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Aviation and shipping — impacts on Europe's environment

TERM 2017: Transport and Environment Reporting Mechanism (TERM) report

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Executive summary

TERM 2017 — A focus on aviation and shipping

Domestic and international aviation and shipping are key components of Europe's mobility system. They are both economic sectors that directly bring many societal and economic benefits, such as the delivery of a wide range of goods and services and provision of employment and mobility for personal, leisure or business purposes. However, from a broader environmental perspective, both sectors are also seen as challenging, as increasing demand is leading to increased pressures on the environment and climate. The joint consideration of aviation and shipping in the year 2017 report reflects key similarities — opportunities and challenges — between the two economic sectors. These similarities include:

- International rather than local factors are largely responsible for the significant transport demand from these modes, for example driven by the globalisation of trade.
- Demand in these sectors is often led by consumers through tourism and the global supply chain of certain types of food and manufactured goods.
- The sectors have environmental impacts. They are responsible for a growing proportion of greenhouse gas (GHG) emissions, as well as contributing significantly to regional and local air pollution, noise pollution, pressure on land resources, water, etc.
- Mitigation actions are mainly regulated at the global rather than European or national levels.
- Robust monitoring and verification of air pollutant and GHG emissions from aviation and shipping, particularly measuring actual emissions under real-life conditions, are challenging at present.
- These sectors have similar approaches towards governance, with both aviation (airports) and the maritime sector (ports) based around specific hubs, each of which requires efficient connection to secondary logistical and transport connections.

Expected economic growth and higher emissions set the aviation and shipping sectors apart from other economic sectors, which have seen reductions in GHG, air and water pollutant emissions in many regions since 1990. Demand has increased rapidly at the global and European levels for both freight and passenger transport. Driving forces underpinning this demand include the growing globalisation of trade, economic and population growth and an increase in average wealth.

Environmental pressures

International aviation and maritime transport contribute significantly to total transport GHG emissions in the European Union (EU), comprising 13.3 % and 12.8 %, respectively (EEA, 2017a) (1). GHG emissions from international aviation have more than doubled since 1990; they were almost 25 % higher in 2015 than in 2000. Emissions from the sector have increased over each of the past 4 years (2013-2016), at an average rate of almost 2 % each year (EEA, 2017b). Emissions of GHGs from international shipping in the 28 Member States of the EU (EU-28) have also increased by 22 % since 1990, the second highest increase of any sector — exceeded only by international aviation. However, emissions from the sector have decreased since their peak in 2007-2008, following the global

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(1) This includes emissions of carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O), hydrofluorocarbons (HFCs), and perfluorinated compounds (PFCs). These emissions are commonly given in tonnes CO_2 equivalent (CO_2e), which is a term for describing emissions of different GHGs in a common unit. For any quantity and type of GHG, CO_2e signifies the amount of CO_2 that would have the equivalent global warming impact over a specified time period.

economic crisis, with levels in 2015 being around the same as those reported by Member States in 2000.

Looking to the future, by 2030 and 2050, EU GHG emissions from all transport sectors ([2]) are projected to be 13 % and 15 % above 1990 levels, respectively (EC, 2016b) under current trends and adopted policies (EU Reference Scenario; EC, 2016b). This is significantly higher than the 60 % reduction target by 2050 set for the sector in the European Commission's 2011 Transport White Paper (EC, 2011).

Aviation and shipping are also important sources of the main air pollutants in the EU, particularly of nitrogen oxides (NO_x), sulphur oxides (SO_x) and primary particulate matter (PM) ([3]). These pollutants contribute significantly to local and regional air pollution. For example, in 2015, international shipping contributed 16 % of EU NO_x emissions, 7 % of emissions of particulate matter with a diameter of 2.5 µm or less ($PM_{2.5}$) and 16 % of SO_x emissions, respectively (EEA, 2017d).

The report also describes the environmental pressures caused by the aviation and shipping sectors in other environmental areas, namely:

- Noise pollution arising from flight movements and port operations. Around 4.1 million people in Europe (EEA, 2017c) are affected by exposure to noise above the 55 decibel (dB) day-, evening- and night-level (L_{den}) indicator, designed to assess annoyance and set under the EU's Environmental Noise Directive (EU, 2002). In addition, aircraft typically generate more annoyance and sleep disturbance than other sources with the same L_{den} levels. Shipping- and port-related noise, while not reported separately under the Environmental Noise Directive, can also be a significant source of local noise exposure and, in addition, shipping movements can lead to disturbance of marine animals.

- Pressures on land use and natural habitats around the locations of airports and ports. Expansion of airport and port operations typically entails development of previously unused land, as well as the need for access and infrastructure support services around airports.

- Changes to morphology and hydrology with negative impacts on water quality.

- Water demand for the developed infrastructure services at airports and ports, as well as risks of water pollution from operational activities — de-icing of aircraft and, at ports, from oil spills, inappropriately managed bilge water, etc.

- Waste generation from air and shipping activities.

Transitions to a more efficient aviation and shipping sector

When discussing transitions to sustainable aviation and shipping, an understanding of lock-ins and barriers to change is key. This report identifies three key themes that act as challenges to change in the two sectors:

1. financial aspects;

2. knowledge needs; and

3. stakeholder interests.

Understanding these areas, in turn, can help identify the mechanisms and the extent to which these barriers and lock-ins can be overcome. This report touches upon mitigation aspects for the two sectors framed from this transitions perspective.

