC inventories and official AEAs. Indeed, military emissions are reported under item 1.A.5.b (Non-specified mobile sources) in UNFCCC inventories, i.e. not with domestic or international aviation, and under industry O (Public Administration and Defence) in AEAs, i.e. not with air transport. Again, it is only for the United States that specific information on the corresponding CO_2 emissions is available. All other countries aggregate military emissions with other types of emissions, not related to aviation, under item 1.A.5.b in their inventories, and they do not provide any further detail in their National Inventory Report. In the case of the United States, these emissions largely occur in domestic territory and, by definition, they are caused by resident units. Therefore, they do not contribute to bridging items.

52. Table 4.1 compares the accuracy of estimated CO_2 emissions on a territory basis when using information on scheduled and actual flights in 2019.[28] Official UNFCCC inventories are used as benchmarks. Detailed results for all UNFCCC Annex-I countries are available in Annex B. Based on scheduled flight data and on average across countries, OECD estimates are 7.2% below UNFCCC inventories for international aviation and 7.3% below for domestic aviation. Based on actual flight data, OECD estimates move even closer to UNFCCC inventories for international aviation, being only 3.7% below on average across countries. The 10.9% gap for domestic aviation is largely related to CO2 emissions from general aviation in the United States which, so far, is still imperfectly captured

[27] Detailed results are available at:

http://stats.oecd.org/Index.aspx?DataSetCode=AIRTRANS_CO2.

[28] 2019 is the only year for which the two information sets are available.

by ADS-B. Excluding this country reduces the difference for domestic aviation to -2.7% and leaves the difference for international aviation practically unchanged at -4.1%.

53. Note that official CO_2 emissions are also subject to uncertainty. For example, Canada reports that the uncertainty around its official measures of CO_2 emissions from domestic aviation is around 7% (Environment and Climate Change Canada, 2019, p. 75).

Table 4.1. Comparison of aviation-related CO_2 emissions on a territory basis

Ratio of OECD estimates to official UNFCCC inventories, 2019

Available information on air traffic	Domestic and international aviation	Domestic aviation	International aviation
Scheduled passenger and freight flights. General aviation only taken into account for the US, based on National Inventory Report	-7.3%	-7.3%	-7.2%
Actual passenger and freight flights. General aviation taken into account for all countries, based on ADS-B information	-6.8%	-10.9%	-3.7%

Note: Table 4.1 reports the percentage difference between the weighted average of estimated and official CO_2 emissions on a territory basis for the year 2019. Relative shares in overall CO_2 emissions are used as country weights. All Annex-I countries to the UNFCCC except Liechtenstein and Monaco are included in the sample. Negative figures indicate that OECD-estimated emissions are below official UNFCCC inventories.
In the first row, CO_2 emissions are estimated based on information on scheduled passenger and freight flights. General aviation is only taken into account for the US. For this country, CO_2 emissions from general aviation available from the US National Inventory Report are added to estimated CO_2 emissions from scheduled passenger and freight flights. This contributes to reduce the gap with official UNFCCC inventories.
In the second row, CO_2 emissions are estimated based on information on actual passenger and freight flights based on ADS-B information, which partly covers general aviation.

54. Table 4.2 compares the accuracy of estimated CO_2 emissions on a residence basis when using information on scheduled and actual flights for 32 countries in 2019. Official SEEA Air Emission Accounts (AEAs) are used as benchmarks. The results show that both sets of information provide accurate estimates of the CO_2 emissions generated by the Air Transport (H51) industry in 2019. The OECD estimates are only 7.5% lower for scheduled flights and 4.7% lower when using the more accurate information on actual flights that is available from 2019 onwards. Looking beyond 2019, it is important to keep in mind that information on actual flights is key to provide reliable results during the COVID-19 pandemic, during which the difference between scheduled and actual flights has significantly increased.

Table 4.2. Comparison of aviation-related CO_2 emissions on a residence basis

Ratio of OECD estimates to official SEEA AEAs, 2019

Available information on air traffic	Air Transport (H51)
Scheduled passenger and freight flights. General aviation not taken into account for any country	-7.5%
Actual passenger and freight flights. General aviation taken into account for all countries, based on ADS-B information	-4.7%

Note: Table 4.2 reports the percentage difference between the weighted average of estimated and official CO_2 emissions on a residence basis for the year 2019. Relative shares in overall CO_2 emissions by the Air Transport industry (H51) are used as country weights.
32 Annex-I countries to the UNFCCC that also compile official SEEA Air Emission Accounts are included in the sample (Austria, Belgium, Bulgaria, Croatia, Cyprus, the Czech Republic, Denmark, Estonia, Finland, France, Germany, Greece, Hungary, Iceland, Ireland, Italy, Latvia, Lithuania, Luxembourg, Malta, the Netherlands, Norway, Poland, Portugal, Romania, Slovakia, Slovenia, Spain, Sweden, Switzerland, Turkey and the United Kingdom).
Negative figures indicate that OECD-estimated emissions are below official AEA emissions.

55. Beyond CO_2 emissions from a territory and a residence perspectives, the OECD database also provides bridging items to relate the two. As shown in Figure 3.1, two different bridging items are considered: (1) to account for CO_2 emissions by resident airlines abroad, and (2) to account for CO_2 emissions by non-resident airlines on the territory of a given country. Taken together, these bridging items allow relating the CO_2 emissions generated by the Air Transport (H51) industry of a given country (i.e. all its resident airlines operating anywhere in the world), and the CO_2 emissions generated by all *domestic* flights taking place on its territory.[29]

56. The differences between estimated and officially reported bridging items that are shown in Annex B may be related to three main reasons: i) differences in the application of the residence principle (see Section 3.2.2), ii) the fact that many countries include "adjustments and statistical discrepancies" in addition to bridging items in their AEAs whereas such adjustments and discrepancies do not exist in the OECD database, and iii) differences in the way bridging items are defined, with some countries using them to relate the CO_2 emissions generated by their Air Transport (H51) industry and the CO_2 emissions generated by all *domestic and international* flights taking place on their territory. As a result, potential differences between estimated and officially reported bridging items are not straightforward to interpret, but they usually concern small numbers.

[29] Only emissions generated by *domestic* aviation are to be reported in national inventory totals, according to IPCC (2006) guidelines. *International aviation* is only mentioned as a *memo item* but not included in UNFCCC inventory totals (see Box 1.1). This explains the definition of bridging items in the OECD database, as well as in Eurostat's Manual on AEAs (2015).

5. Conclusion

57. This paper has described a new OECD database building on air traffic data from ICAO and providing near-real-time and global information on aviation-related CO_2 emissions, with allocations across countries following either the territory or the residence principle. This database is a contribution to both statistical measurement and environmental policy analysis. On the statistical front, it will facilitate the compilation of global air emission accounts according to the SEEA, bring granular and timely information on a significant source of CO_2 emissions, and allow tracking their evolution during and after the COVID-19 pandemic. The comparison with official statistical sources that are available with a significant delay and at lower frequency demonstrates the accuracy of the near-real-time OECD estimates. On the environmental policy front, it is expected that the OECD database will help monitor the impact of technological developments and policy measures to curb aviation-related CO_2 emissions in the future.

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Annex A. OECD work on global air emission accounts according to the SEEA

According to the 2021 Global Assessment of Environmental Economic Accounting performed by the United Nations,[30] 87 countries currently compile at least one type of environmental economic account in line with the SEEA Central Framework. Among these 87 countries, 42, mostly OECD countries, compile Air Emission Accounts.

The UN Statistical Commission (UNSC) has asked the UN Committee of Experts on Environmental-Economic Accounting (UNCEEA), of which the OECD is a Bureau member, to scale up the implementation process by supporting capacity building in countries, developing methodological guidelines, compiling global SEEA databases and promoting the use of SEEA for policymaking. Within the UNCEEA Bureau, the OECD coordinates a group leading the development of global SEEA databases. The strategy for developing these databases is to use nationally available data compiled according to the SEEA if available, and to supplement this with estimates based on internationally available data sources whenever possible.

The OECD has taken the lead on the development of global Air Emission Accounts according to the SEEA. It has developed a methodology to estimate SEEA air emission accounts for large countries that do not provide this information but compile detailed UNFCCC inventories (e.g. Japan, Kazakhstan, Russia, Ukraine and the United States). The OECD estimation methodology is described and evaluated in Flachenecker et al. (2018). The estimates are available at https://stats.oecd.org/Index.aspx?DataSetCode=OECD-AEA. The OECD database on CO_2 emissions from air transport is an additional contribution to the development of global Air Emission Accounts according to the SEEA.

[30] See https://seea.un.org/content/2021-global-assessment-results.

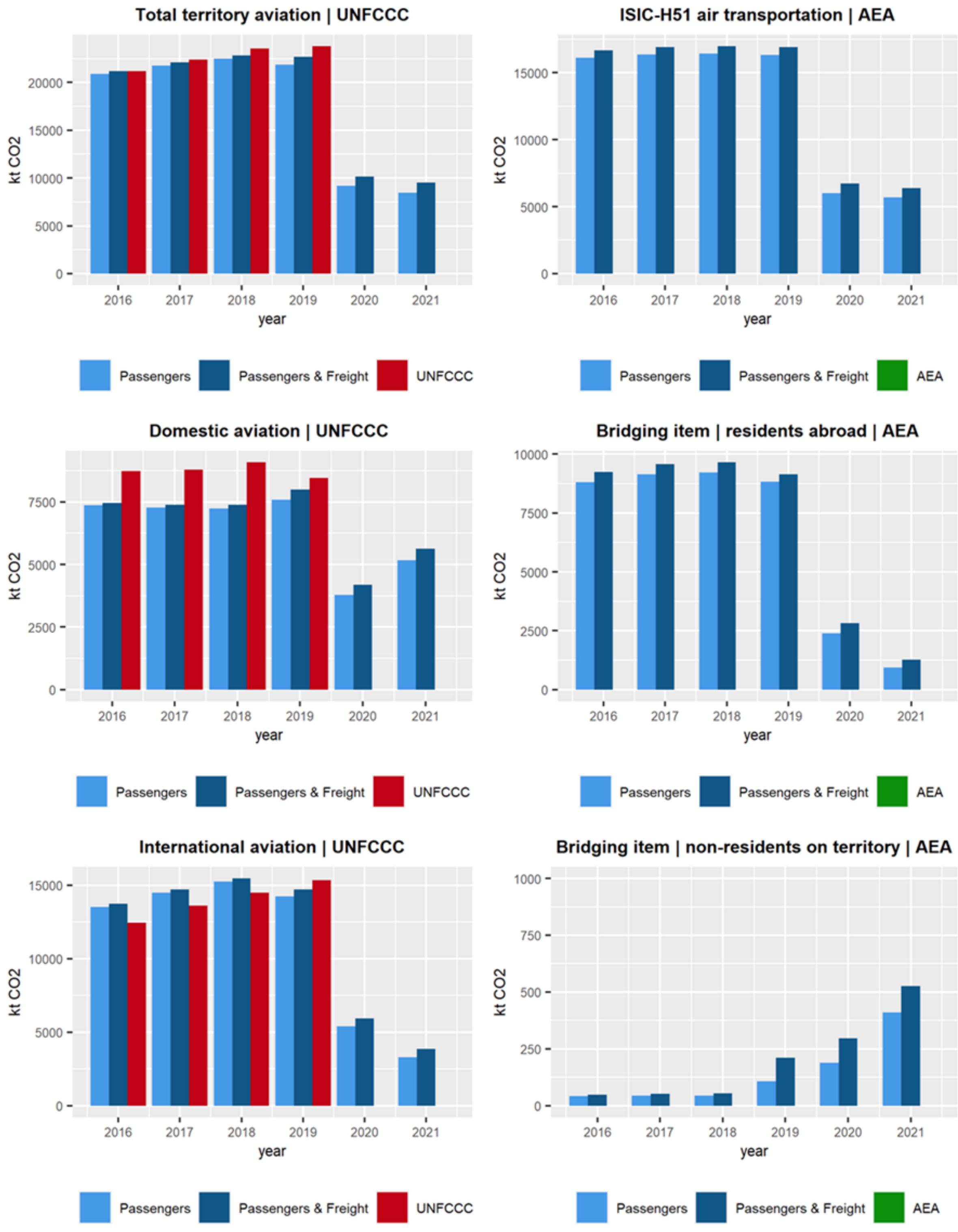
Annex B. Detailed results for UNFCCC Annex-I countries

This Annex provides country-specific comparisons of the aviation-related CO_2 emissions estimated by the OECD with the available official statistics provided by UNFCCC inventories and SEEA Air Emission Accounts (AEAs). For the countries providing both types of official statistics, the following charts are available:

- 3 charts comparing territory-based CO_2 emissions estimated by the OECD with the corresponding information in UNFCCC inventories, for international, domestic, and total aviation (left column).
- 3 charts comparing residence-based CO_2 emissions estimated by the OECD with the corresponding information in SEEA AEAs (right column). One chart focuses on the CO_2 emissions generated by the air transport industry (coded H51 in the ISIC rev.4 classification), and two other charts focus on the bridging items between residence- and territory-based estimates. These bridging items are defined according to Figure 3.1.

In case some countries do not release UNFCCC inventories or SEEA AEAs, the corresponding histograms are left missing in these charts and only OECD estimates (blue histograms) are provided.

Figure B.1. Australia[31]