Financial aspects identified in the report include the historical investment that has been made in existing airport and port infrastructure, the costs of renewable energy sources and technologies, and fuel subsidies and (the lack of) taxation on fuels used for international transport in the relevant sectors.

Knowledge needs relate, for example, to the importance of accessible and transparent data concerning the viability of new technologies and operating practices in the aviation and shipping sectors. This includes the need to improve and share knowledge on aspects such as design, efficiency of alternative fuels and the benefits of changes in operating practices, such as slow-steaming in the maritime sector and weather-based routing techniques.

([2]) Including international aviation but excluding international maritime and other transportation.

([3]) Primary PM emissions from aircraft contribute relatively little to fine PM mass concentrations (measured, for example, in micrograms $PM_{2.5}$ per cubic metre). However, they emit a high number of ultrafine PM ($PM_{0.1}$), which can have significant health impacts, as they are deposited in the lungs, where they have the ability to penetrate tissue and be absorbed directly into the bloodstream. So far, EU air quality legislation does not regulate PM number concentrations.

Stakeholders' interests relate to the existing interests including resistance to change from incumbent transport operators. Aeroplanes and vessels have long lifespans, typically spanning several decades. While energy efficiency standards are in place, a lot more could be achieved, and current aircraft and vessel designs are inevitably being locked in into the medium and longer term. There can be an unwillingness of operators to invest in alternative fuel technologies and associated vessels and aircraft that have a limited alternative fuel supply infrastructure, while investments in new alternative fuelling stations are less attractive without an increasing demand for such fuels.

'Niches' have a key role to play in transitioning to a more sustainable aviation and shipping sector (for definition, see Box 5.1). They create the space for the development and uptake of innovation that can be hindered by existing barriers and lock-ins. Governments can use a number of different mechanisms to develop niches, including investment in research, product standards and subsidies for new, emerging technologies, and the distribution of new best practices to accelerate the exchange of information. For example, research initiatives (whether government or business led) can reduce the cost, and support development, of new fuels and technologies in each of the sectors, thus addressing financial challenges. They can provide data on the viability of these fuels and technologies addressing knowledge needs, which in turn can provide reassurance with regard to the viability of change and contribute to realigning stakeholder interests. Civil society initiatives can help develop the broader conversations in European society around managing or even reducing demand for some goods and services that contribute to the demand for aviation and shipping services, for example tourist air travel or shipment of exotic goods.

A number of challenges dominate. These include the impact of subsidies and favourable tax regimes compared with other transport modes, existing interests and resistance to change from established operators. 'Landscape change', creating windows of opportunity for innovation, therefore has a key role to play. Regulatory measures can provide clear signals to operators with regard to the steps required for change, helping to overcome resistance and facilitating uptake of new technologies and alternative fuels.

As noted in last year's report, public authorities have a key responsibility to ensure that different transport services are connected and inter-operable, that the required infrastructure is in place and that price signals are consistent (EEA, 2016a). Through their regulatory and funding power, public authorities also have the opportunity to help proactively shape the future aviation and shipping sectors.

1 Introduction

The Transport and Environment Reporting Mechanism (TERM) report has been monitoring progress in integrating environmental objectives in transport since 2000. It has been providing information to the European Environment Agency's (EEA) member countries, the European Union (EU) and the public.

The EU's Seventh Environment Action Programme (7th EAP) put forward a clear vision: 'In 2050, we live well within the planet's ecological limits. Our prosperity and healthy environment stem from an innovative, circular economy where nothing is wasted and where natural resources are managed sustainably, and biodiversity is protected, valued and restored in ways that enhance our society's resilience' (EU, 2013a). To achieve this vision, environmental pressures arising from all sectors of the economy should be significantly reduced. As a key economic sector, reducing the environmental and climate pressures arising from Europe's transport sector will be critical in achieving the 7th EAP's longer term objectives.

The 'Transport and Environment Reporting Mechanism (TERM)' includes a number of indicators used for tracking the short- and long-term environmental performance of the transport sector and for measuring progress in meeting key transport-related policy targets. In 2017, the indicator-based assessment component of TERM is published as a separate briefing accompanying this report.

Last year's TERM report (EEA, 2016a) reflected upon the prospects for significant future 'systemic' changes towards improved sustainability for Europe's mobility system. Recent European Commission documents — the *European strategy for low-emissions mobility* (EC, 2016a) and the Commission's 2016 'Reference Scenario' (EC, 2016b) — suggest that, if no additional measures are taken beyond those currently planned, it will be difficult to reconcile high levels of human development (living well) with environmental sustainability (living within environmental limits). Beyond reducing transport greenhouse gas (GHG) emissions, other transport-related environmental pressures, such as air pollution, biodiversity fragmentation, traffic congestion, inefficient use of urban space and noise, also require more ambitious actions to reach the 7th EAP's 'living well, within the limits of our planet' vision. The TERM 2016 report highlighted that a transition to sustainable mobility implies an understanding that small incremental steps are not enough to reach the necessary reduction in transport-related pressures on the environment.

This year's report builds upon the more general assessment undertaken in 2016 by providing a more detailed analysis, also from a transitions perspective, of two transport modes important to the functioning of Europe's mobility system — international aviation and shipping.