31 Includes Australian overseas territories: Christmas Island, Cocos (Keeling) Islands and Norfolk Island.

Figure B.2. Austria

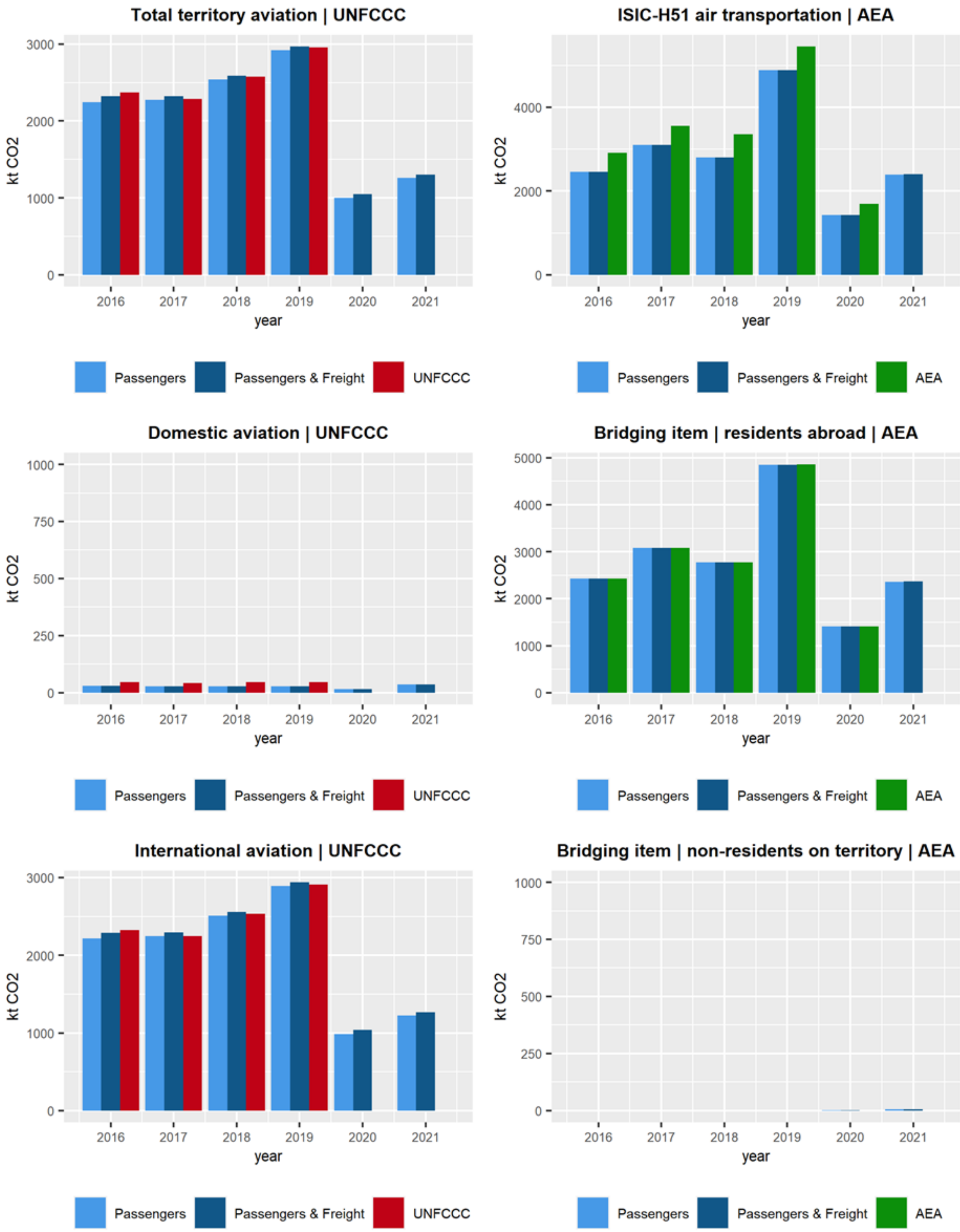


Figure B.3. Belarus

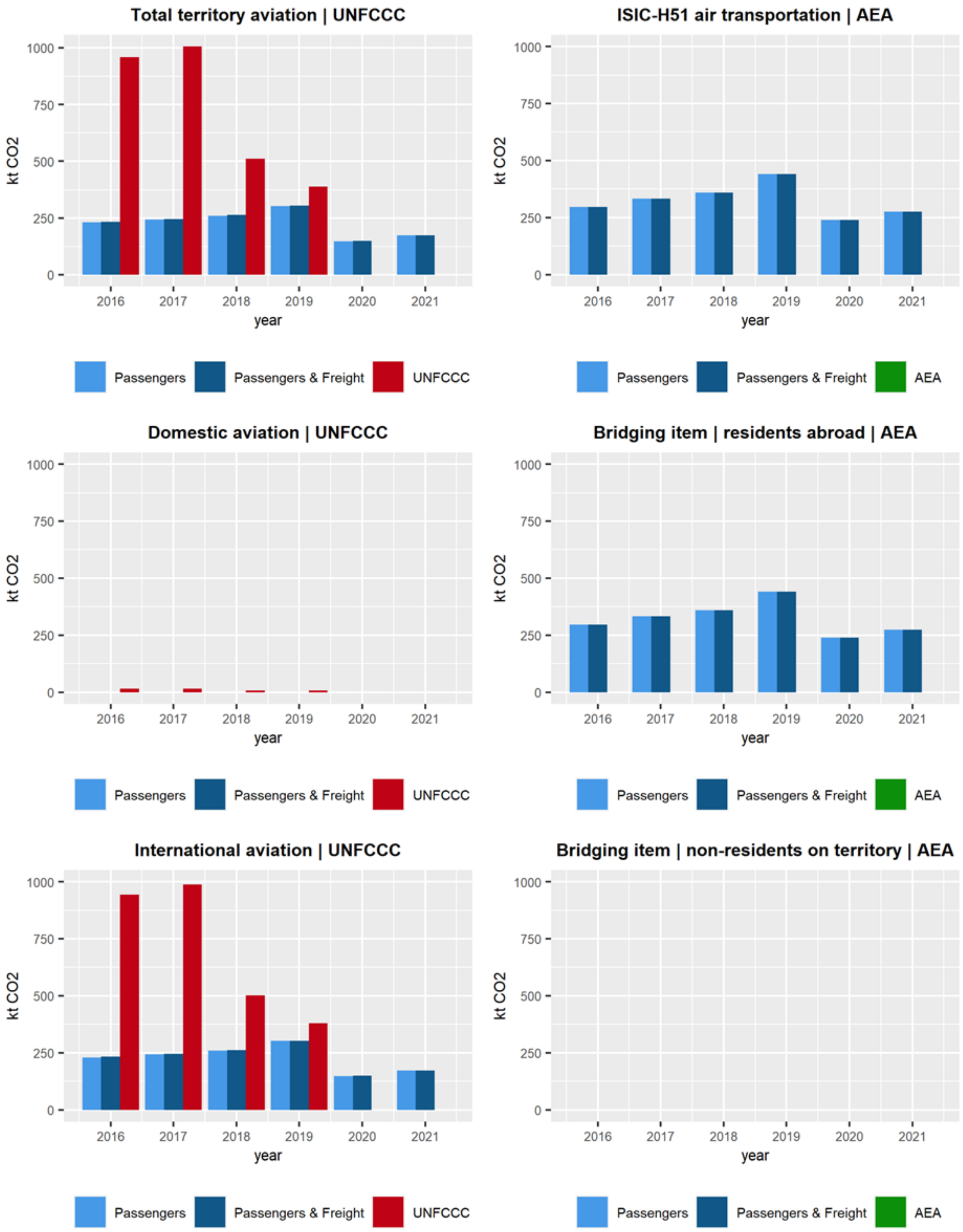


Figure B.4. Belgium

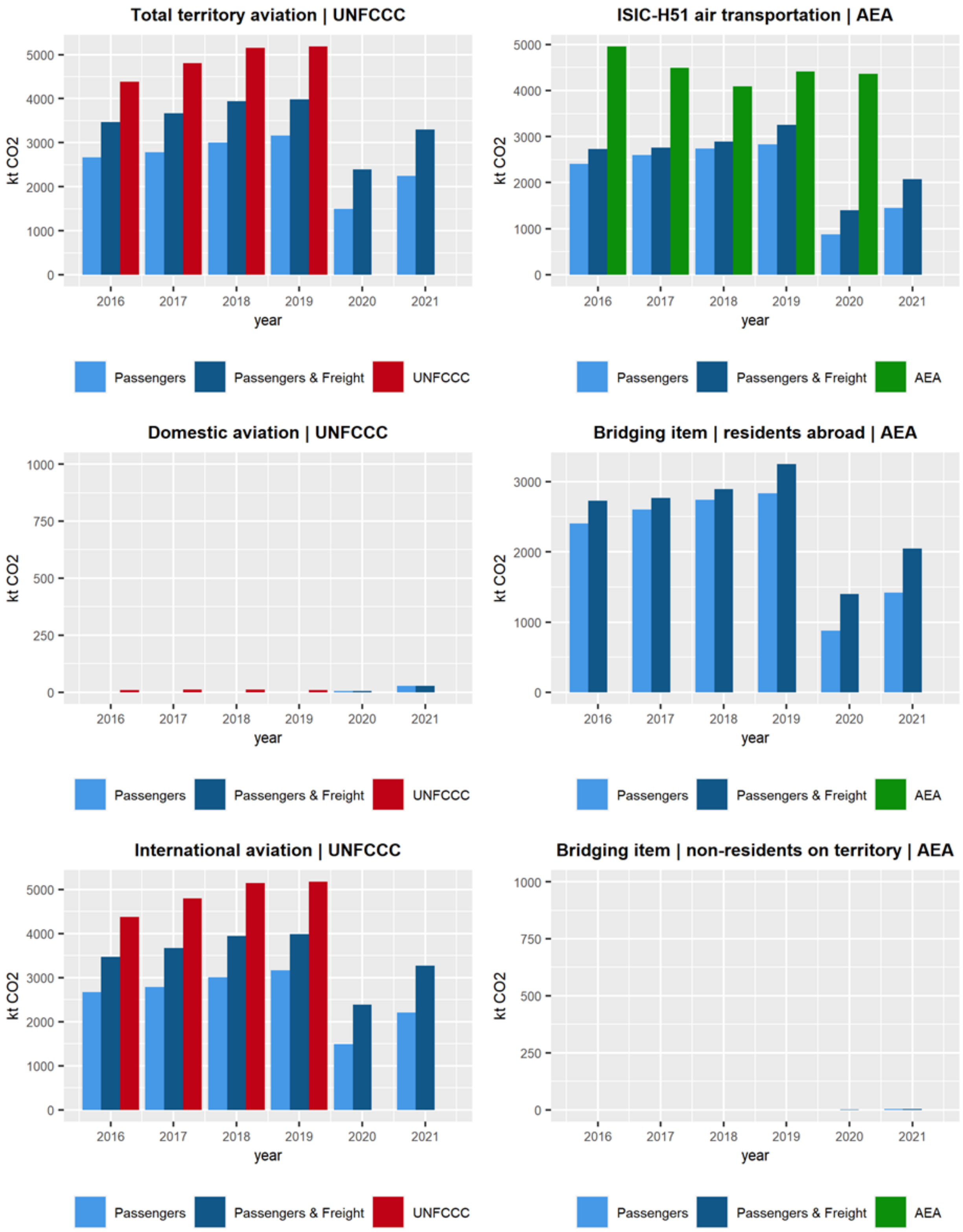


Figure B.5. Bulgaria

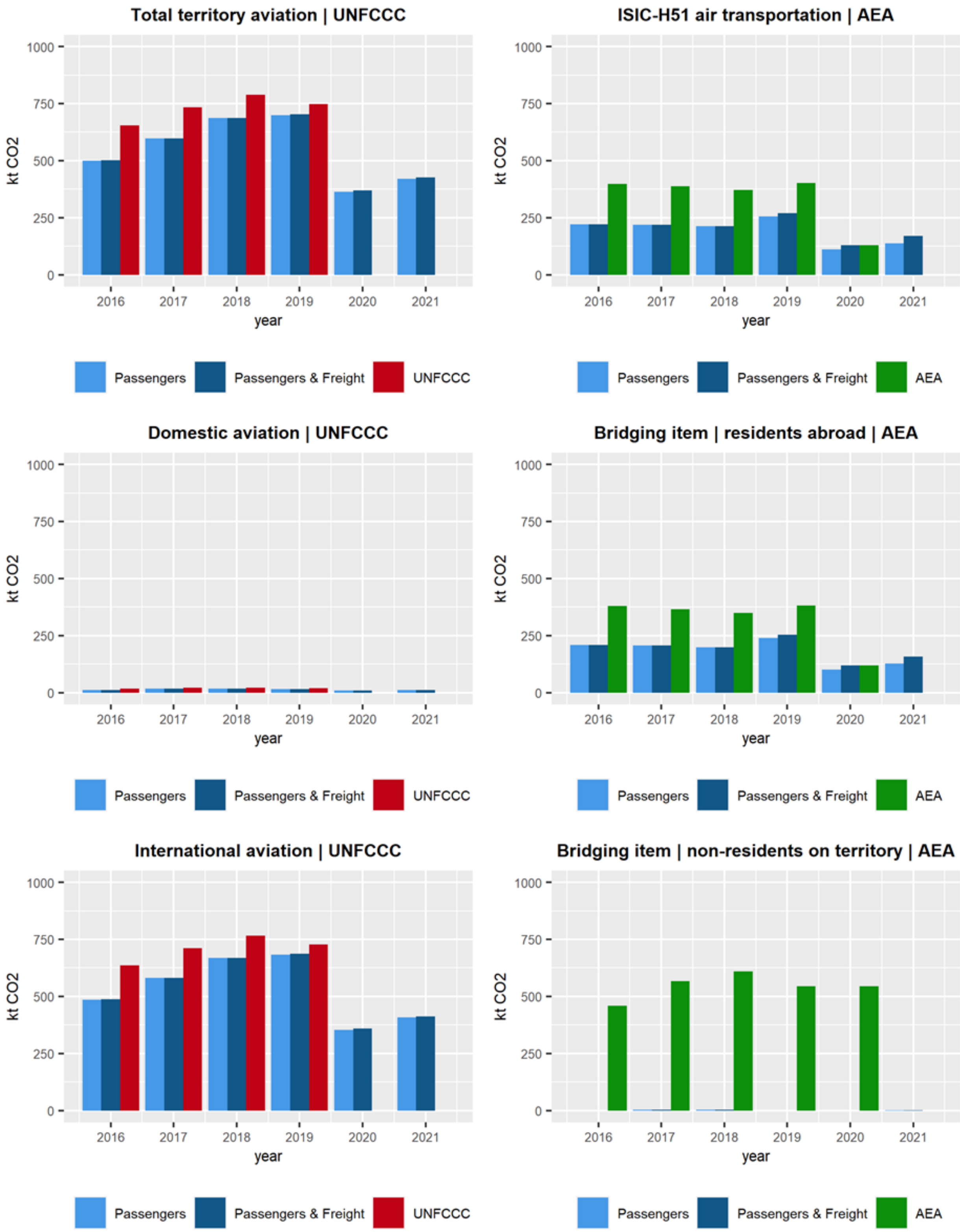


Figure B.6. Canada

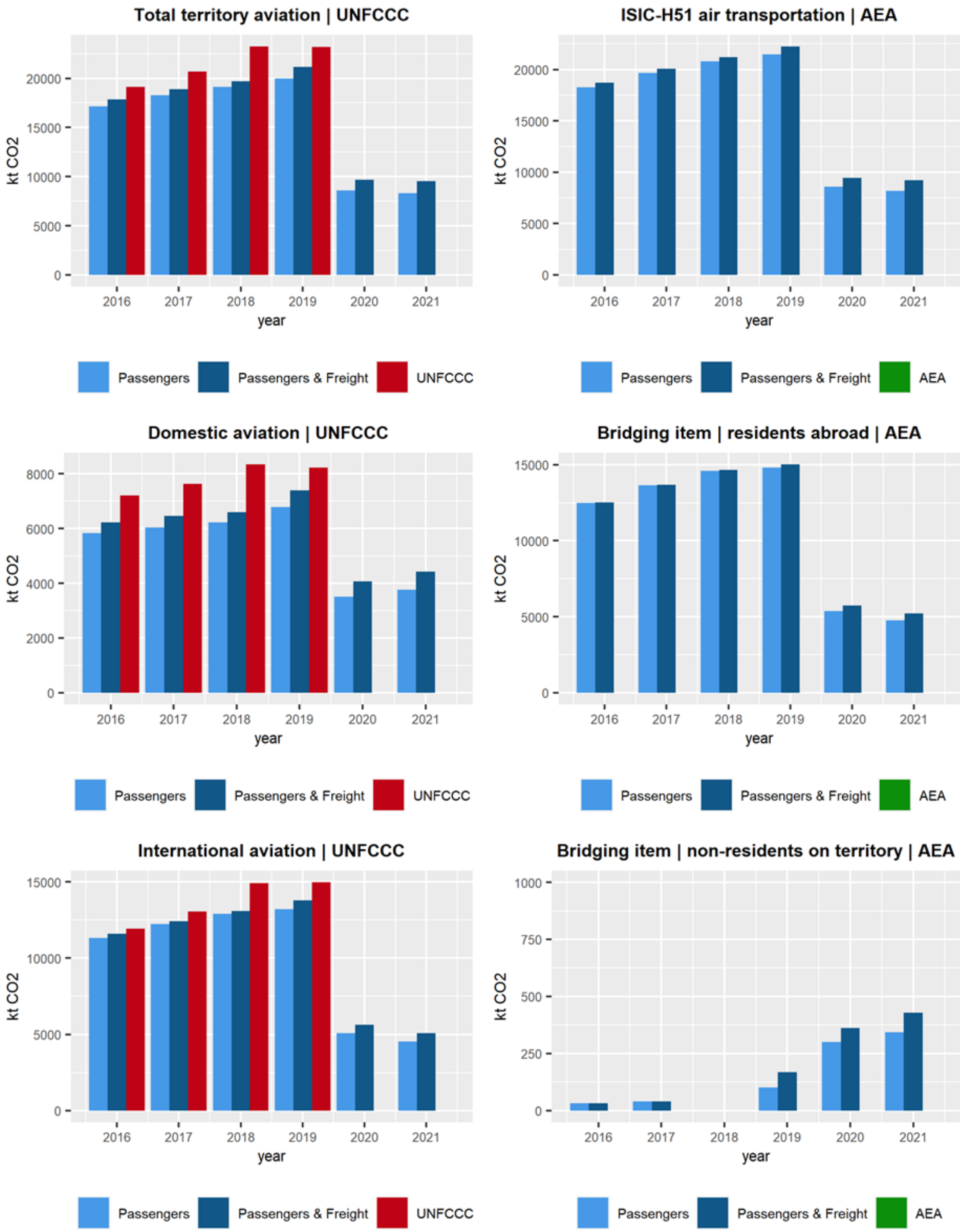


Figure B.7. Croatia

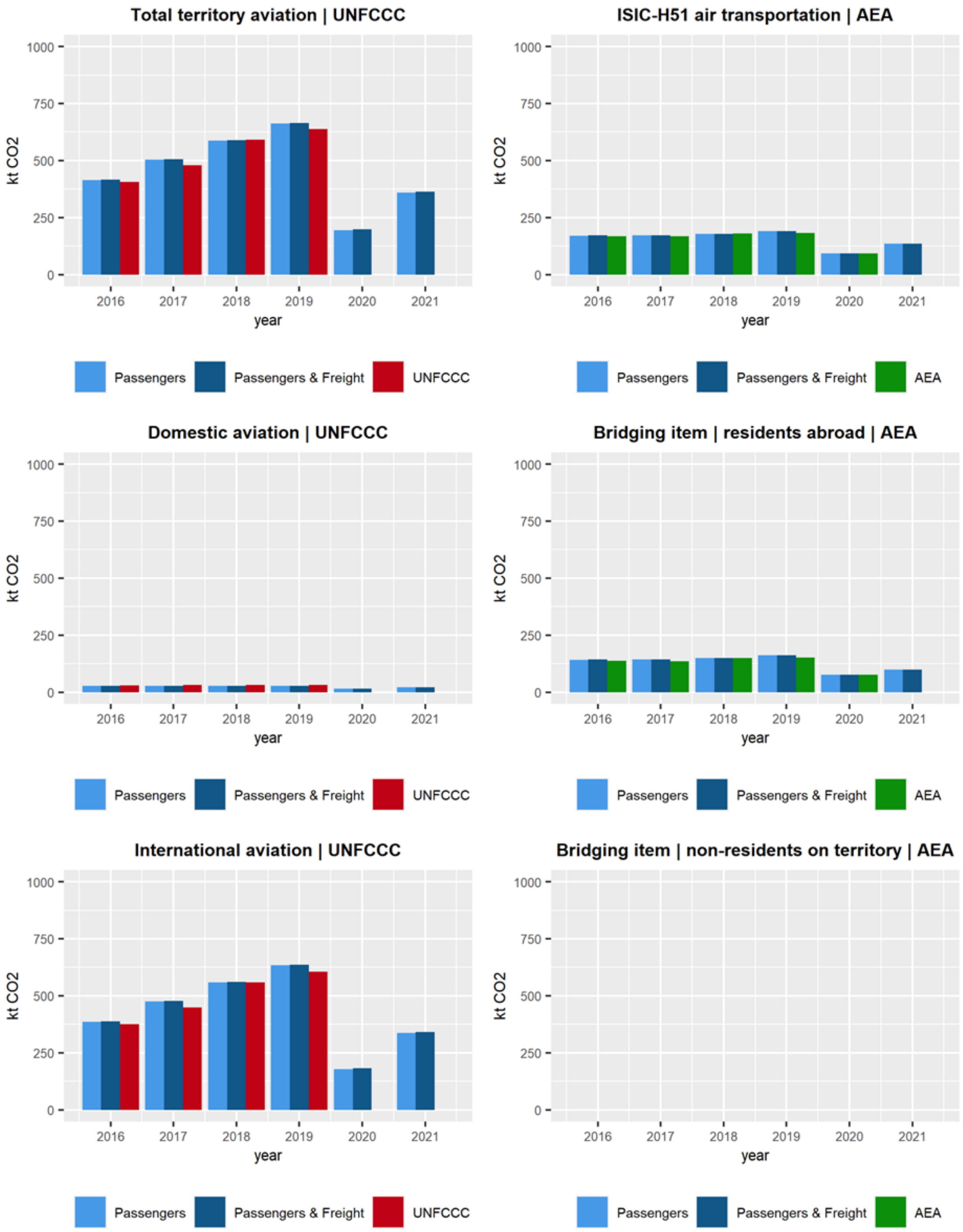


Figure B.8. Cyprus

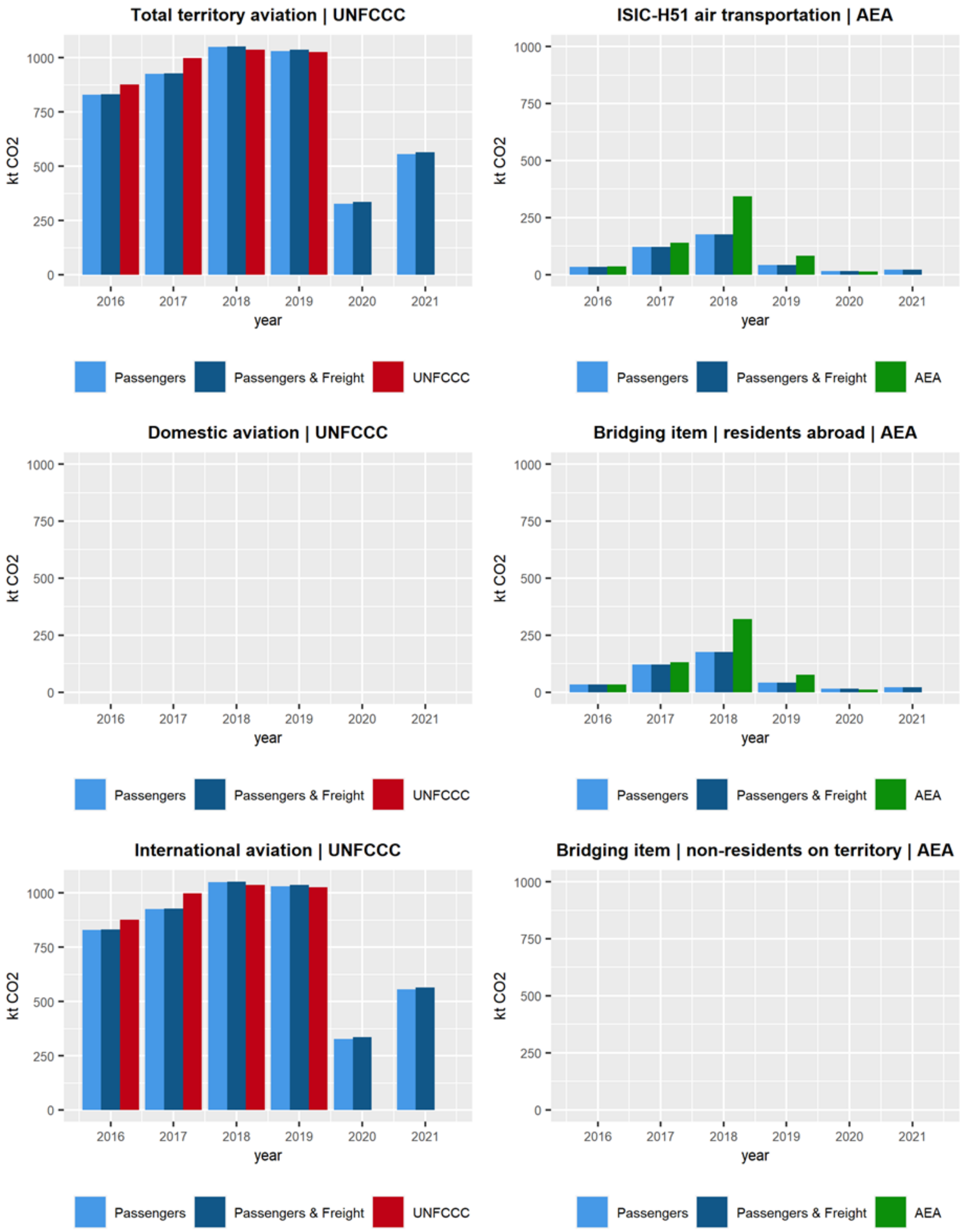


Figure B.9. Czech Republic