1.1 TERM 2017 — A focus on aviation and shipping

- Domestic and international aviation and shipping are key components of Europe's mobility system. They are both economic sectors that directly bring many societal and economic benefits, such as the delivery of a wide range of goods and services and provision of employment and mobility for personal leisure or business purposes. However, from the broader environmental perspective, both sectors are also seen as challenging, because increasing demand within each of the sectors is exerting increasing pressures on the environment and climate. Their joint consideration in this TERM 2017 report also reflects key similarities, opportunities and challenges between them. These similarities include:

- International rather than local factors are largely responsible for the significant transport demand from these modes, for example driven by the globalisation of trade and the impact of economic growth at the global level. This reflects historical trends in industrialised countries and current and future gross domestic product (GDP) growth rates in emerging economies.

- Drivers for demand in these sectors are often consumer led, through tourism and the global scale of supply chains of certain types of food and manufactured goods. Disposal of subsequent waste can, in turn, create demand for transport requirements. Mitigation thus also needs to consider how the relevant consumer demand can be reduced, especially in the context of overall sustainable development, projected economic growth at the global level and the associated levels of demand.

- The sectors have environmental impacts. They are responsible for a growing share of GHG emissions, as well as contributing significantly to regional and local air pollution, noise pollution, and pressure on land resources, water, etc. By 2050, global aviation and shipping together are anticipated to contribute almost 40 % of global carbon dioxide (CO_2) emissions unless further mitigation actions are taken (EP, 2015). This expected growth sets them apart from other economic sectors, which have seen reductions in CO_2 emissions in many regions since 1990.
- Mitigation actions are regulated mainly at the global rather than European or national levels, for example through the International Civil Aviation Organization (ICAO) or International Maritime Organization (IMO), reflecting the cross-boundary nature of movements and fleet fuelling. While neither aviation nor shipping are specifically referred to in the 2015 Paris Agreement under the United Nations Framework Convention on Climate Change (UNFCCC), various stakeholders have identified the development and agreement of a '1.5 °C' (4) compatible vision for aviation and shipping as one of the most important steps to achieve the Paris Agreement objectives. ICAO, for example, has reflected this to some degree and has reaffirmed 'work being undertaken to explore a long term global aspirational goal for international aviation in light of the 2 °C and 1.5 °C temperature goals of the Paris Agreement' (ICAO, 2016).
- Robust monitoring and verification of air pollutant and GHG emissions from aviation and shipping are presently challenging in terms of obtaining necessary information on the fuel consumption and emissions from the large numbers of aircraft and ships travelling each day. Allocating these emissions spatially to inform environmental impacts or goals can similarly be difficult due to the cross-boundary nature of transport by these modes.
- These sectors have similar approaches towards governance, with both aviation (airports) and the maritime sector (ports) based around specific hubs, each of which requires efficient connection to secondary logistic and transport connections.

1.2 The structure of this report

Figure 1.1 summarises how the report is structured; in detail:

- Chapter 2 assesses some of the key drivers responsible for the increasing demand for aviation and shipping transport.
- Chapters 3 and 4 describe the status of selected environmental pressures, impacts and policy measures within the aviation and shipping sectors, respectively. The chapters provide a summary of the following dimensions:
  - Why is this important for the environment?
  - What current monitoring approaches are in place?
  - What current and future policies are implemented and are being considered?
  - What mitigation options exist?
- Chapter 5 builds upon the transitions approach undertaken in last year's TERM report by considering how these modes could start a transition to improved sustainability. The chapter defines examples of barriers, lock-ins and niches.
- Finally, Chapter 6 of the report summarises the main conclusions.

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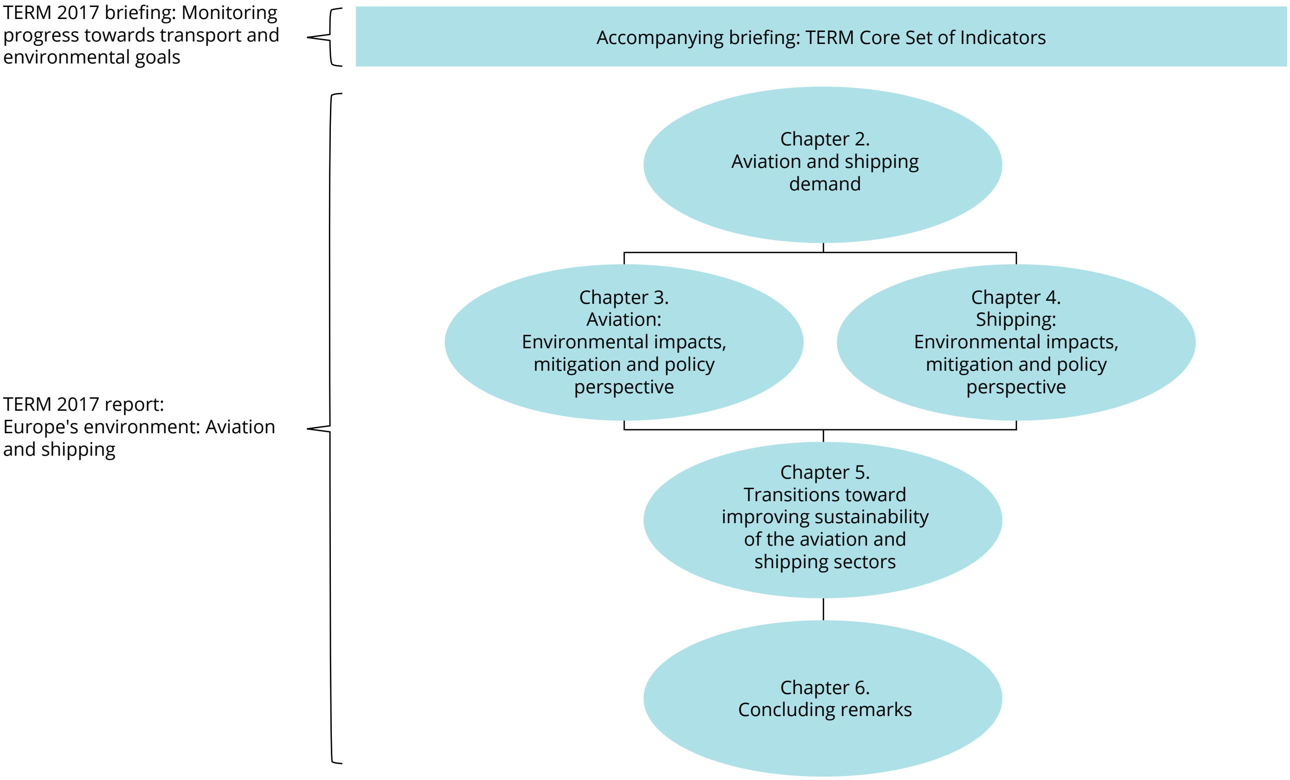
(4) The UNFCCC Paris Agreement aims, among other objectives, to strengthen the global response to the threat of climate change, in the context of sustainable development and efforts to eradicate poverty, including by holding the increase in the global average temperature to well below 2 °C above pre-industrial levels and pursuing efforts to limit the temperature increase to 1.5 °C above pre-industrial levels, recognising that this would significantly reduce the risks and impacts of climate change .

Figure 1.1 **Structure of this report**



2 The drivers for aviation and shipping demand

Key messages

- Aviation and shipping demand has increased rapidly over past years at the global and European levels in both the freight and passenger transport sectors.
- Key drivers for this demand include the increasing globalisation of trade and economic growth. Contributory factors for the increasing demand also include a reduction in real transport prices, increasing competition and the role of economic incentives and tax exemptions.

2.1 Trends in aviation and shipping demand

Over past decades, global population and wealth have grown in many areas of the world, which has allowed people to have access to more affordable air transport, for leisure or business purposes, and to imported goods.

However, while some dominant operators may have little incentive for change, new operators can act as facilitators. An example is low-cost airlines' adoption of newer, more fuel-efficient planes. The average age of Ryanair and EasyJet aircraft is considerably lower than the average age of Air France aircraft (e.g. Airfleet.net, 2017).

The maritime transport sector plays an essential role in the European economy. Nearly 79 % of the EU's external freight trade, measured by weight of transported goods (5), is delivered by shipping, making clear the global dependencies regarding imported goods (EEA, 2016b; Figure 2.1).

Box 2.1 The GHG emission trends of low-cost operators in the aviation sector

In 2016, the aviation sector covered by the EU Emissions Trading Scheme (ETS) emitted 61.4 mega-tonnes (Mt) of carbon dioxide equivalent CO_2e, which represents an increase of 7.6 % over the previous year. The seven largest aircraft operators were responsible for 44 % of these emissions (EEA, 2017e). Ryanair and EasyJet were the two highest emitters in 2016, accounting for 8.4 Mt CO_2e and 5.1 Mt CO_2e respectively, with increasing emissions over the past years. This mainly reflects the annual growth in passenger numbers.

In contrast, the decline in annual emissions for, for example, Air France, despite a slight increase in annual passenger numbers, is likely to reflect fuel efficiency improvements from both the recent reduction in the age of its fleet and operational improvements such as route optimisation and 'eco-flying', for example flying lower and slower or operating at full capacity (EEA, 2017e).

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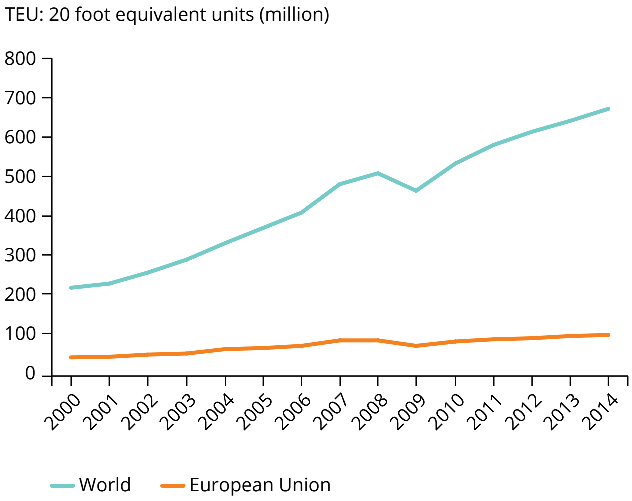
(5) If analysed by value of transported goods, then the role of aviation is more important.