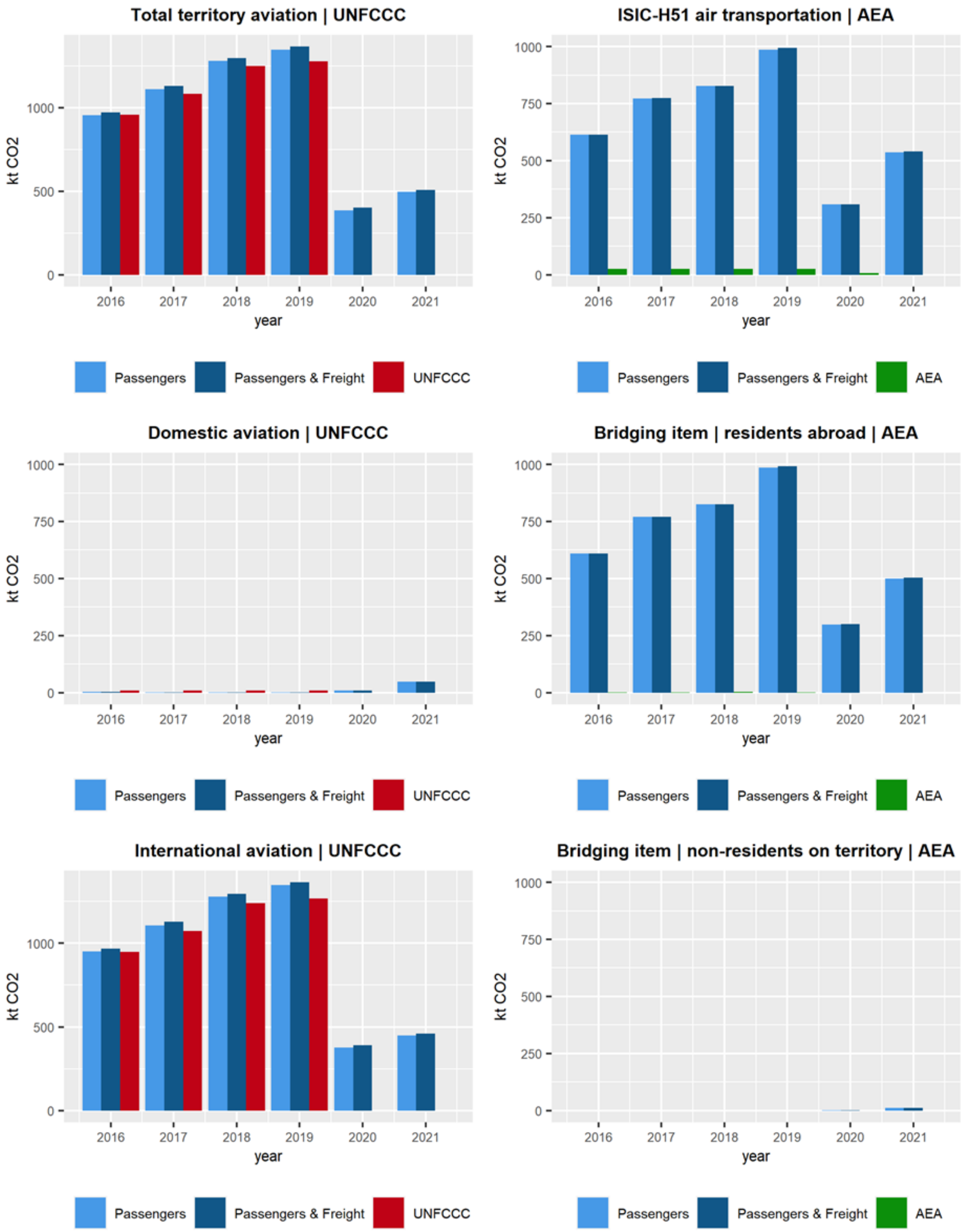
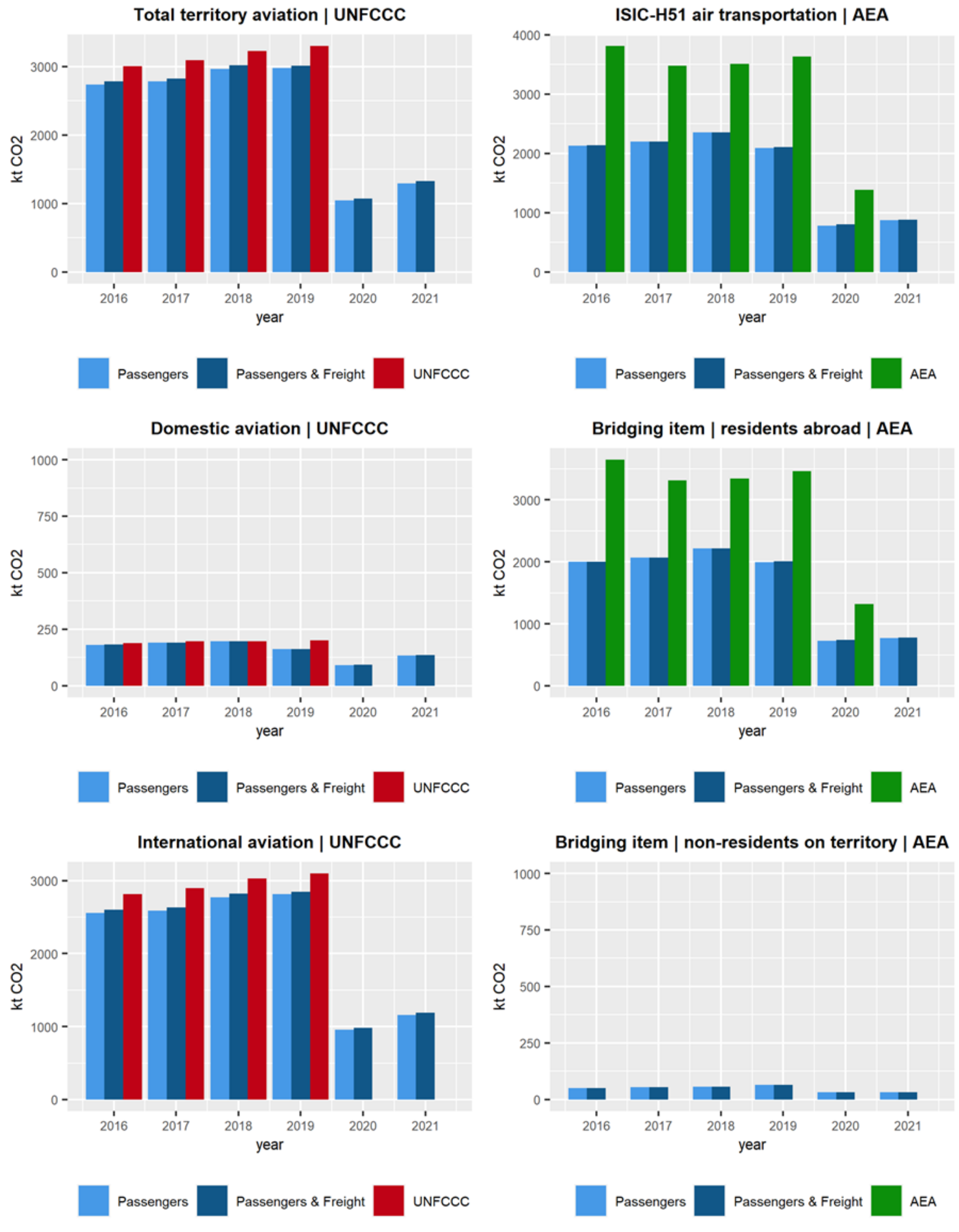


Figure B.10. Denmark[32]



[32] Includes Danish overseas territories: Faroe Islands and Greenland.

Figure B.11. Estonia

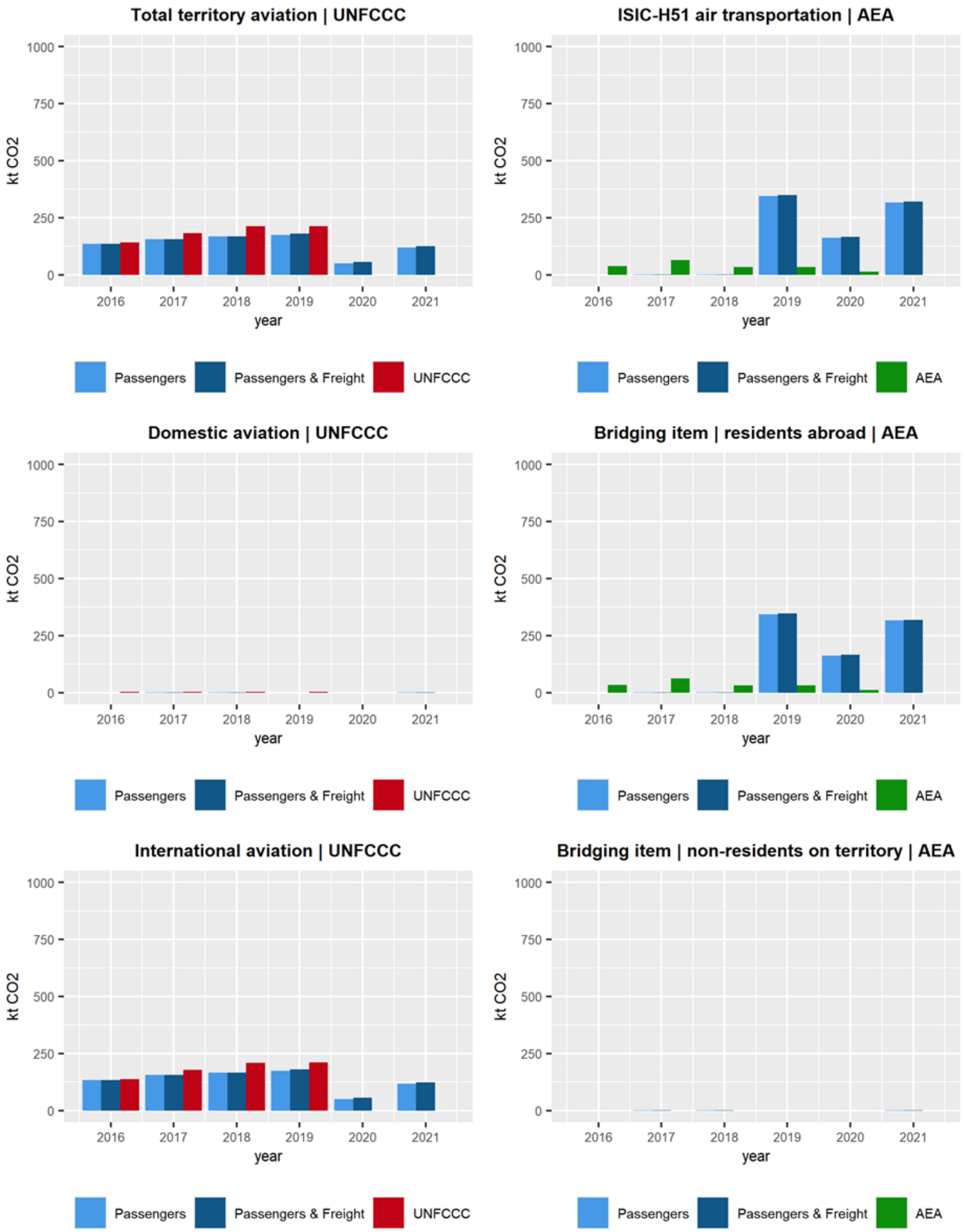


Figure B.12. Finland

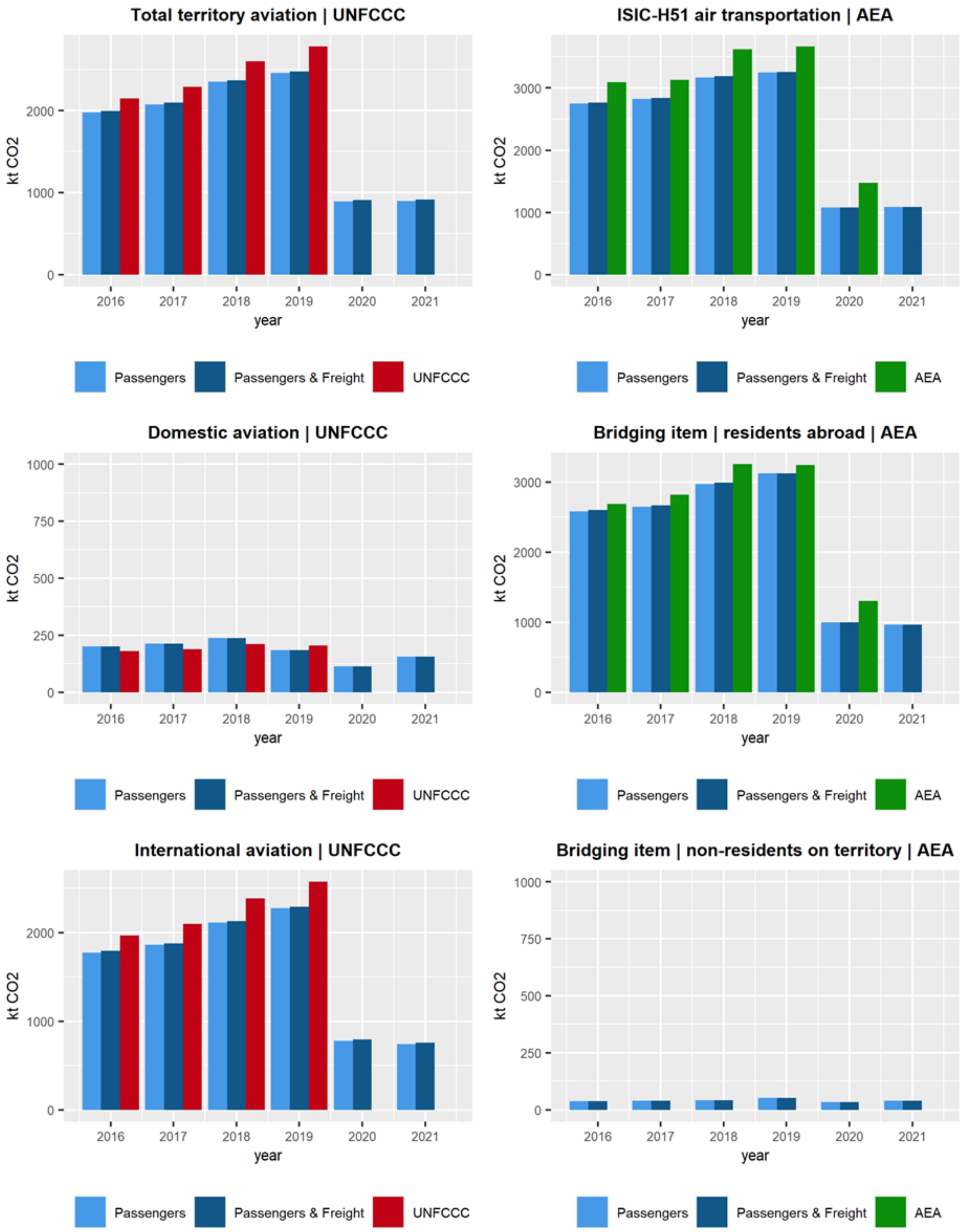
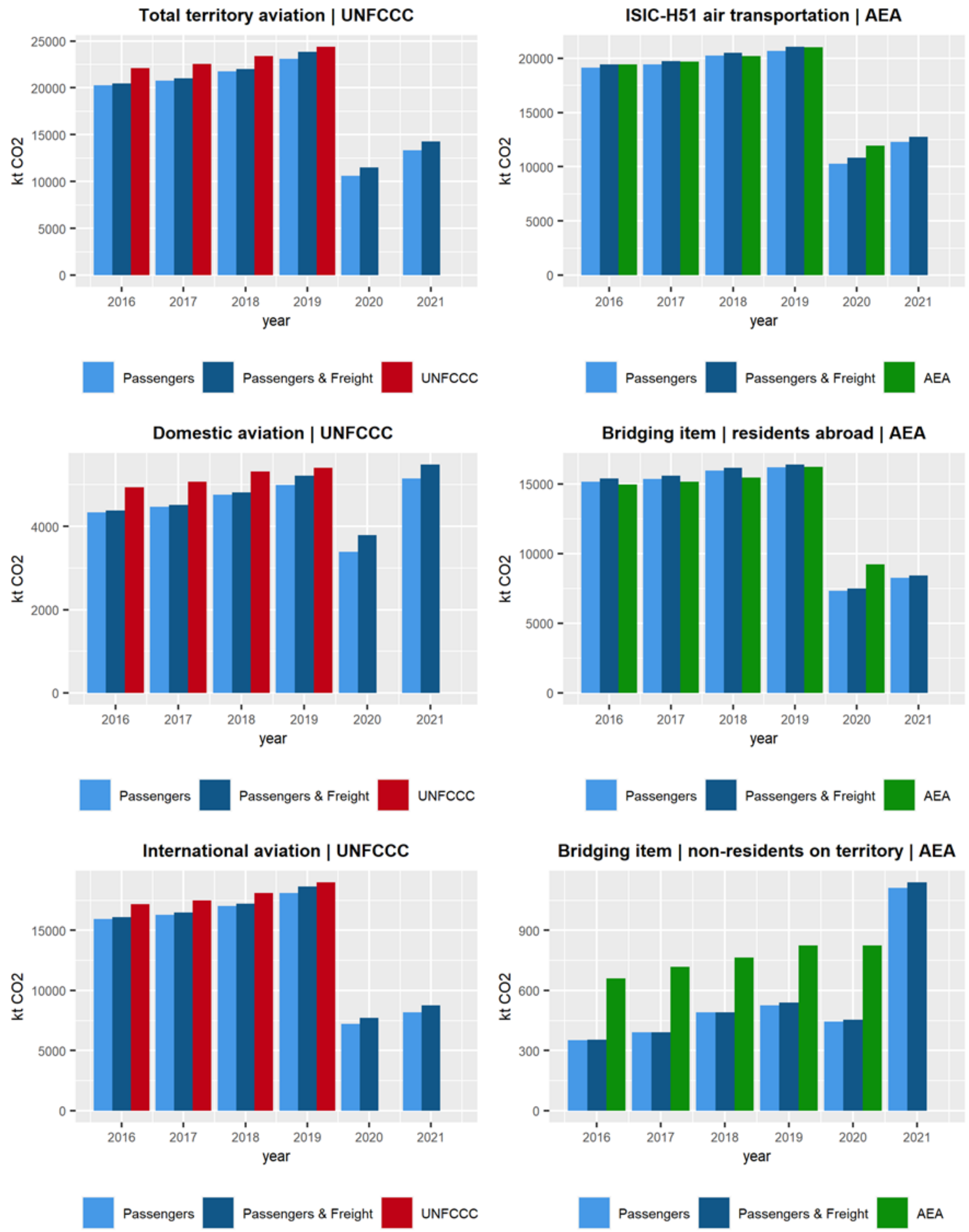


Figure B.13. France[33]



33 Includes French overseas territories: French Guiana, French Polynesia, Guadeloupe, Martinique, Mayotte, New Caledonia, Reunion, Saint Barthélemy, Saint Martin (French part), Saint Pierre and Miquelon, and Wallis and Futuna.