Figure 2.1 Container port traffic



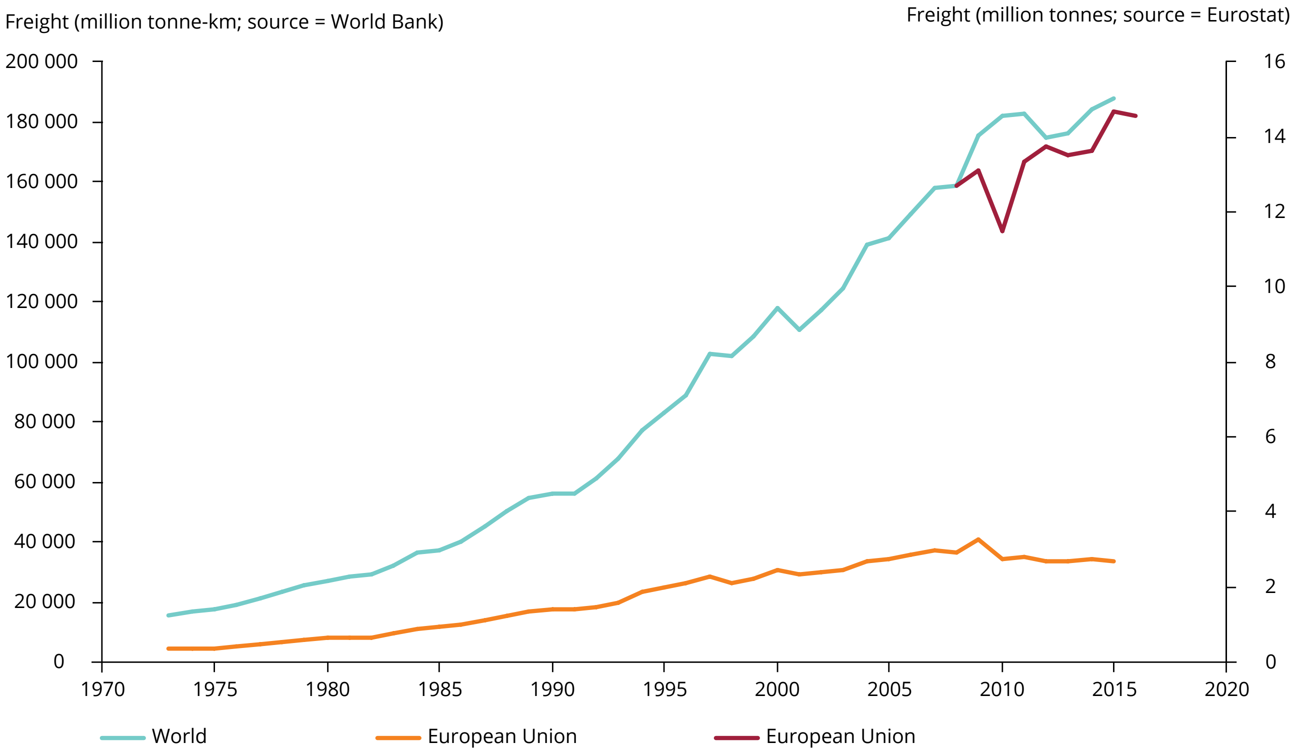
Note: TEU, 20-foot equivalent unit (used to measure a ship's cargo carrying capacity).

Source: World Bank, 2017a.

Demand for air transport freight has similarly increased (Figure 2.2), reflecting growing demand for long-distance transport of time-sensitive high-value goods such as pharmaceutical products and fresh produce. It is estimated that around 69 % of cargo transported between EU Member States, or to and from non-EU countries, is transported over more than 2 500 km (Krueger, 2009; MacGregor and Groom, 2009; Alonso, et al., 2014).

The number of air transport passengers in Europe and globally has tripled since 1990 (Figure 2.3). This demand is expected to increase further. The International Air Transport Association (IATA) suggests that globally air passenger numbers will almost double by 2035 compared with 2016. For Europe, the growth rate is estimated to be 2.5 % per year, the slowest of all world regions, but still resulting in an increase of 570 million passengers per year by 2035 (IATA, 2016). To meet the forecast demand, ICAO has projected that the world's commercial aircraft fleet will almost double in size over the next 20 years, increasing from around

Figure 2.2 Air transport freight



Note: The Eurostat data are shown on the secondary axis. Freight data (in tonnes) are only available in Eurostat's database from 2005 onwards. The data for the EU presented by the World Bank might be an underestimation.

Source: 1973-2016, World Bank, 2017b; 2008-2016, Eurostat, 2017c.

26 000 aircraft in 2016 to 47 500 in 2036 (ICAO, 2010). Once certified, aircraft types can be produced for 20-30 years (an extreme example is the Boeing 747 which, originally certified around 1970, went through various models and did not go out of production until 2010). Once released into service, an aircraft can also have a lifetime of about 20-25 years. Thus, it is possible that examples of aircraft types being certified now could still be in service in the 2050s.

2.2 Explanatory factors underpinning aviation and shipping demand

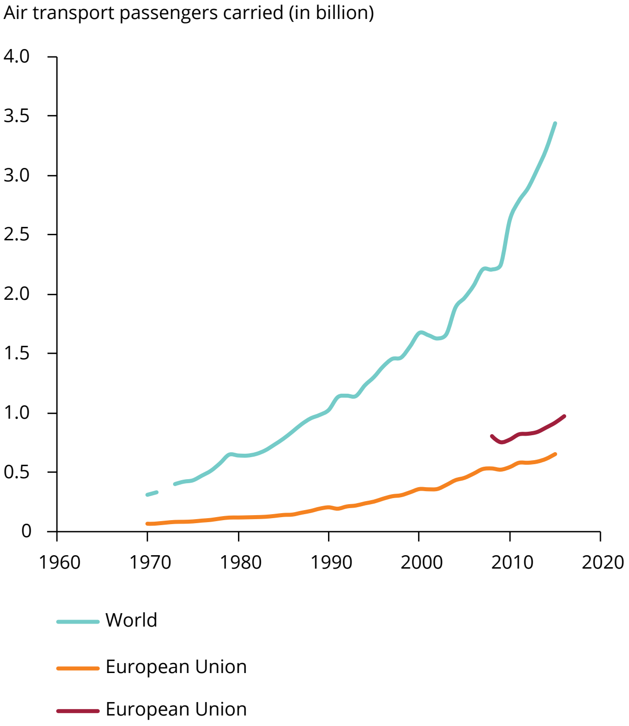
A number of factors underpin the selected trends summarised in the preceding section. Longer term drivers include the globalisation of trade and economic growth. Further, population and disposable incomes have grown significantly in certain regions. Other enabling factors have included increased competition and lower prices arising as a result of low-cost carriers entering the aviation market and the role of subsidies and exemptions, for example with respect to taxation for international transport fuels.

2.2.1 Globalisation of trade

Global rather than local factors are key drivers for demand; the globalisation of trade over past decades has had a significant impact. According to the World Trade Organization (WTO), multilateral and regional treaties have resulted in substantial reduction in tariff and non-tariff protectionist measures (WTO, 2013).

Developed countries, searching for lower cost production, increasingly source materials, products, components and services from the developing world. Driven by structural change, fast-growing workforces and trade liberalisation, developing regions are rapidly increasing their share of total global economic output, trade and investment. Looking ahead, global trade flows are likely to continue evolving (EEA, 2015).

Figure 2.3 Air transport passengers carried

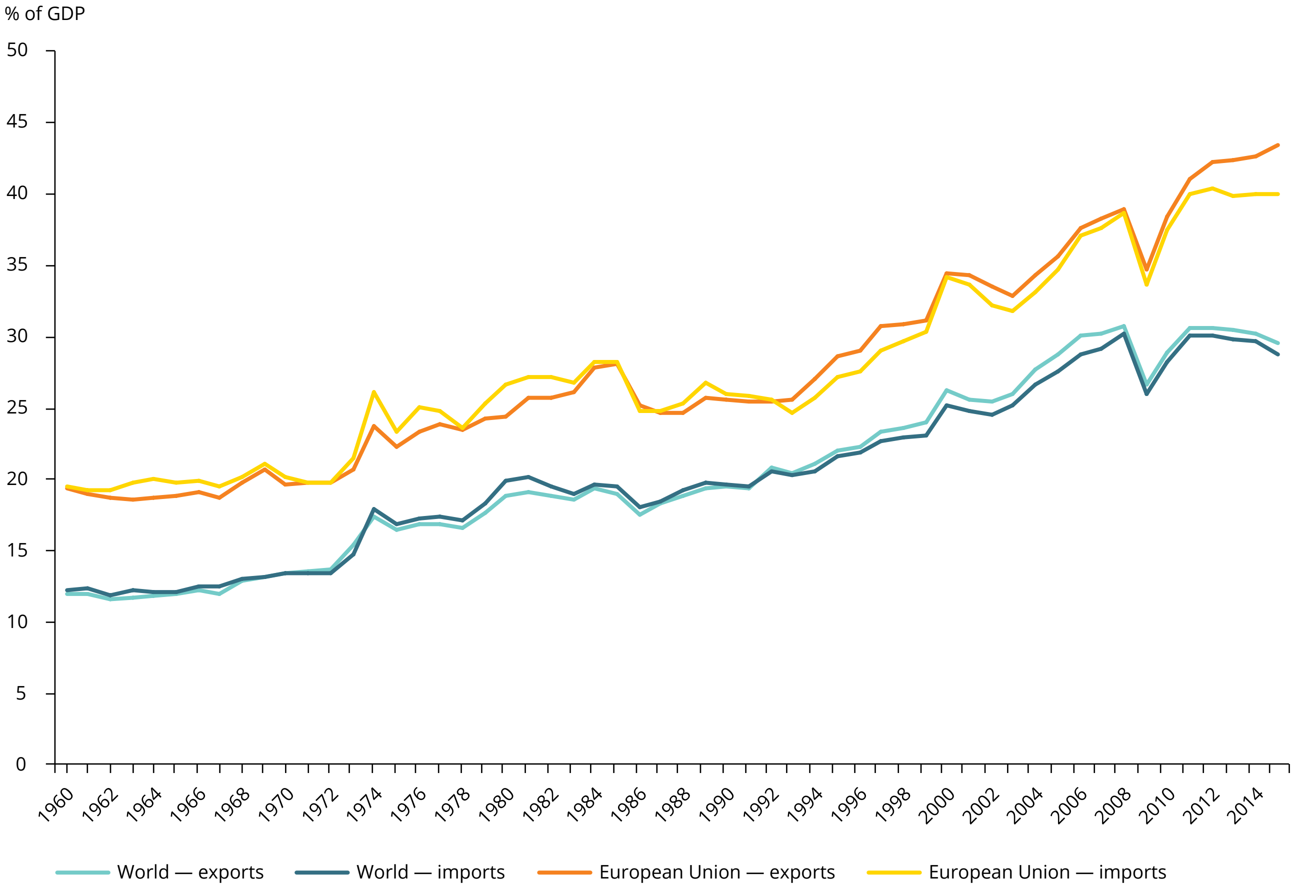


Note: The World Bank numbers for the EU seem to be an underestimation; see Eurostat, 2017: "In 2016, 972.7 million passengers travelled by air in the European Union (EU), up by 5.9 % compared with 2015."