Figure B.14. Germany

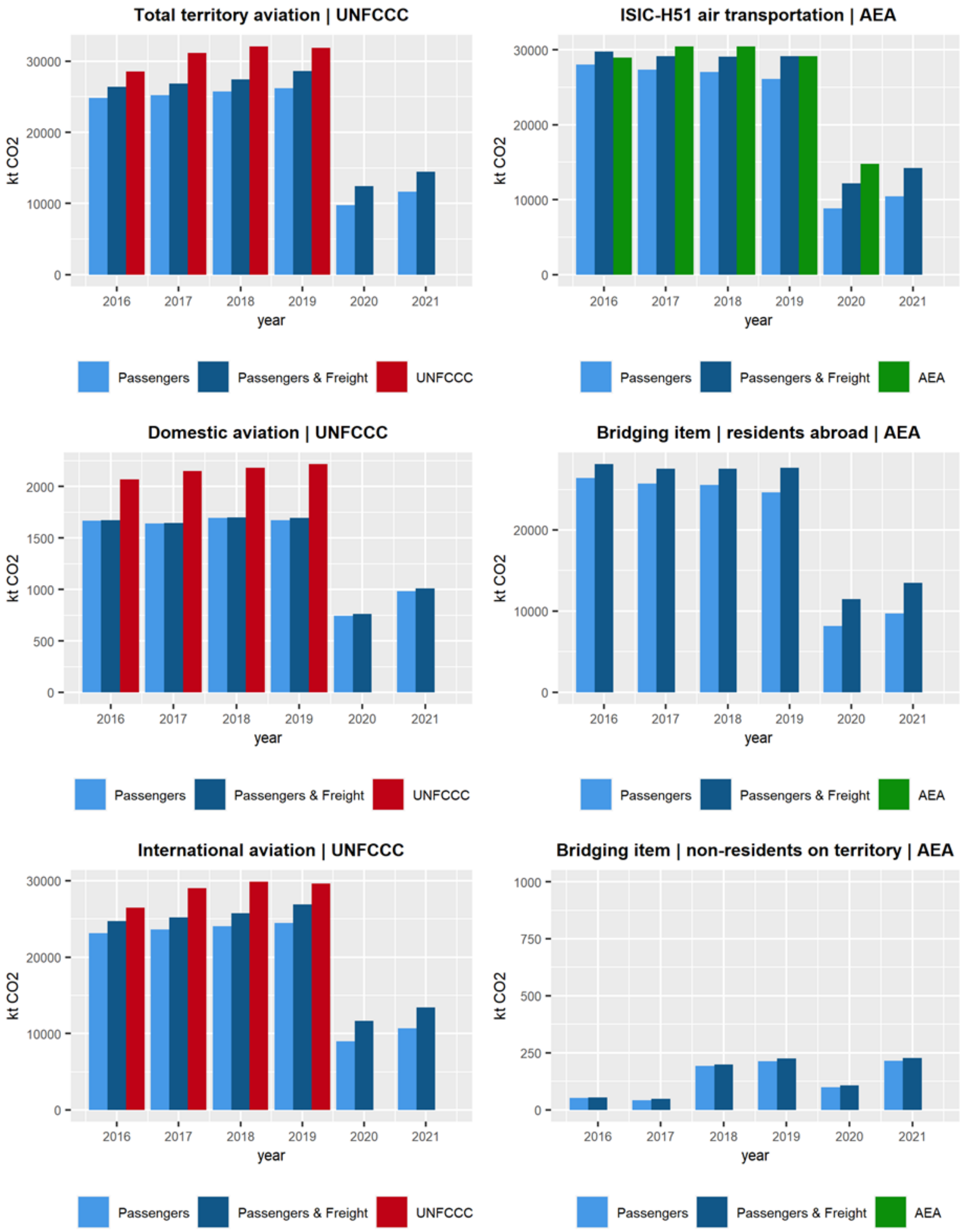


Figure B.15. Greece

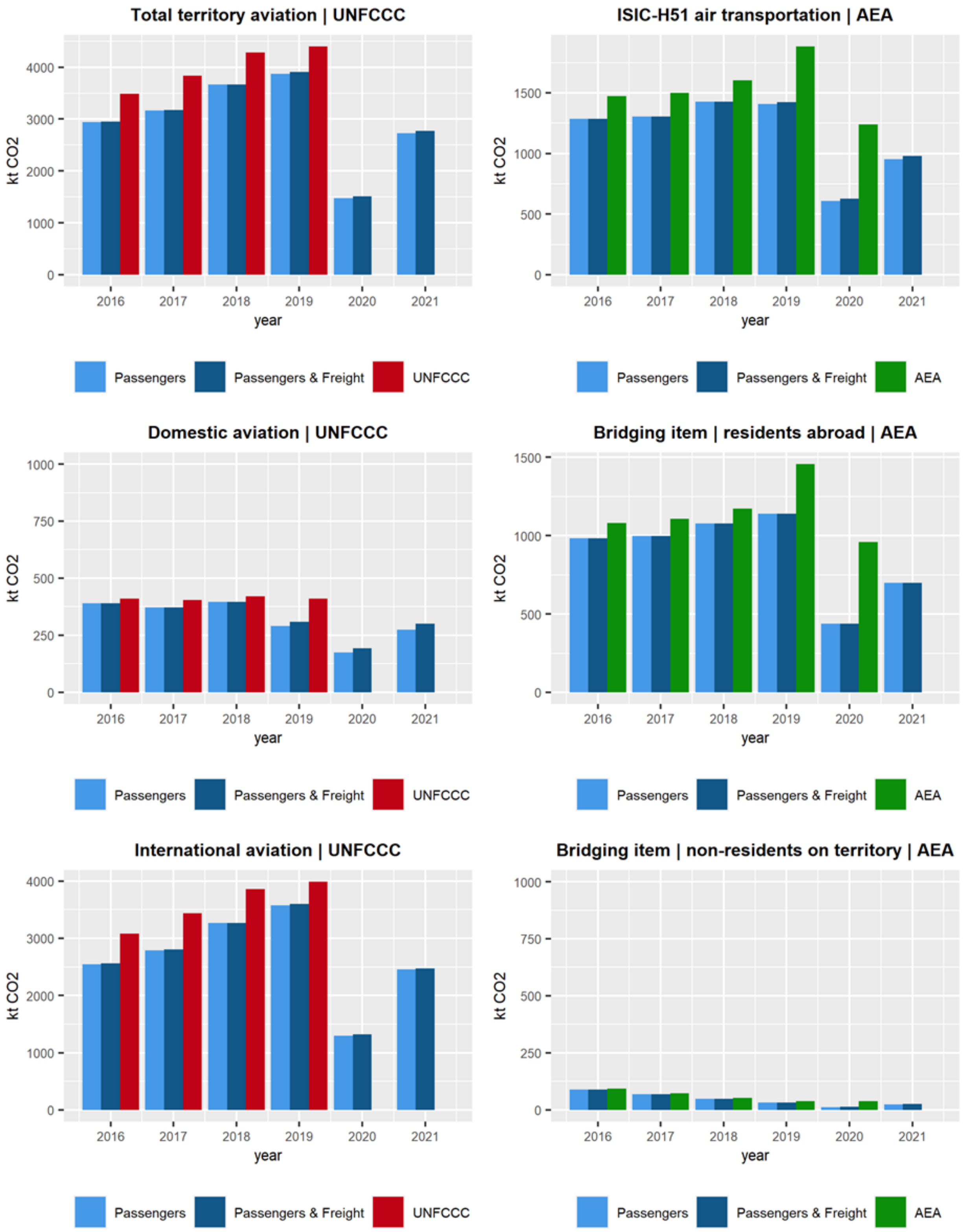


Figure B.16. Hungary

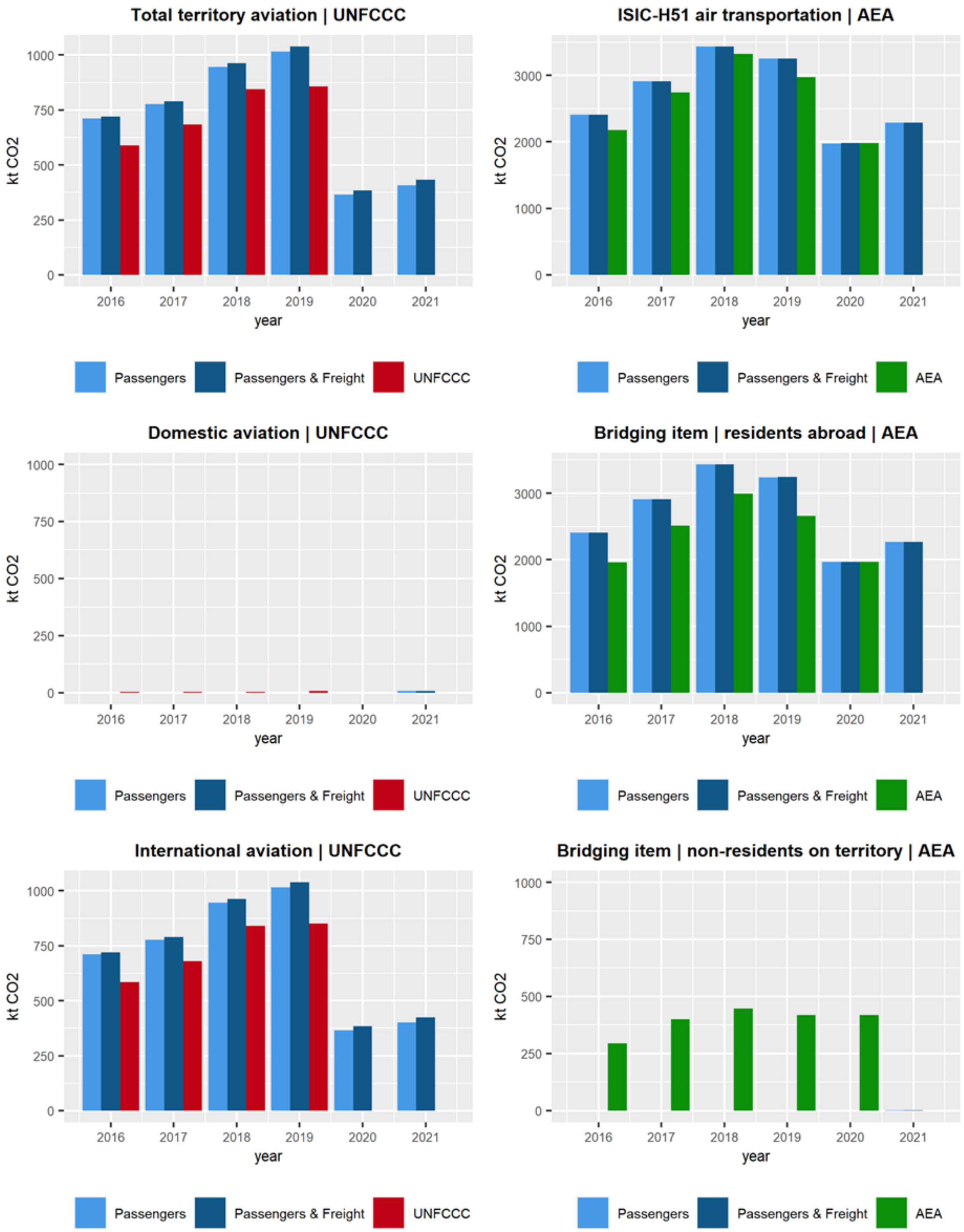


Figure B.17. Iceland

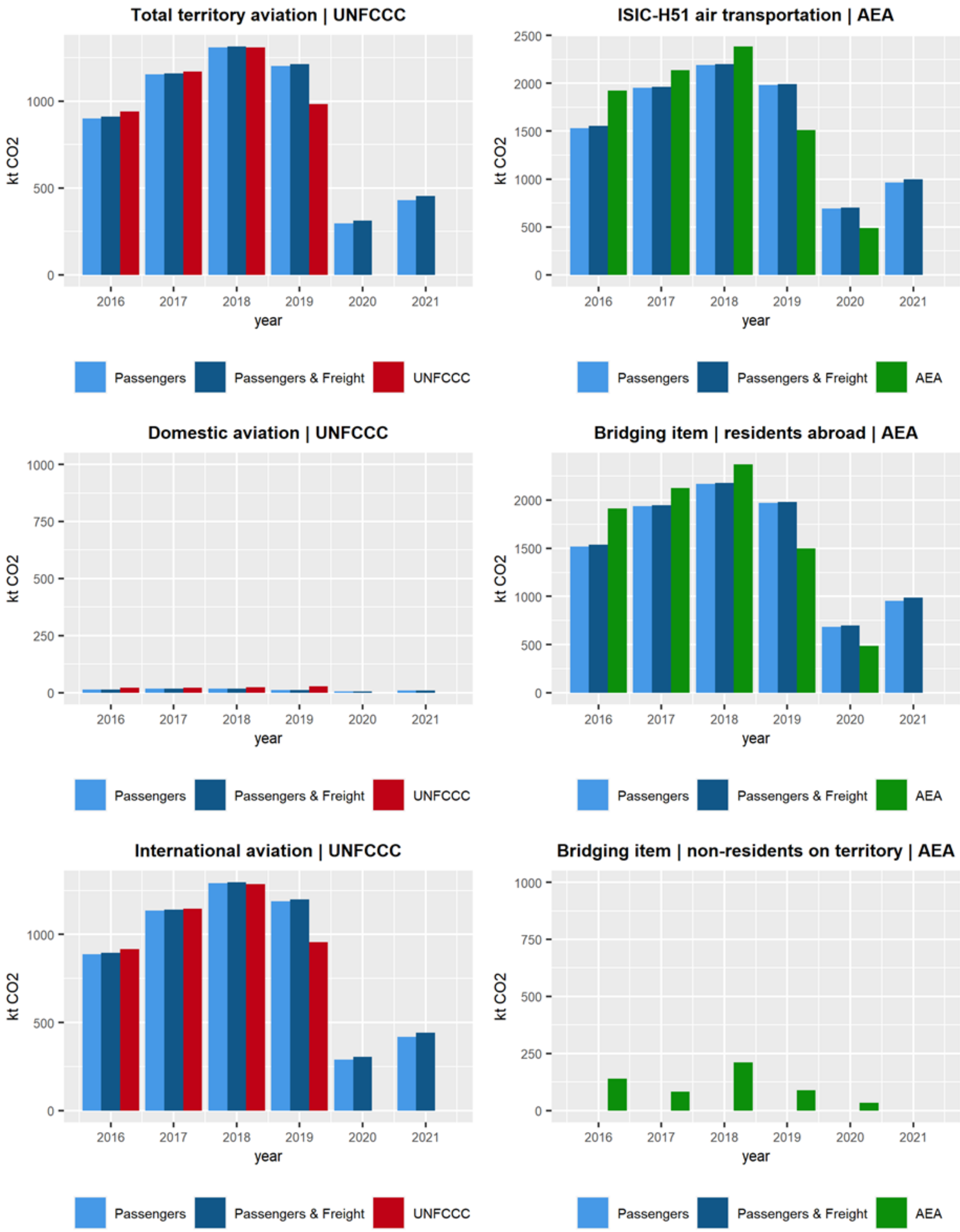


Figure B.18. Ireland

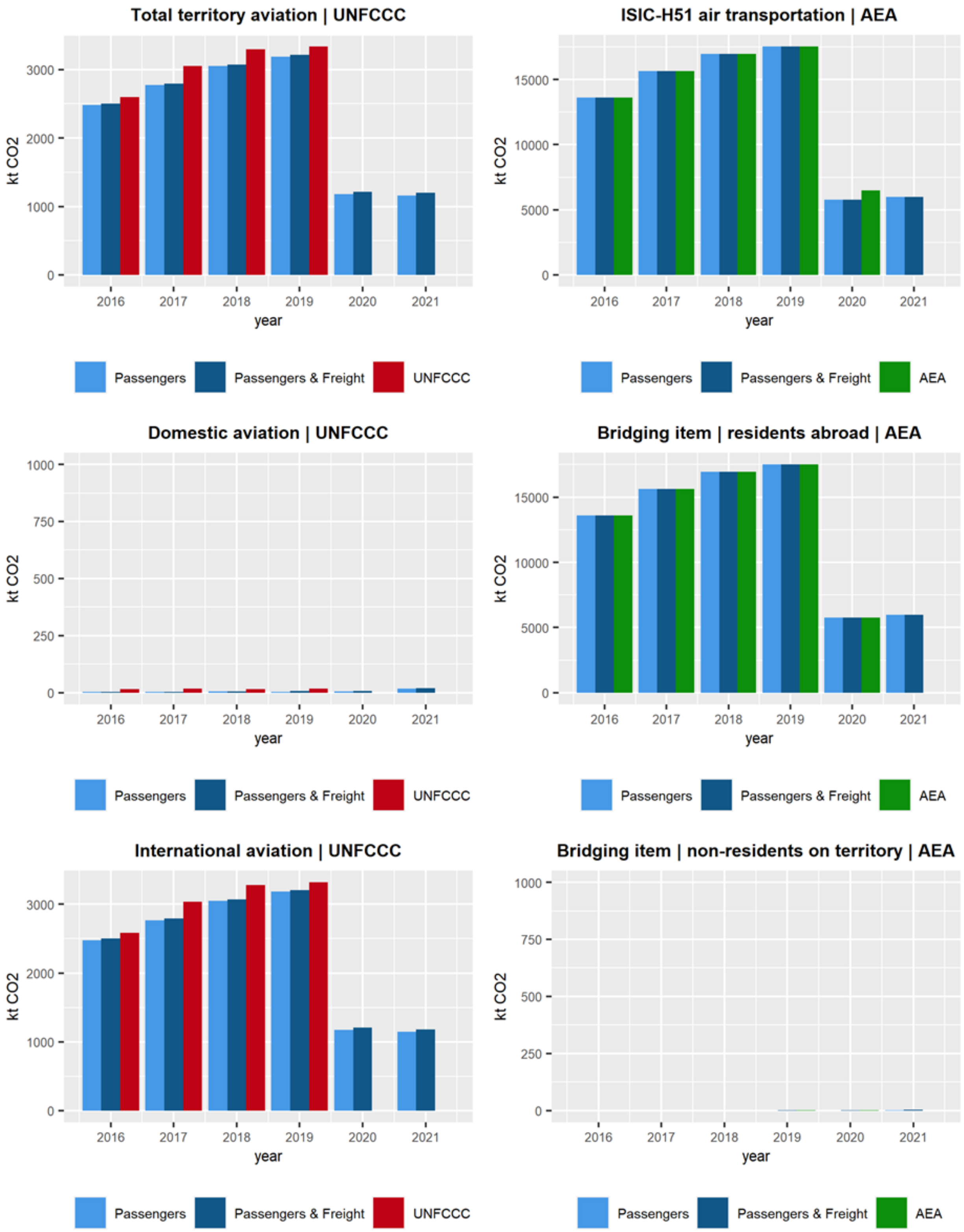


Figure B.19. Italy

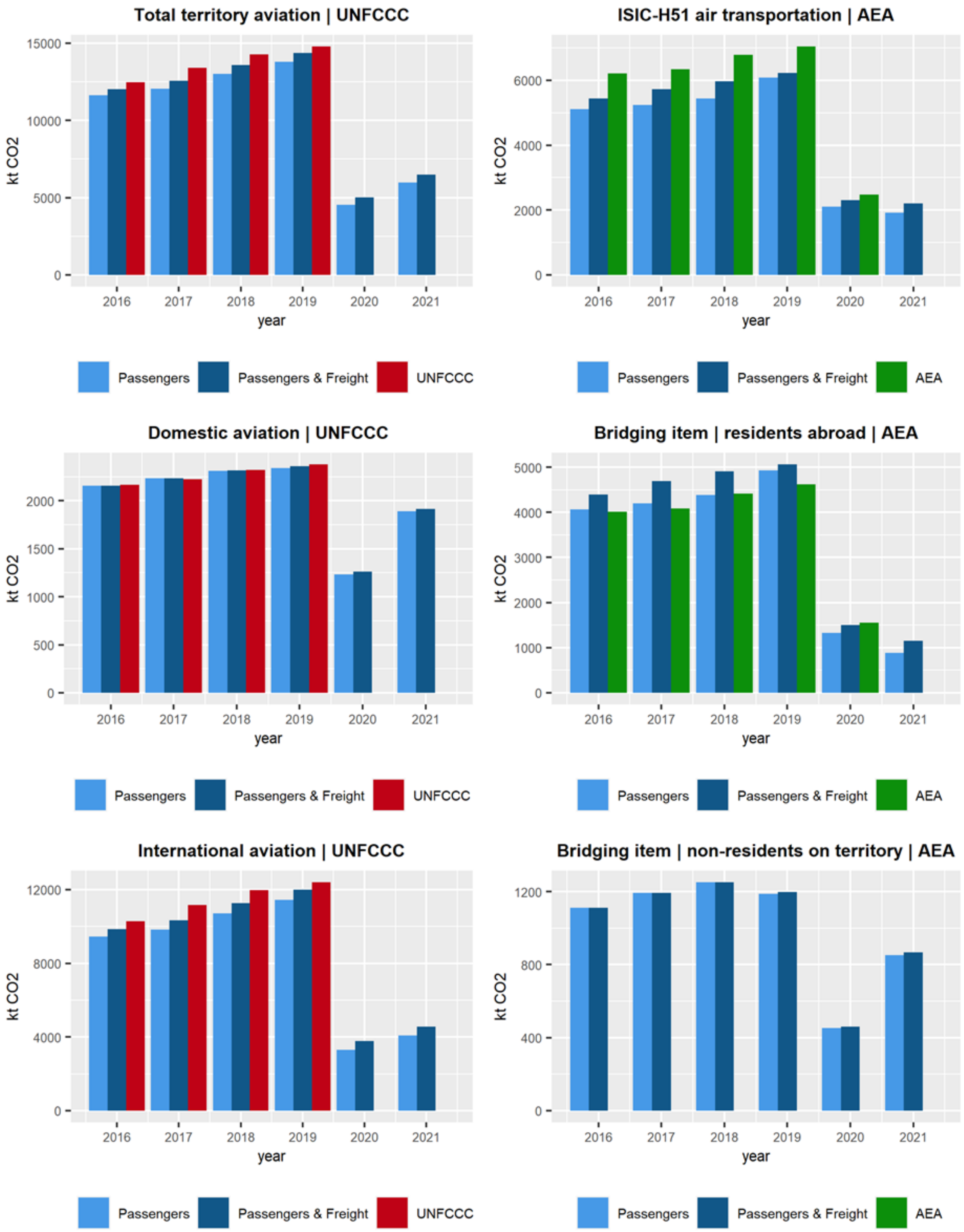


Figure B.20. Japan

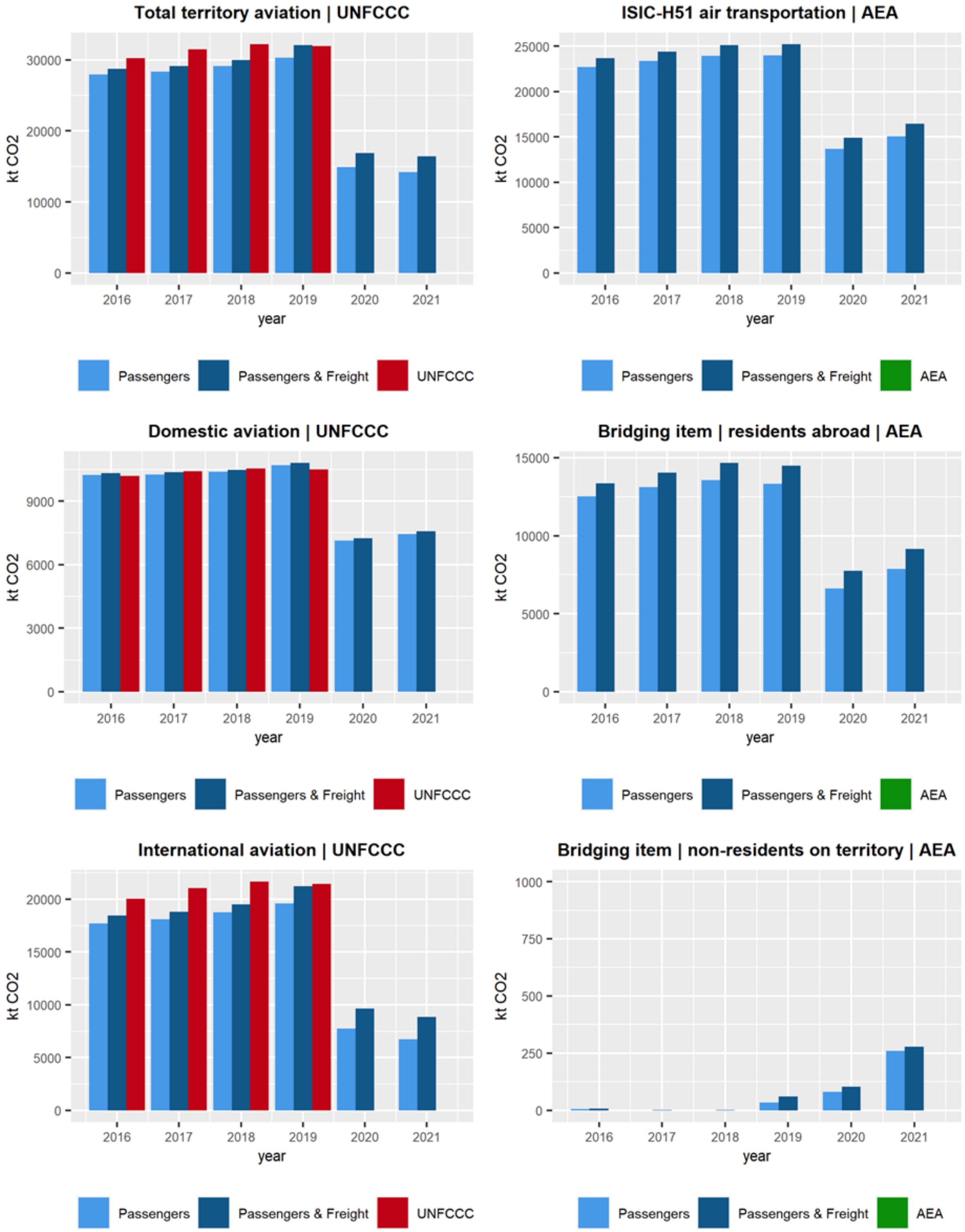


Figure B.21. Kazakhstan