Source: 1973-2016, World Bank, 2017c; 2008-2016, Eurostat, 2017c.

Average tariffs on manufactured products in industrialised countries have decreased, for example, from around 45-50 % in 1948 to an average of around 3 % in 2009 (Krueger, 2009). Furthermore, improvements in information technologies have made international telecommunication much more cost-effective, facilitating trade deals (WTO, 2013) and hence growth of freight demand. The increasing demand for exports and imports in terms of contribution to GDP at the global and European scale is shown in Figure 2.4.

Figure 2.4 Growth in exports and imports of goods and services as a percentage of GDP



Note: GDP, gross domestic product. See also Section 5.2.

Source: World Bank, 2017d, 2017e.

2.2.2 Economic and trade growth

Figure 2.5 shows the gross weight of goods handled in the main EU ports in 2015, imported or exported by the EU.

Shipping plays a considerable role with respect to the supply of fuels used for energy generation in Europe. Liquid bulk goods, which include liquefied gas, crude oil, oil products and other liquid bulk goods, dominate inwards goods movements amounting to over 900 000 tonnes in 2015. These were followed by dry bulk goods, which typically include ores, coal and agricultural products. Large containers carry manufactured goods, while 'roll-on/roll-off' units (6) include wheeled equipment for carrying cargo, such as a truck, trailer or semi-trailer and represent a smaller but still substantial portion of inwards goods.

Looking forwards, the impact of economic growth at the global level, especially the current and future GDP growth rates in China and India, are key drivers: increased trade with emerging economies will result in longer travel distances. There will also be changes in the type of goods transported. Oil shipping accounts for nearly one third of global maritime trade at present. On a 2050 timescale, this proportion is predicted to reduce because of increased use of renewables and energy efficiency measures in the EU. However, the use of unitised cargo ships (large containers and general cargo) is predicted to increase rapidly, reflecting increased demand for manufactured goods.

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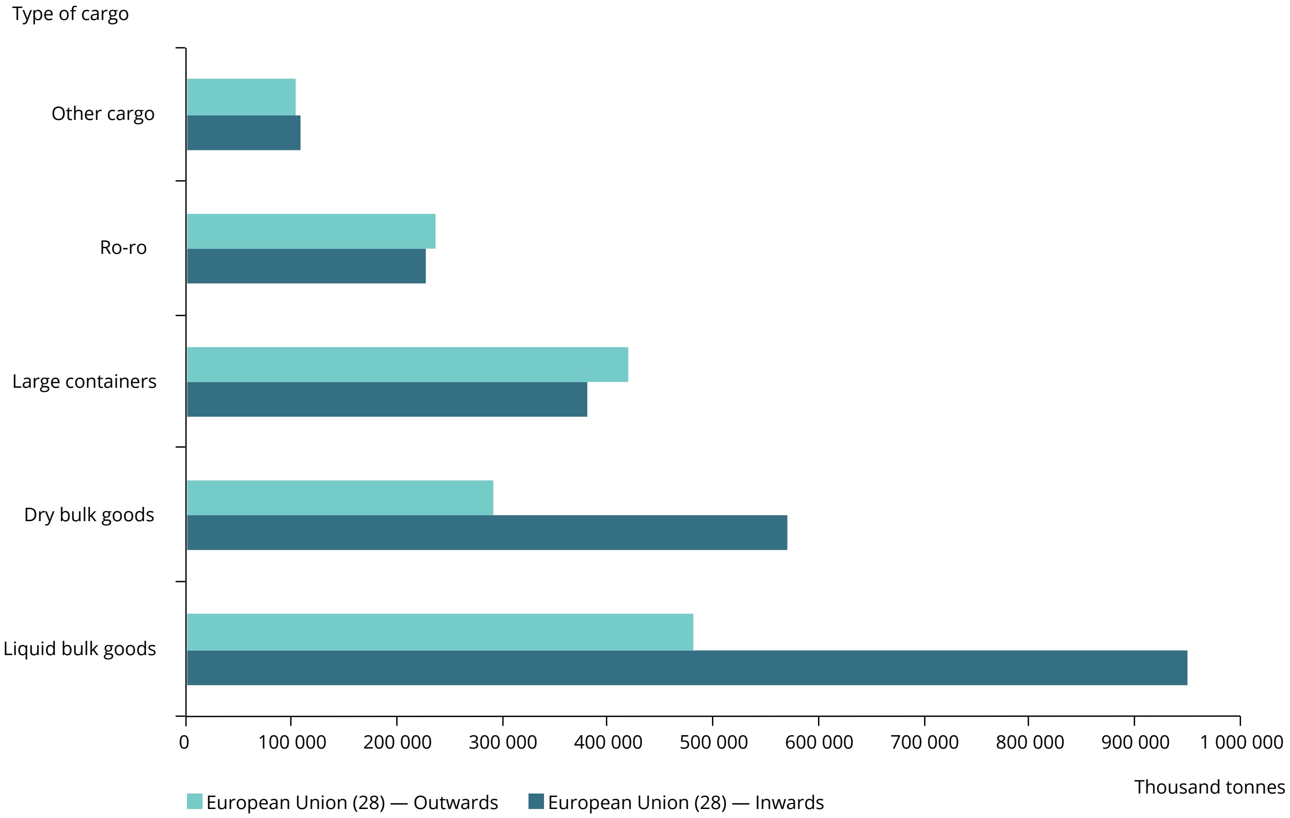
(6) Roll-on/roll-off (ro-ro) ships are vessels designed to carry wheeled cargo, such as cars, trucks, semi-trailer trucks, trailers and railroad cars, which are driven on and off the ship on their own wheels or using a platform vehicle, such as a self-propelled modular transporter.