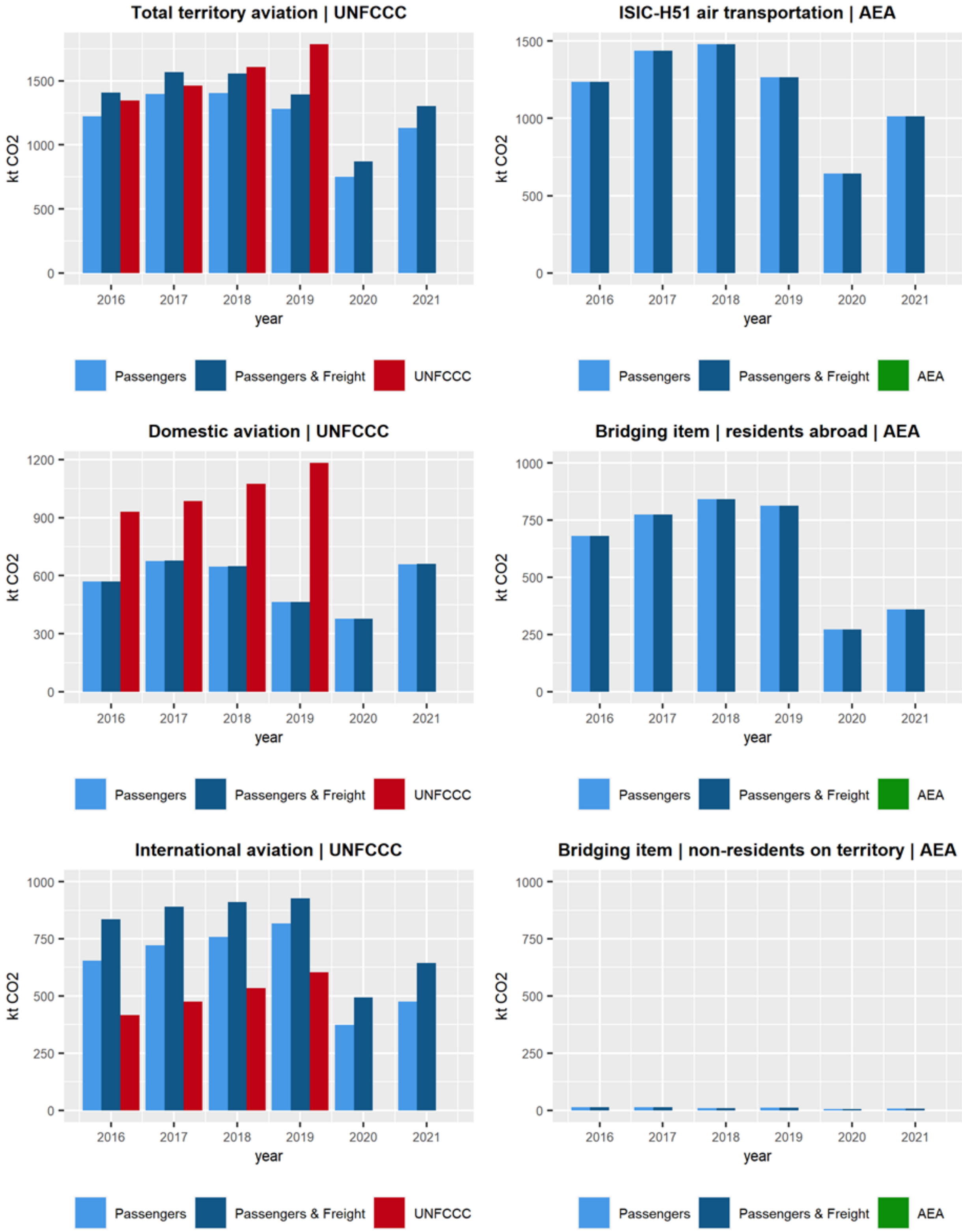


Figure B.22. Latvia

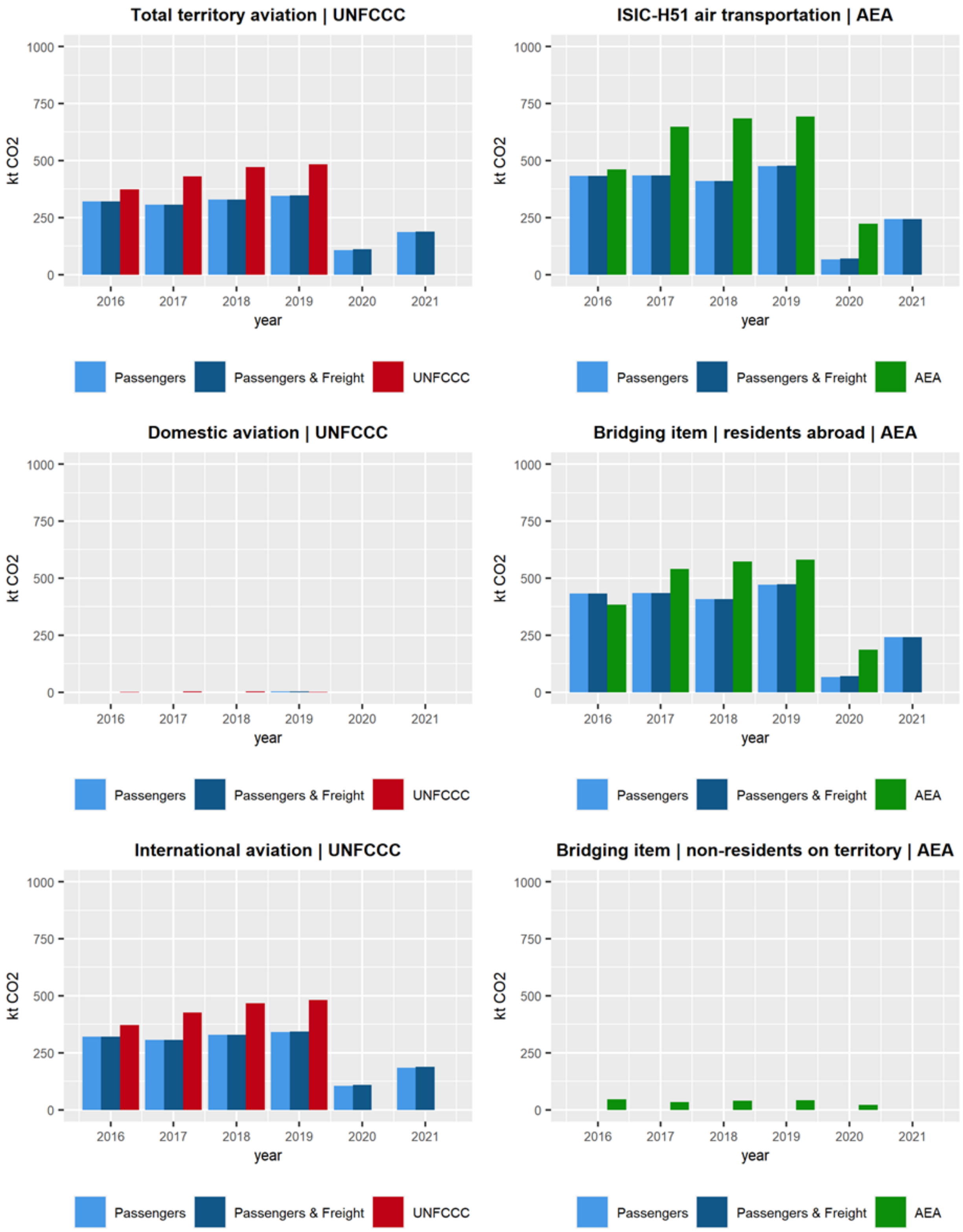


Figure B.23. Lithuania

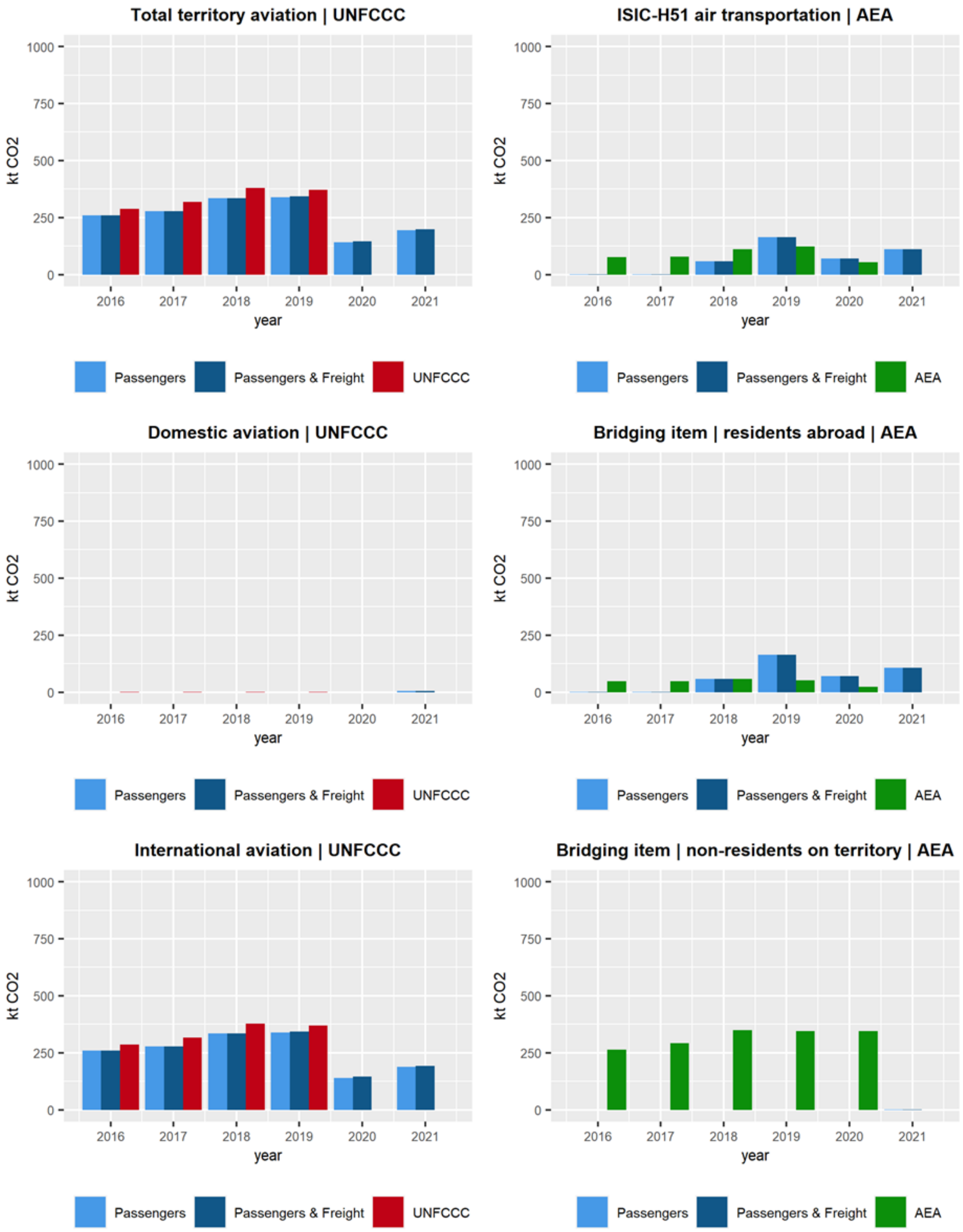


Figure B.24. Luxembourg

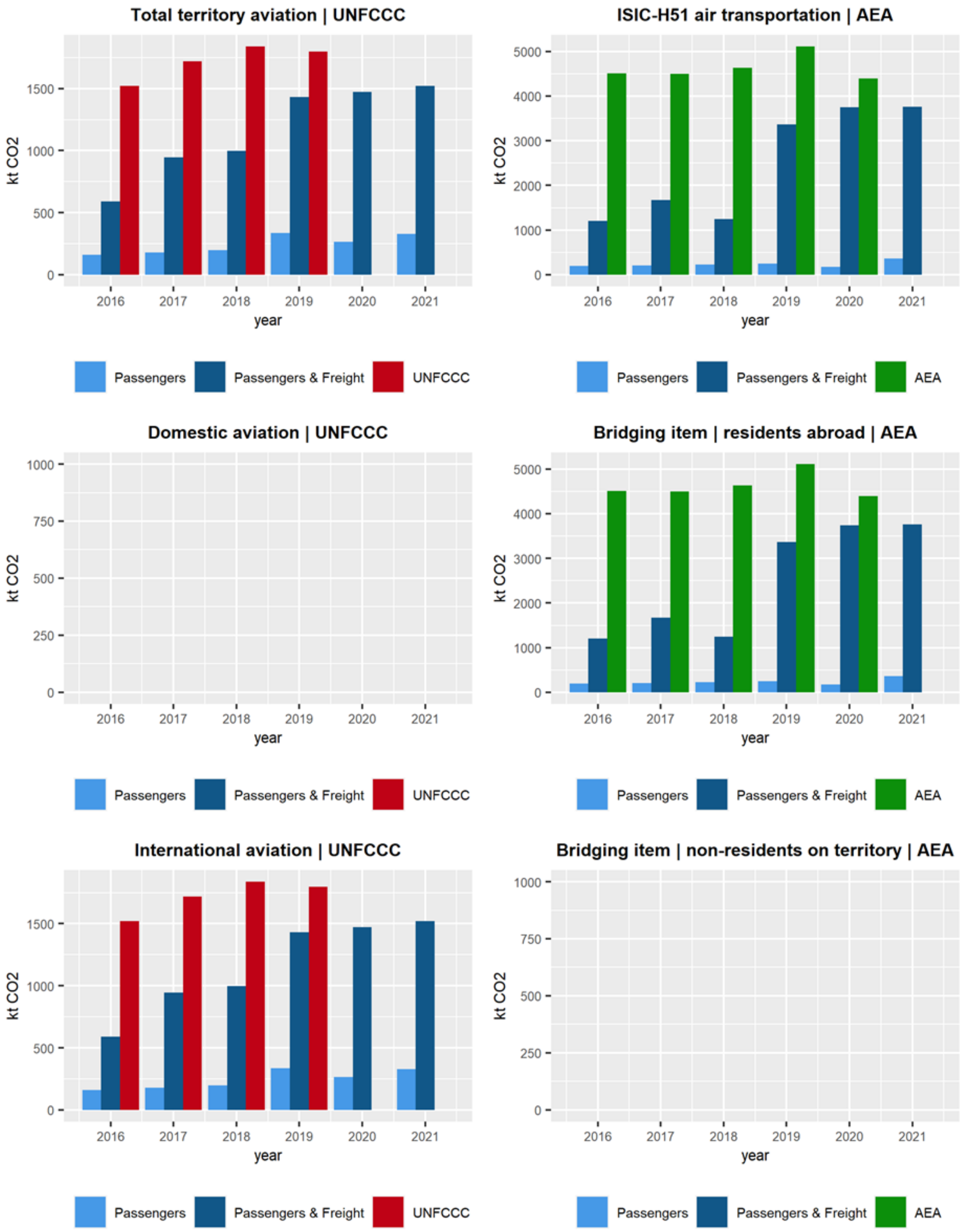


Figure B.25. Malta

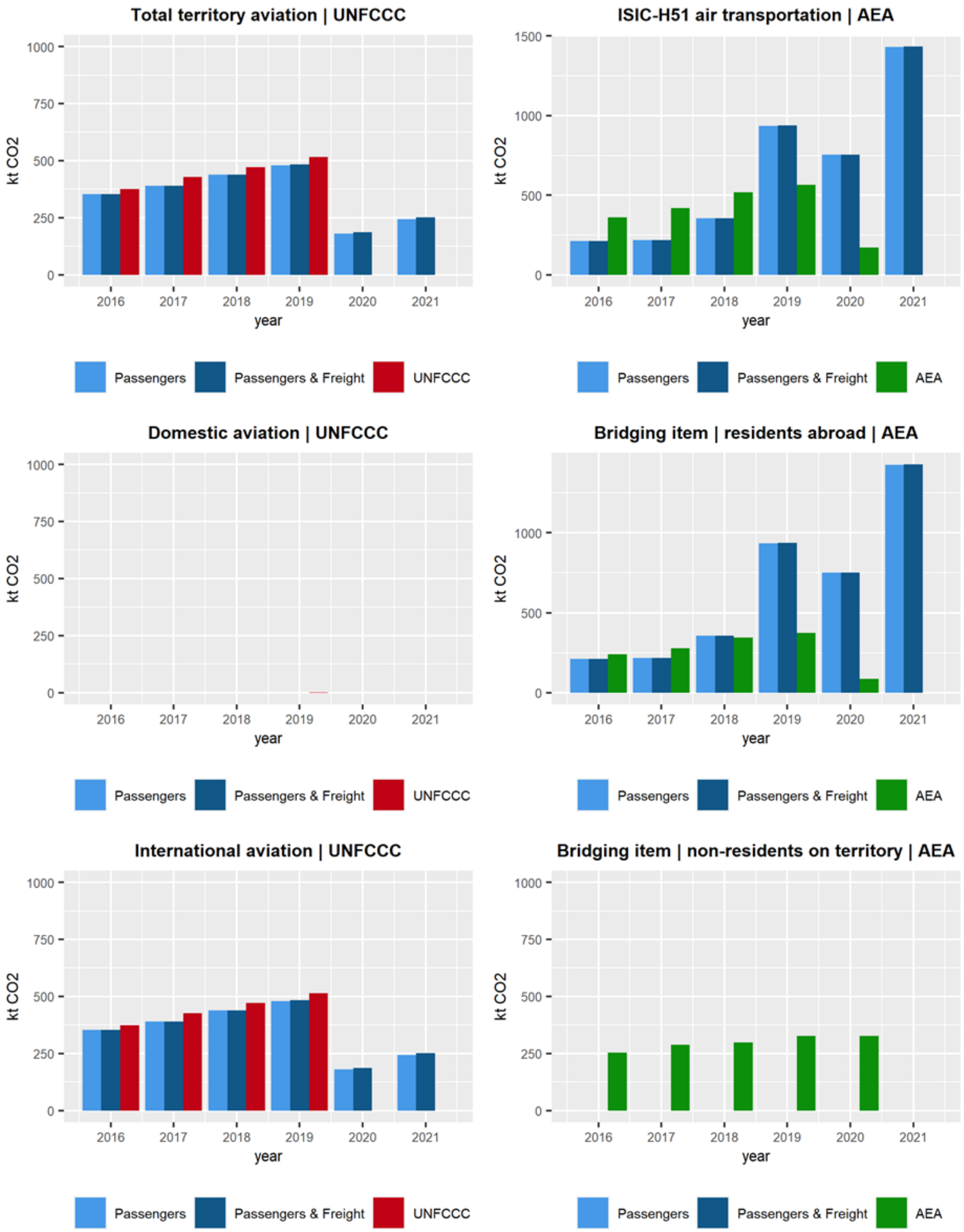
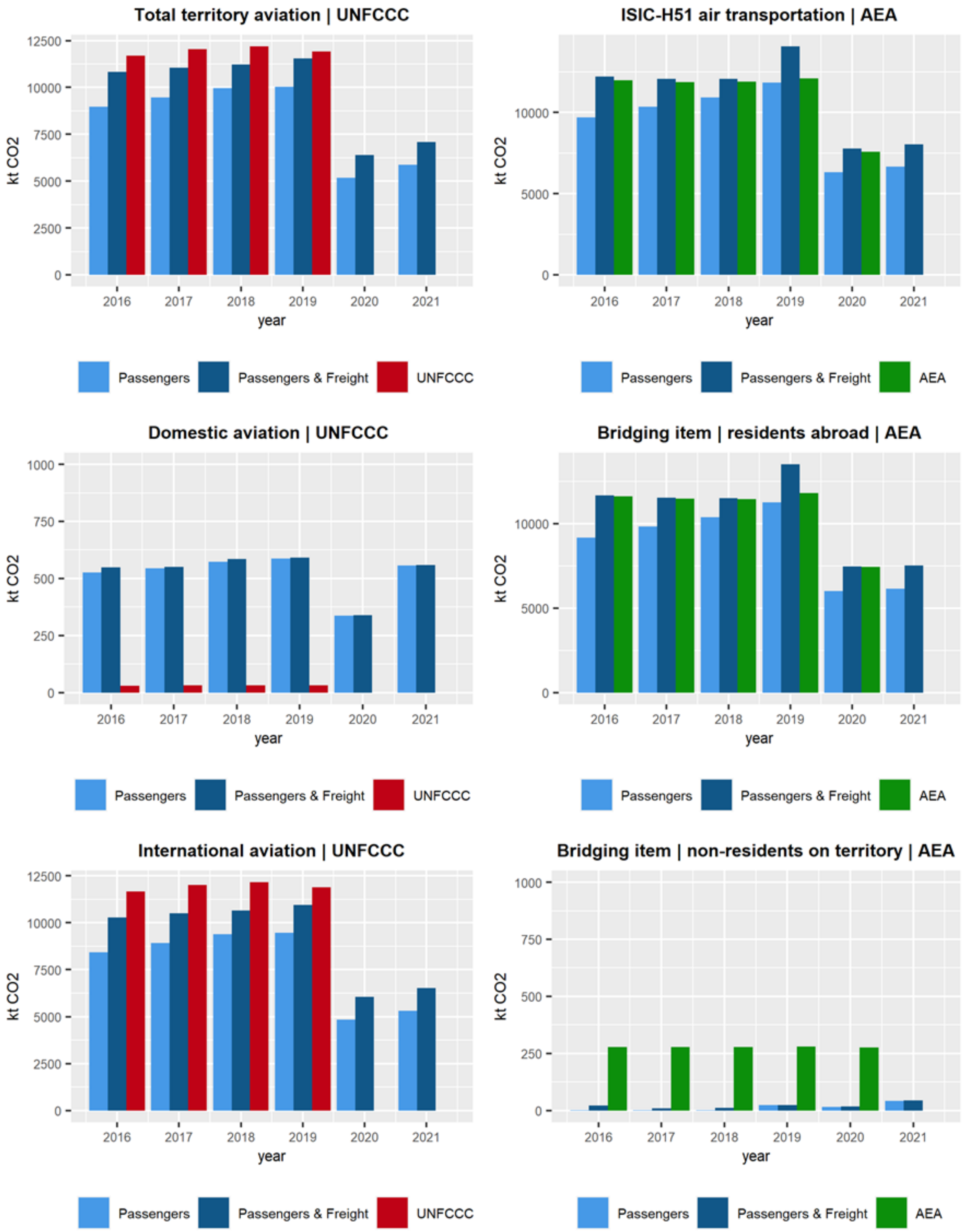


Figure B.26. Netherlands[34]



[34] Includes Dutch overseas territories: Aruba, Bonaire, Saint Eustatius and Saba, Curacao and St Maarten (Dutch Part).

Figure B.27. New Zealand

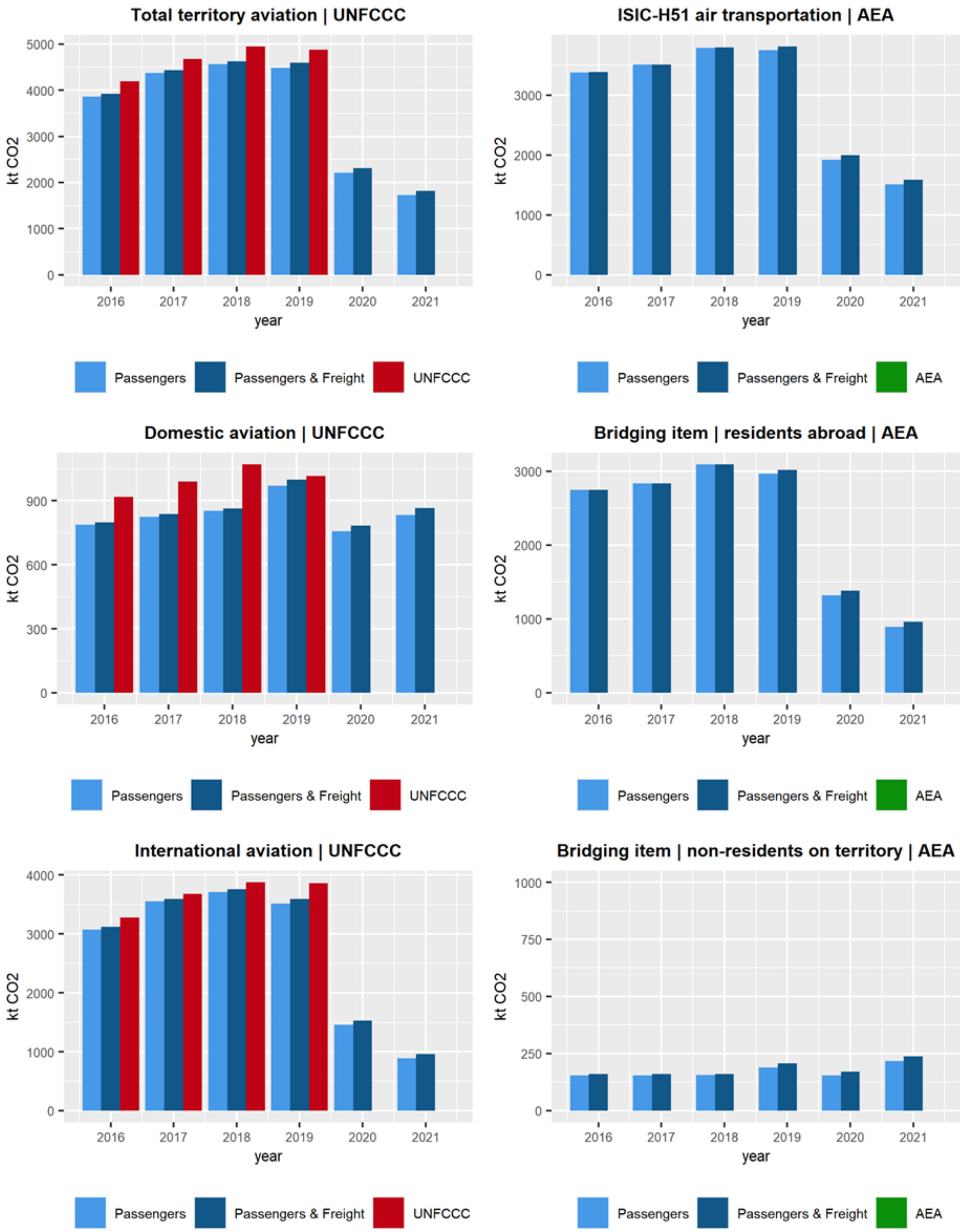


Figure B.28. Norway

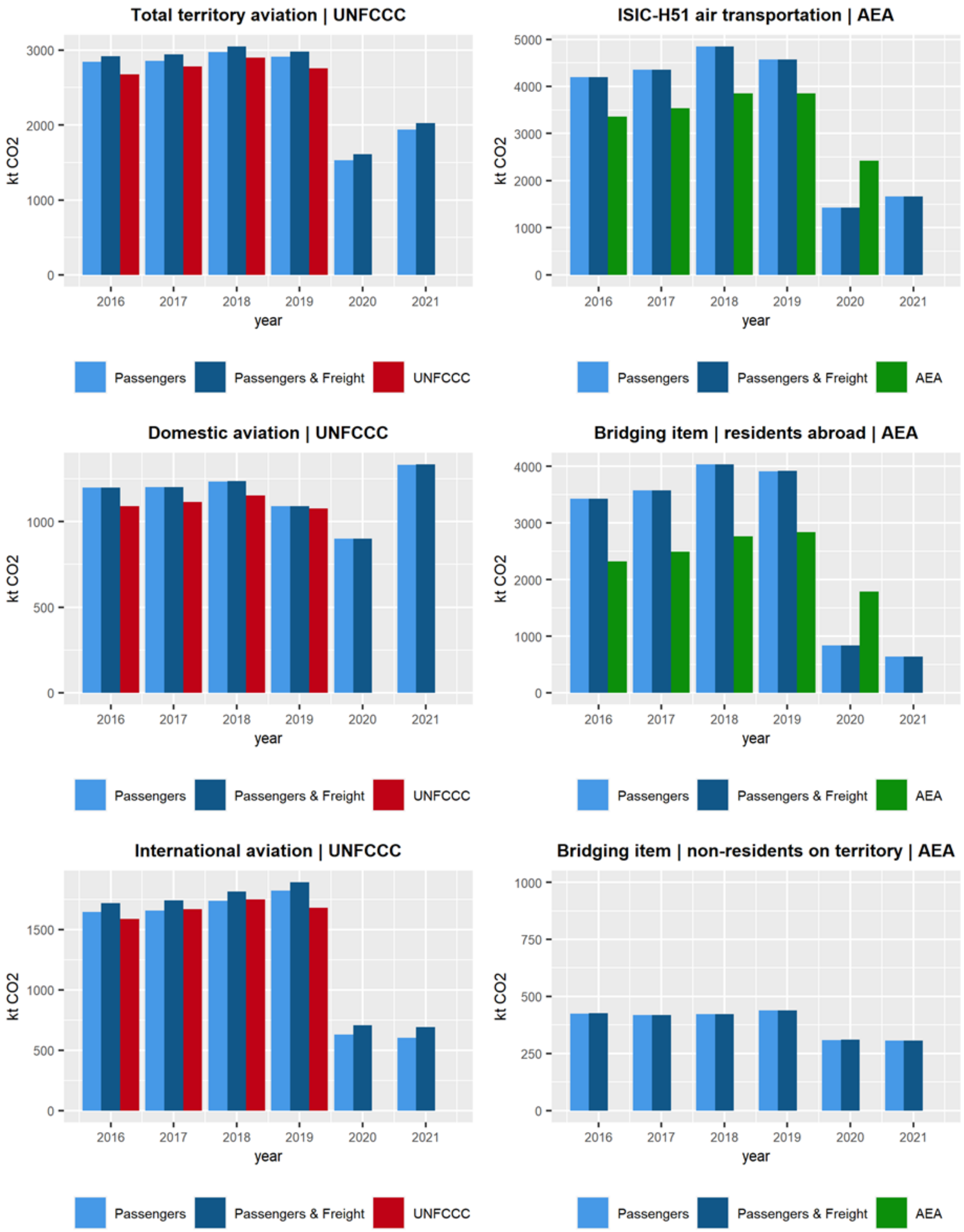


Figure B.29. Poland

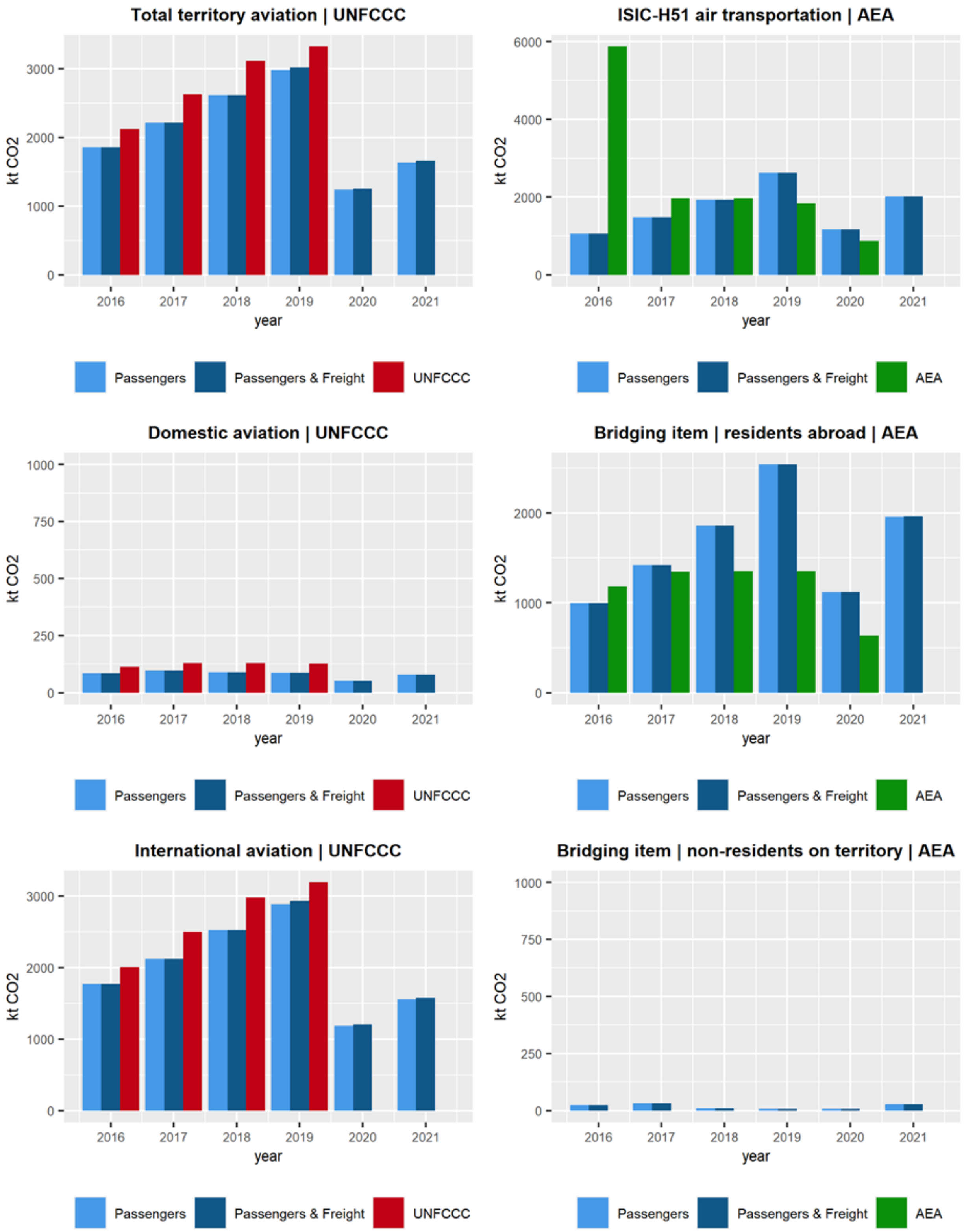


Figure B.30. Portugal

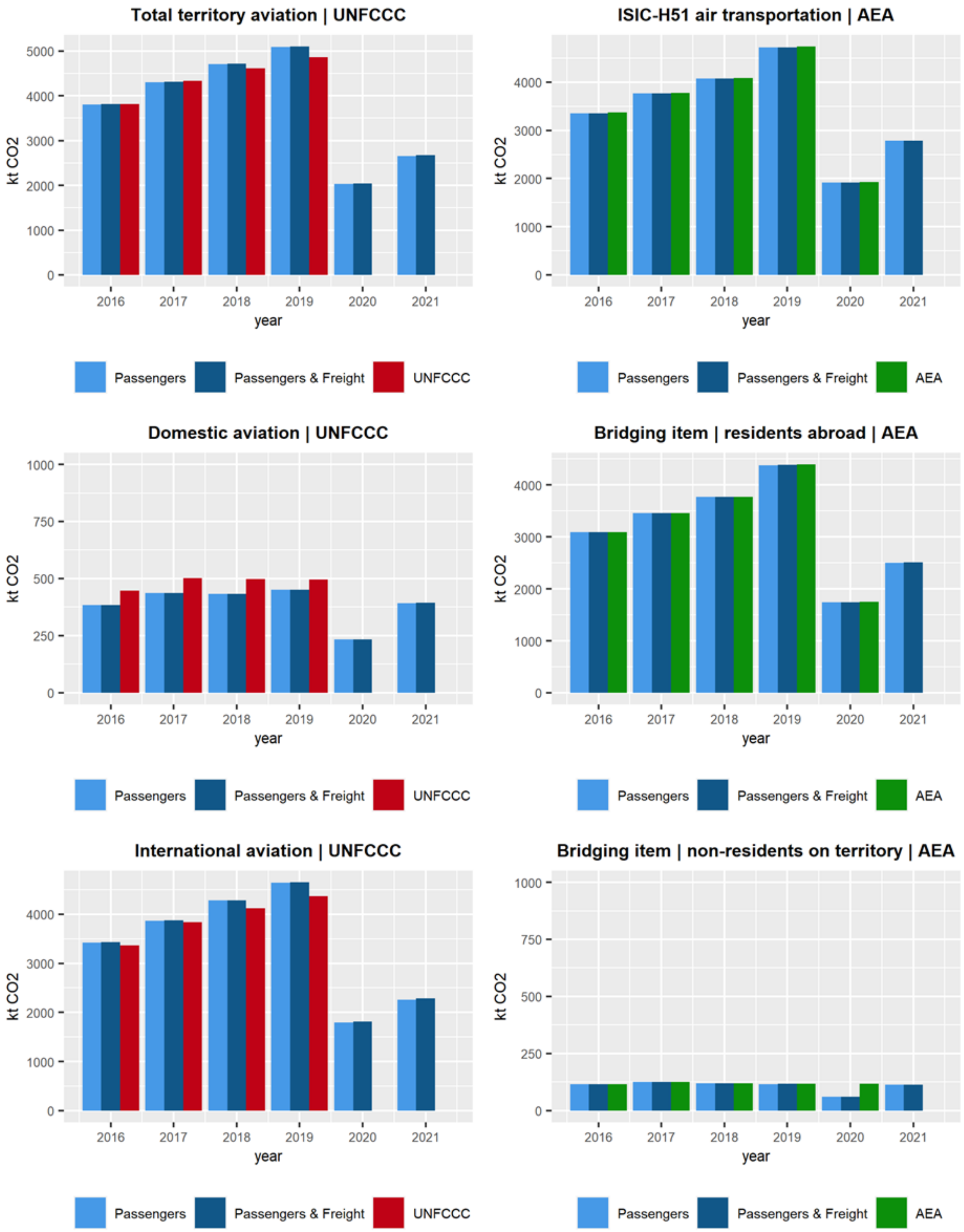


Figure B.31. Romania

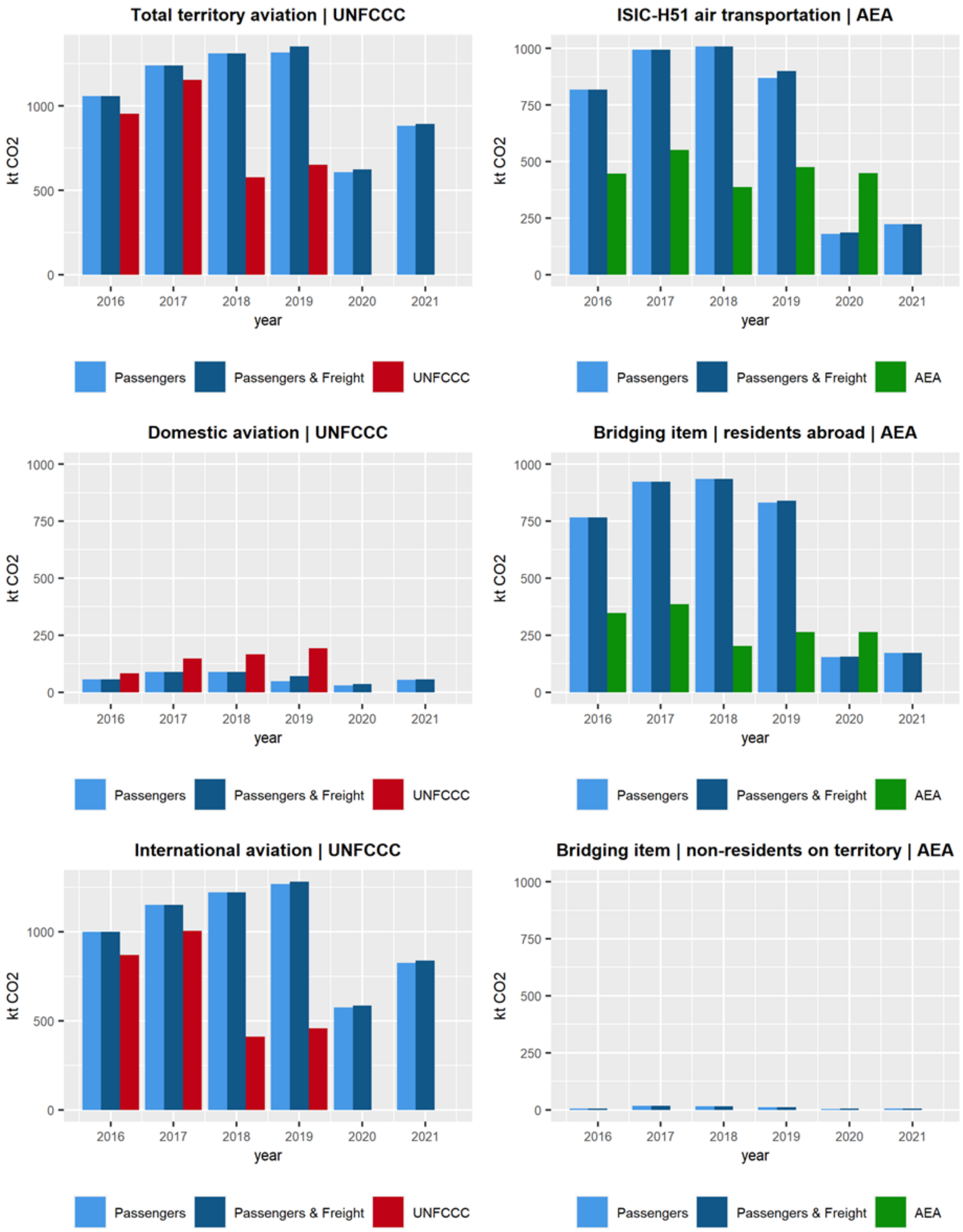


Figure B.32. Russian Federation

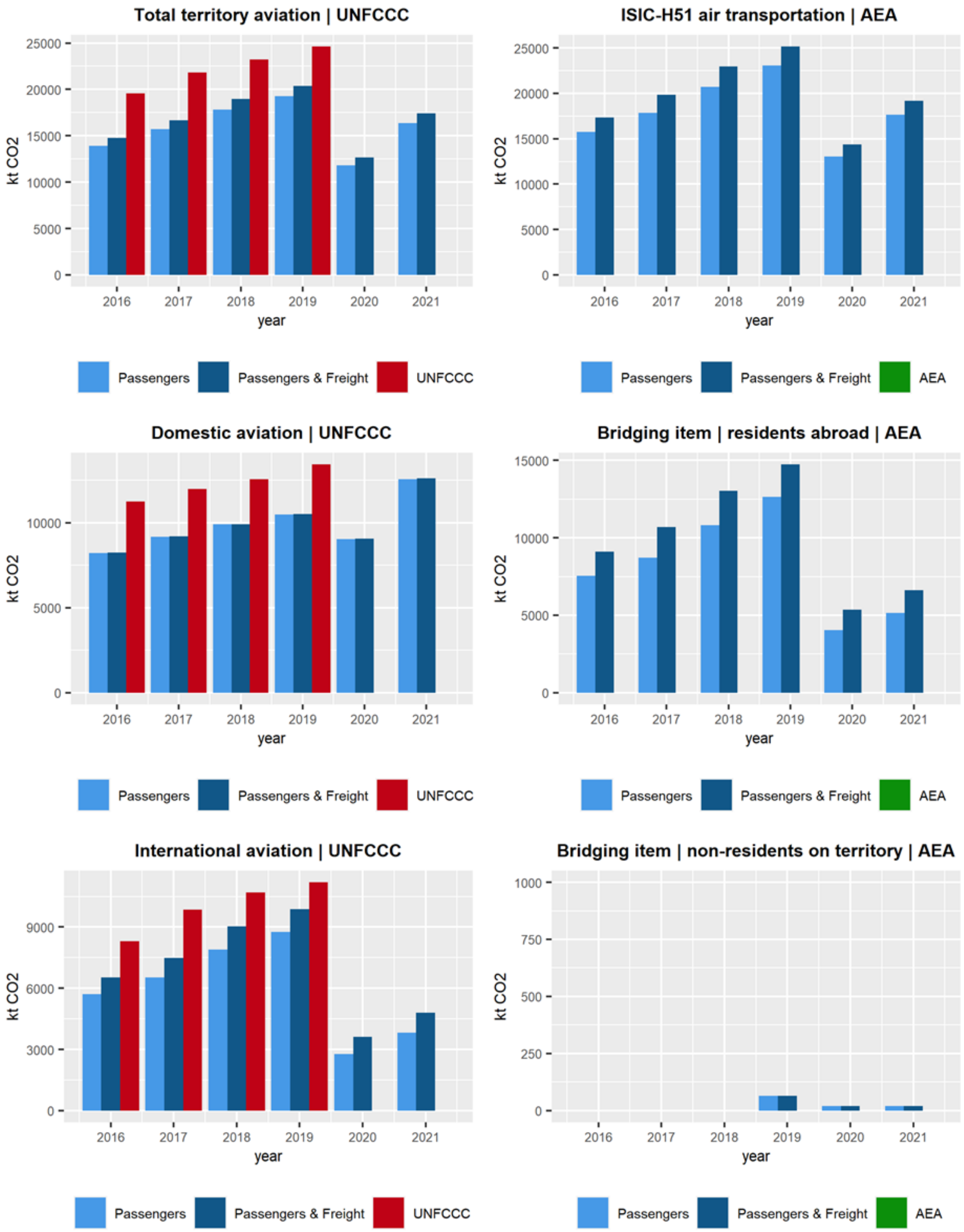


Figure B.33. Slovakia

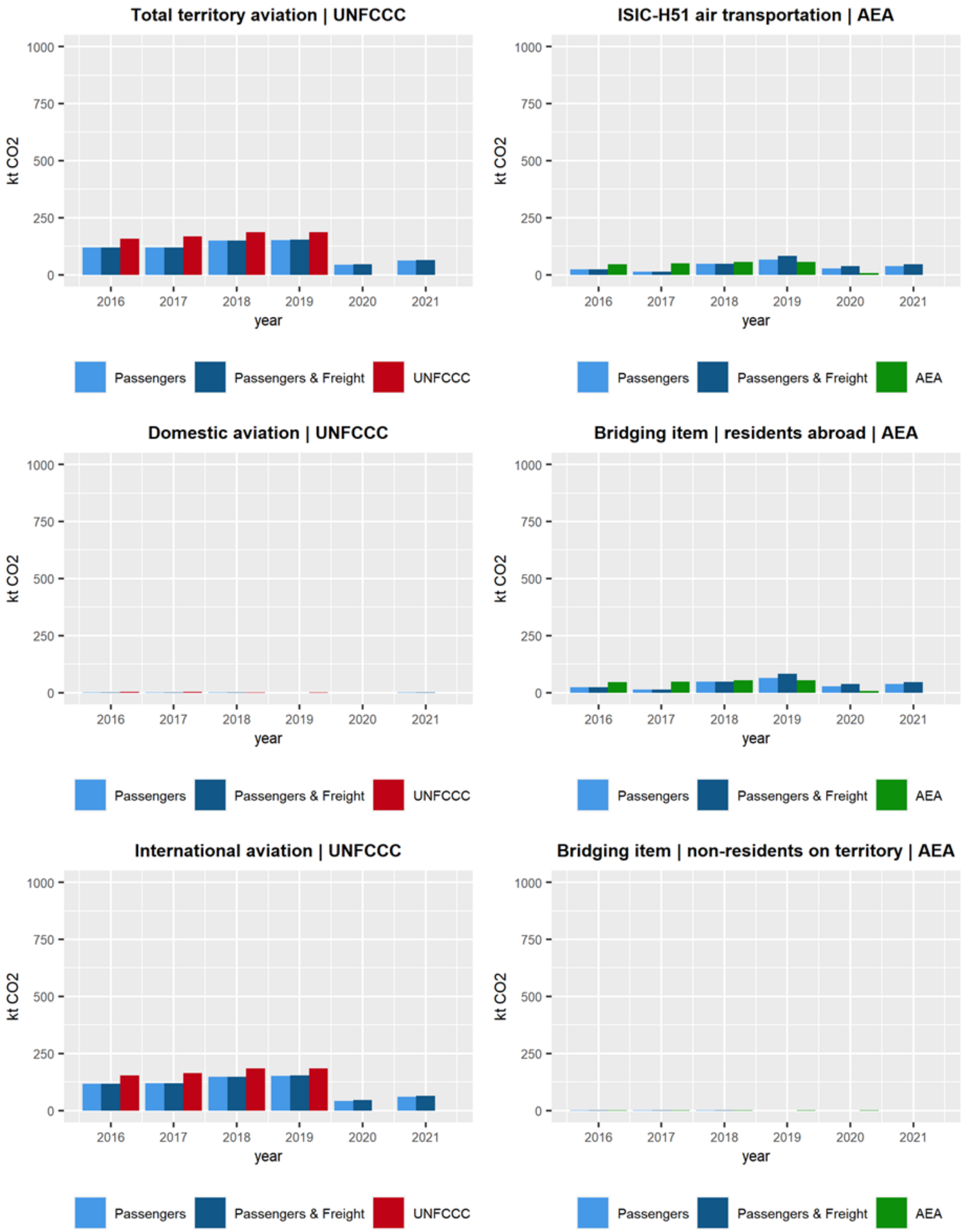


Figure B.34. Slovenia

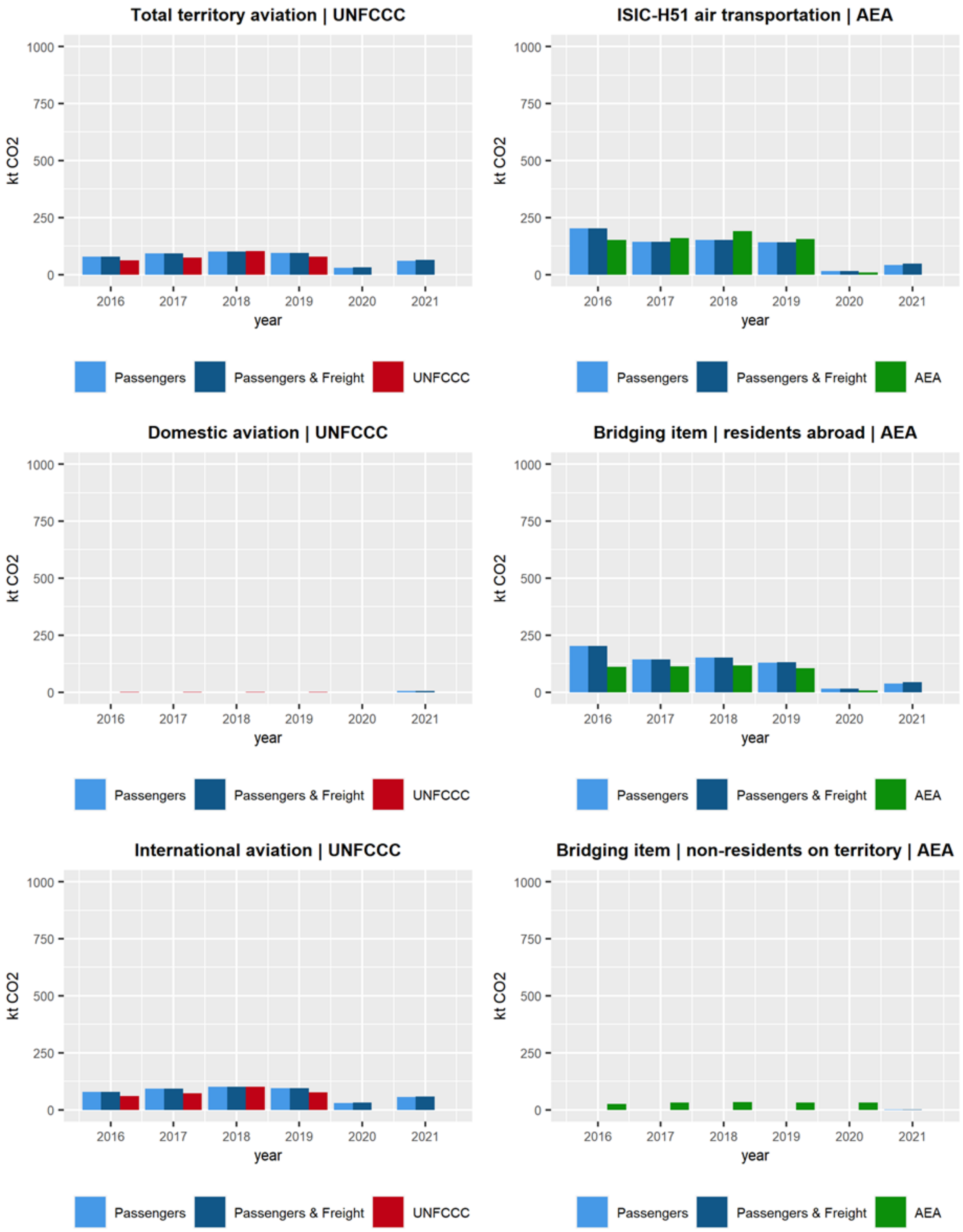


Figure A B.35. Spain

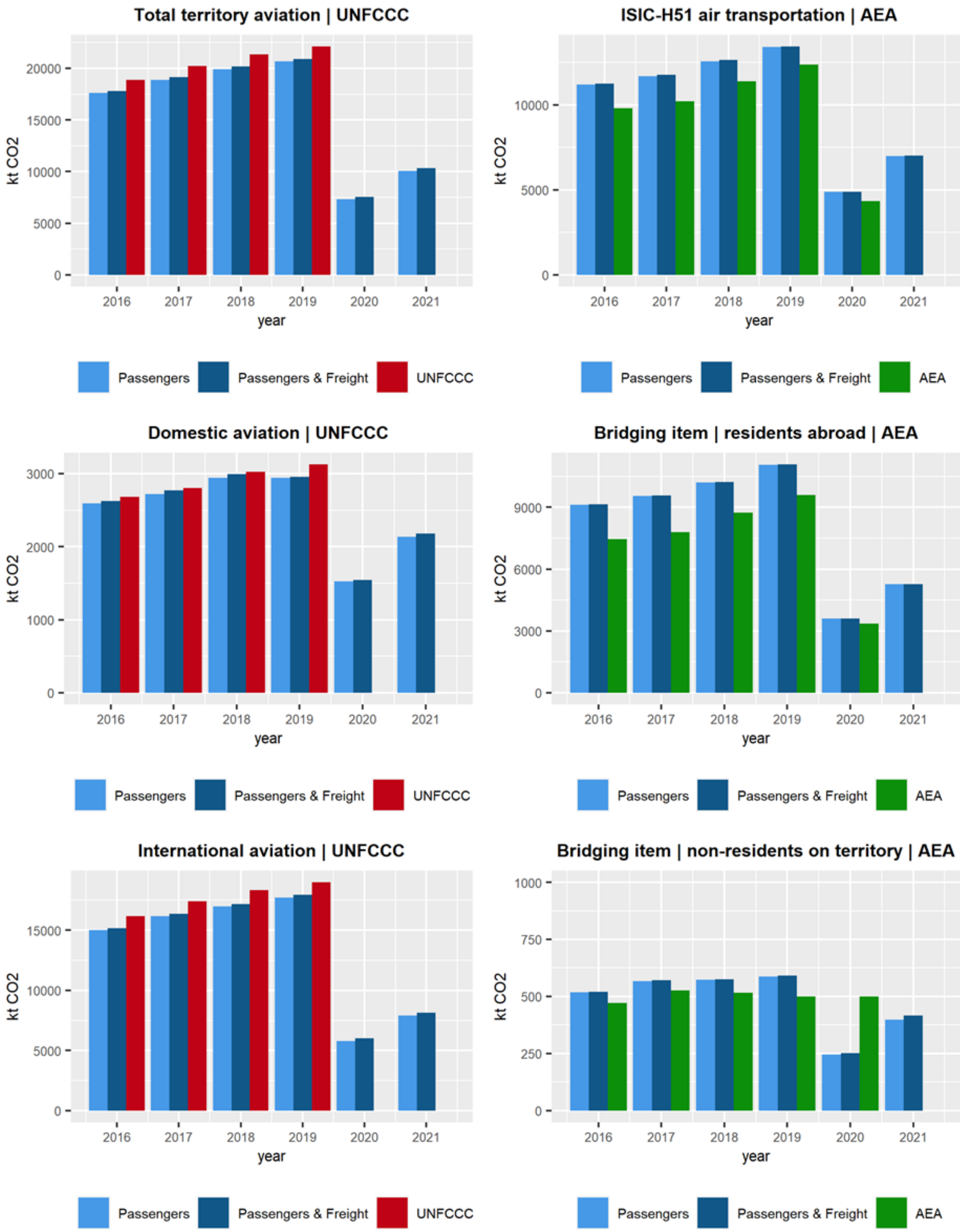


Figure B.36. Sweden

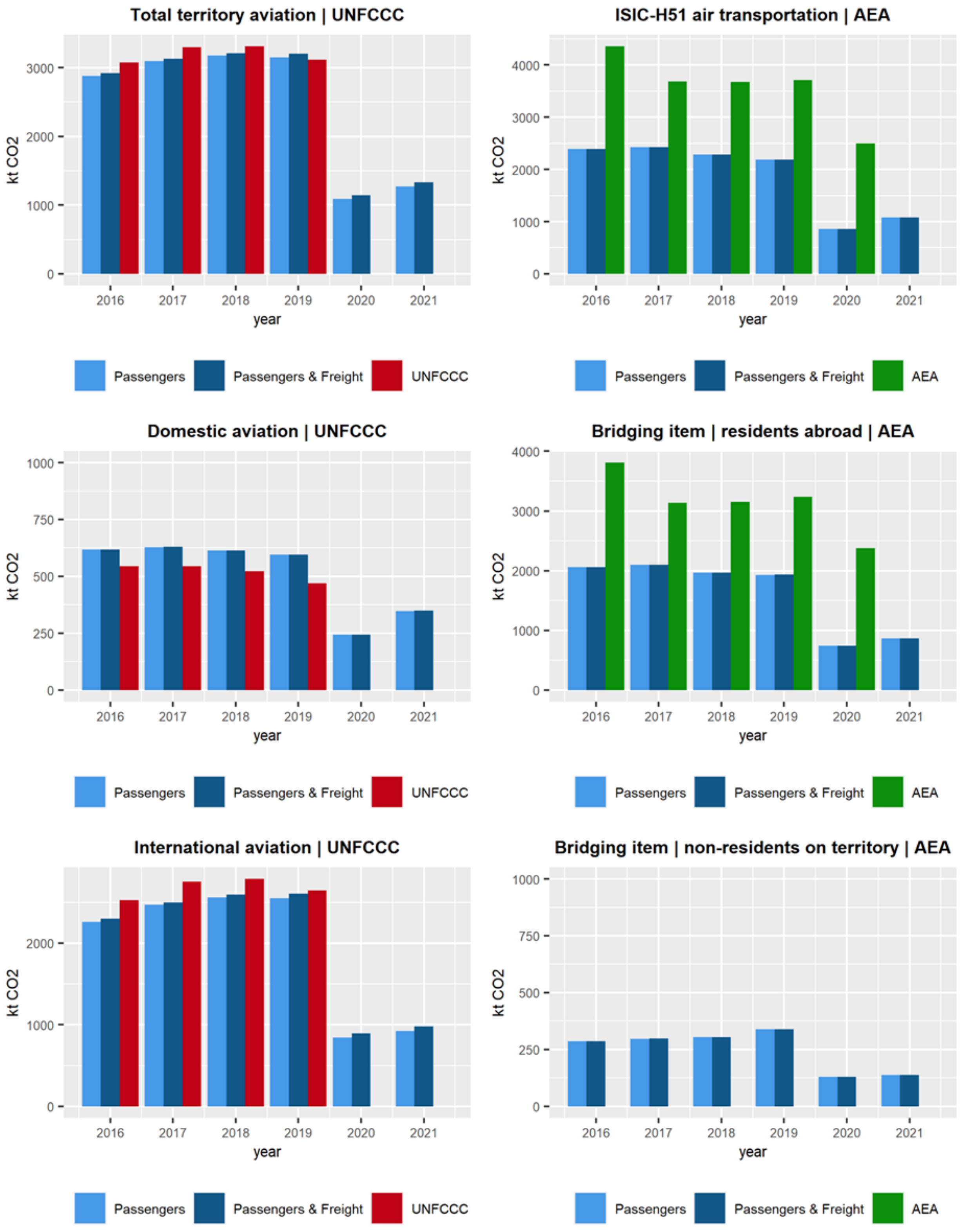


Figure B.37. Switzerland

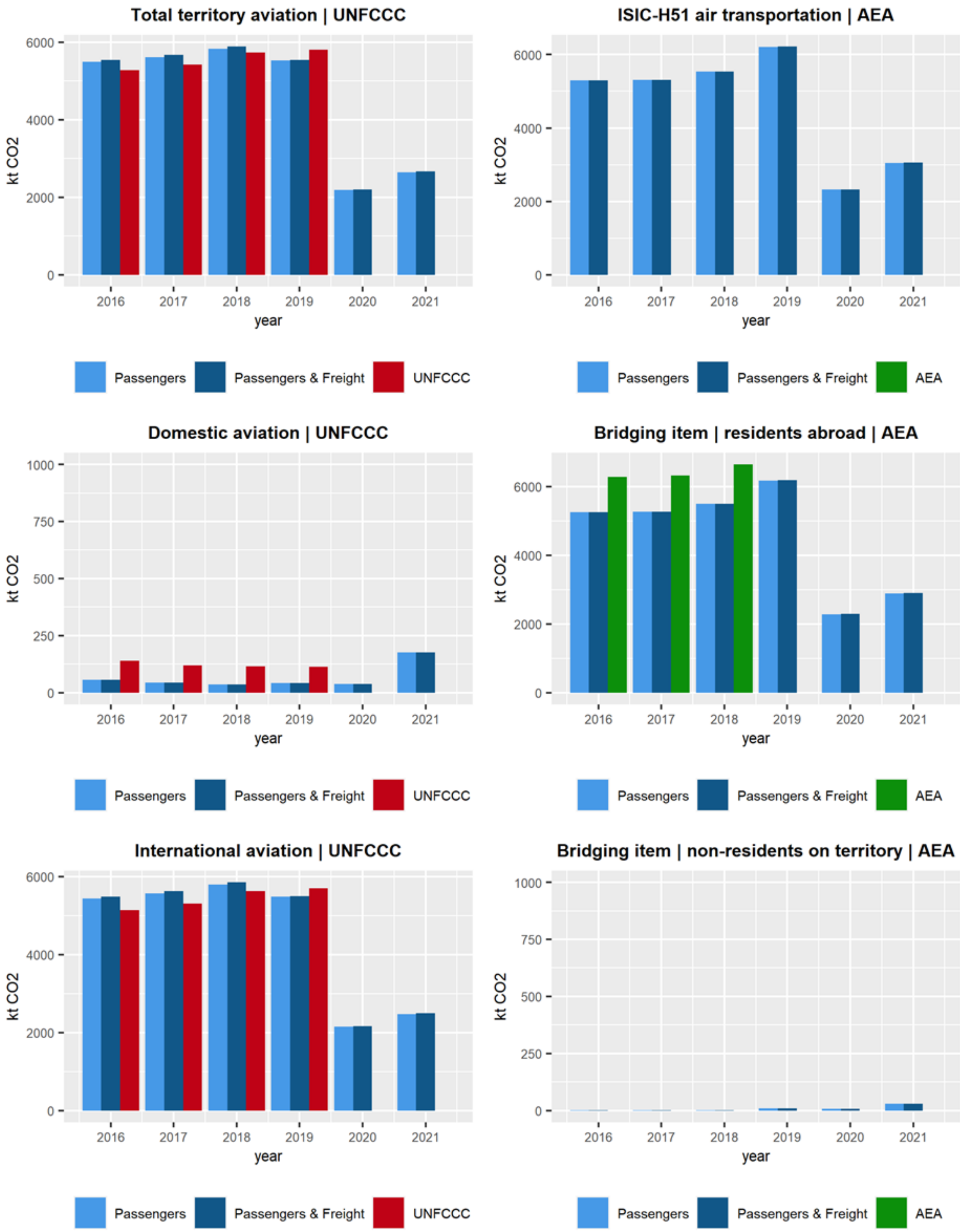


Figure B.38. Turkey

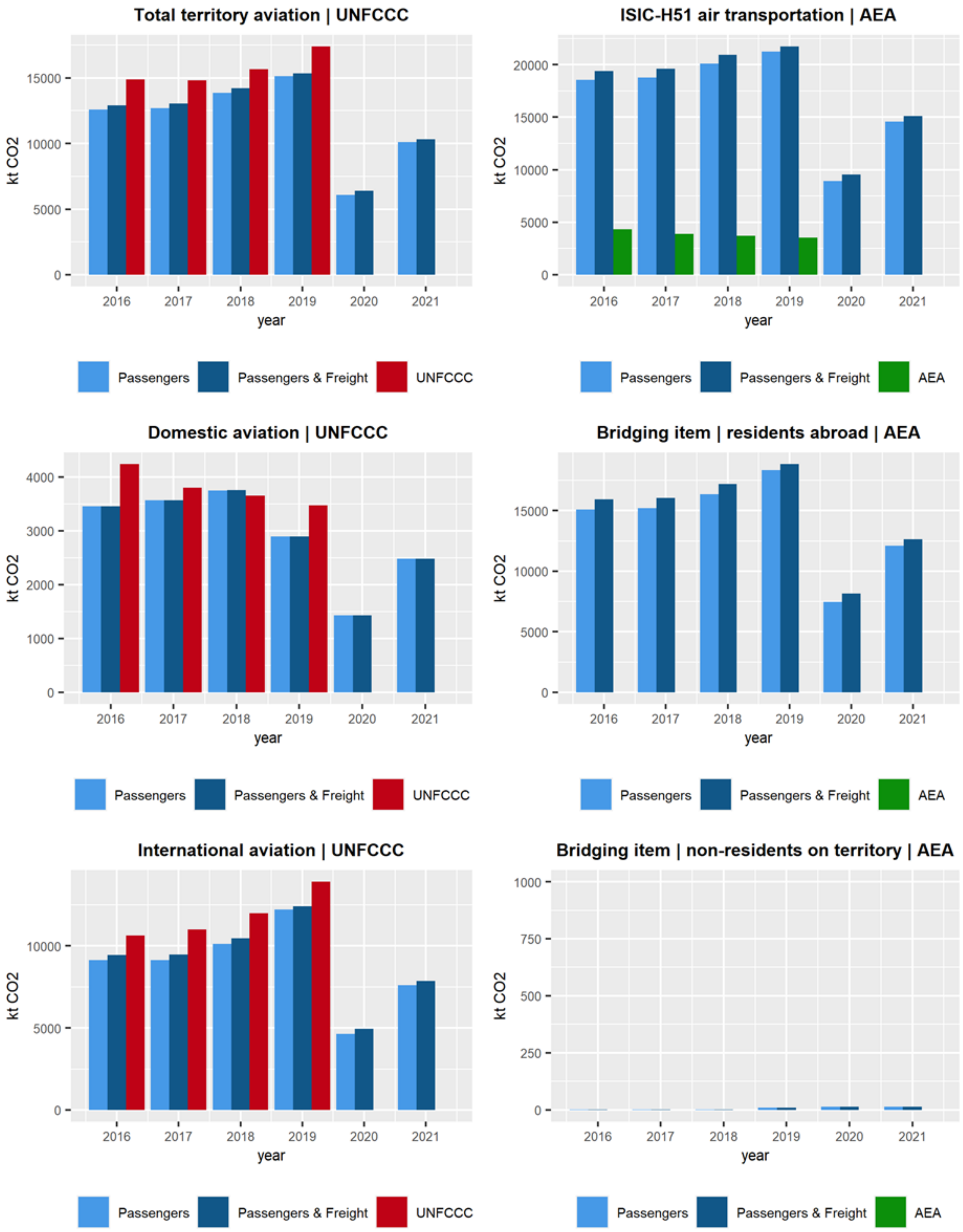


Figure B.39. Ukraine

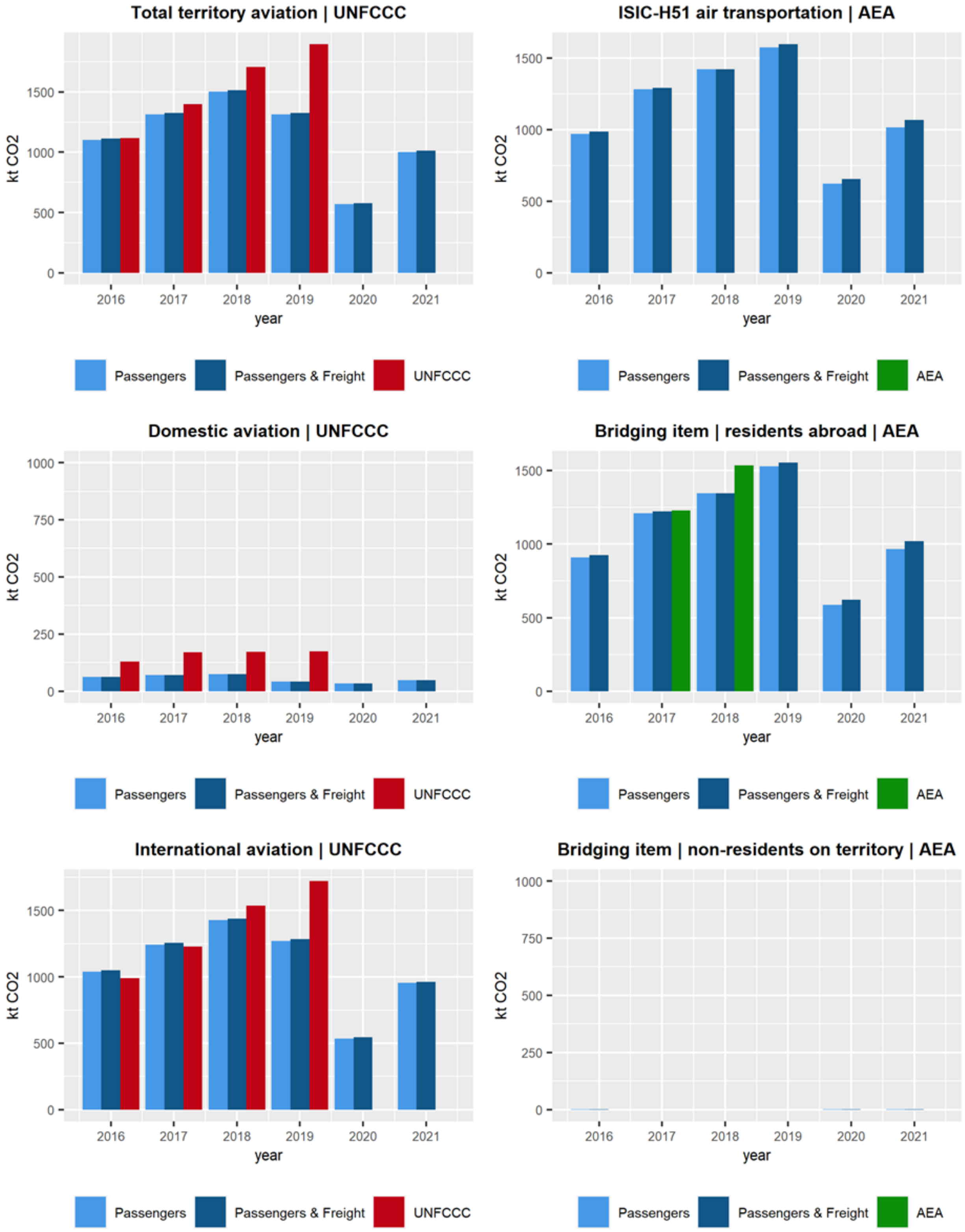
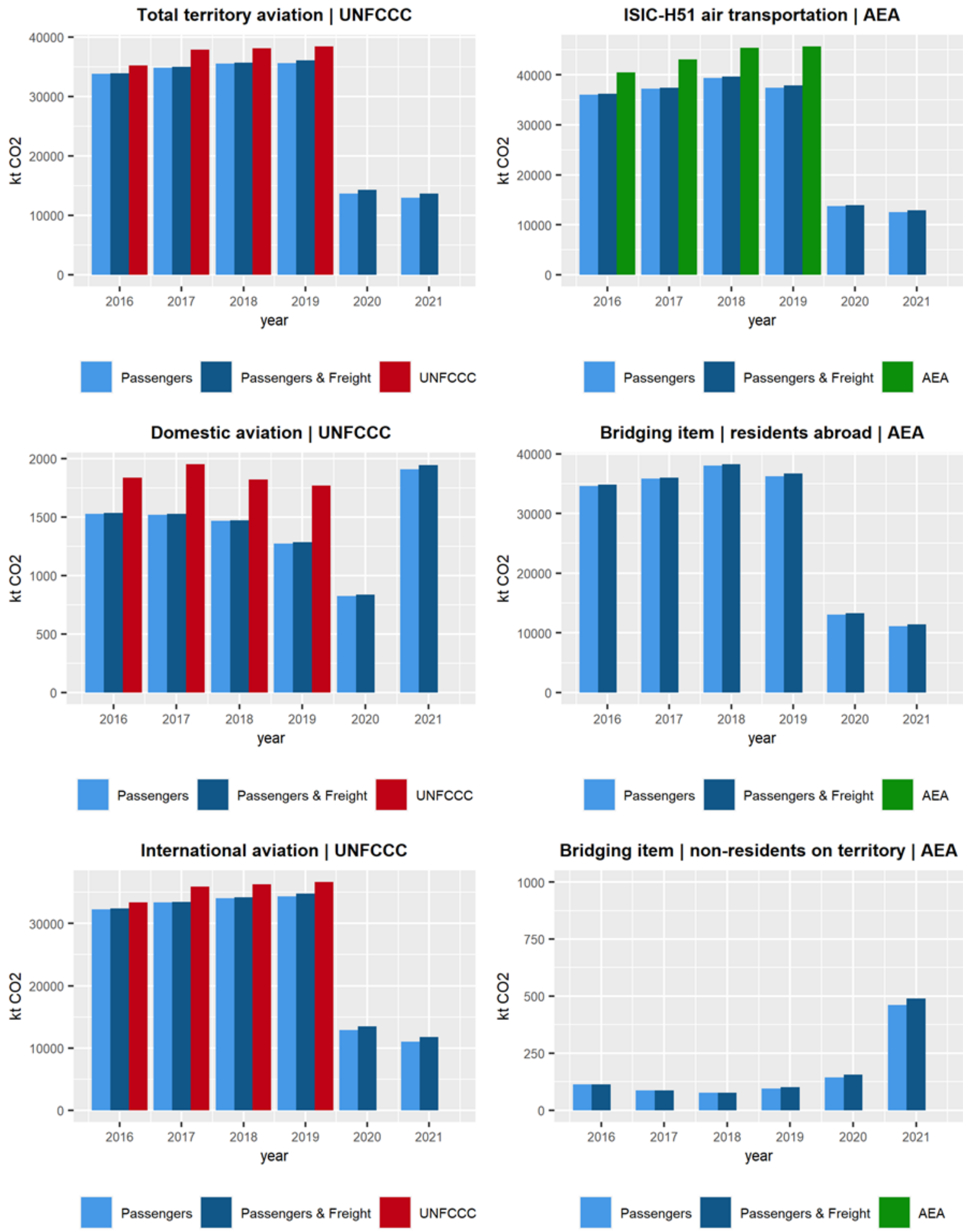
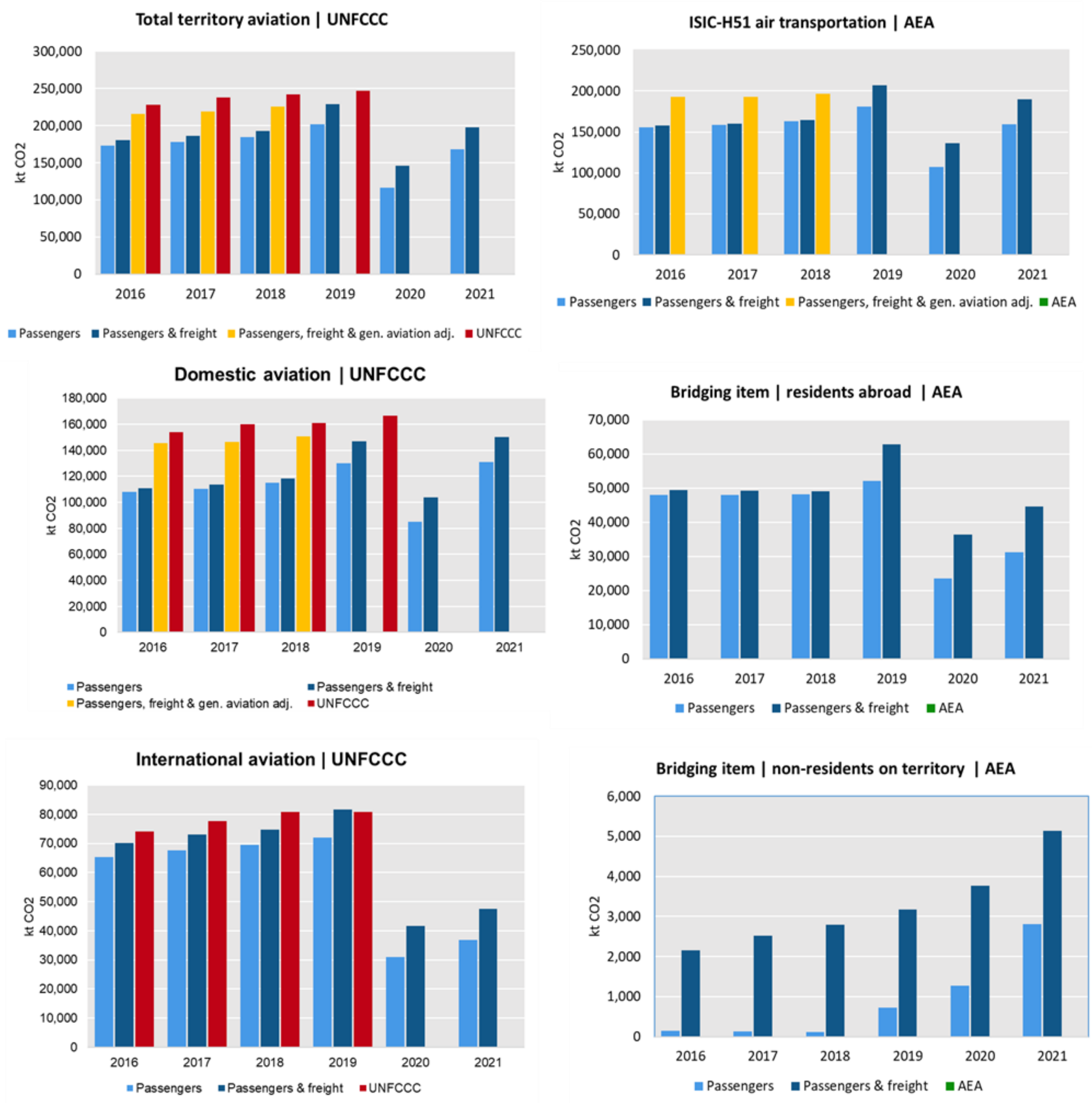


Figure B.40. United Kingdom[35]



[35] Includes British overseas territories: Anguilla, Leeward Islands, Bermuda, Cayman Islands, Falkland Islands, Gibraltar, Montserrat, Leeward Islands, Saint Helena, Turks and Caicos Islands, and Virgin Islands (British part).

Figure B.41. United States[36]



[36] Includes US overseas territories: American Samoa, Guam, Northern Mariana Islands, Puerto Rico, and Virgin Islands (US part). Up to 2018, the information on CO2 emissions from general aviation is sourced from the US UNFCCC inventories, where they are separately available under item 1.A.3.a (Civil aviation). According to the US National Inventory Report (US EPA 2019, Table 3-13), these emissions largely occur on the domestic territory. For convenience, they are assumed to only be caused by resident units and thus, they do not show up in bridging items. From 2019 onwards, all CO2 emissions are calculated from ADS-B information provided by ICAO, without any further adjustment for general aviation.