Figure 2.5 **Gross weight of goods handled in main ports by direction and type of cargo in 2015**



Note: The main ports are those that have annual movements of more than 200 000 passengers or record more than 1 million tonnes of cargo. Ports are selected on one of these criteria.

Ro-ro, roll-on/roll-off.

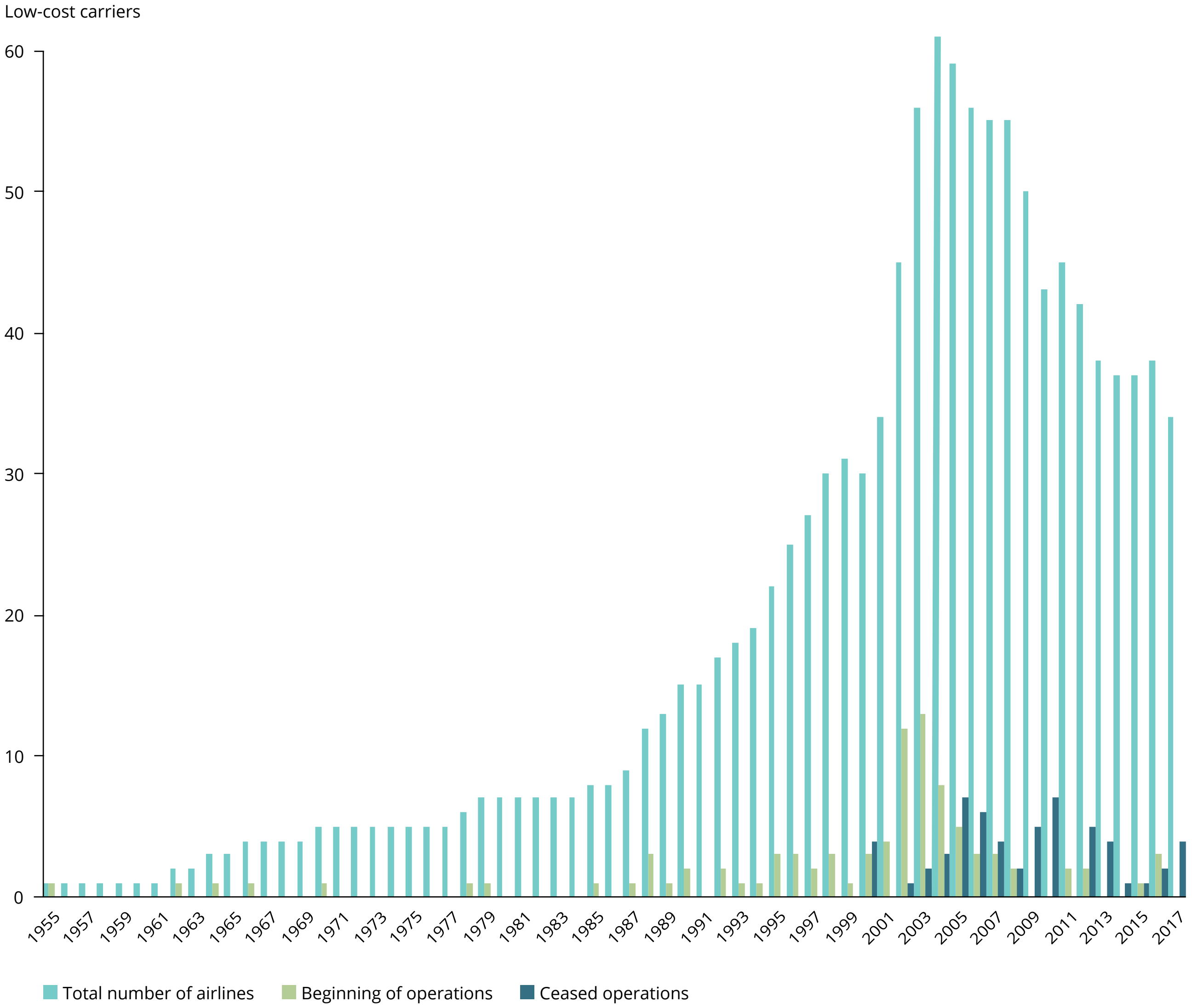
Source: Eurostat, 2017a.

In scenarios with high levels of economic growth, projections suggest that these unitised cargo ships could produce, for example, two thirds of all global maritime CO_2 emissions by 2045-2050 (IMO, 2014).

2.2.3 Transport prices

Reductions in transport costs have also had an important impact on the development of both the aviation and the shipping sectors. This includes the increasing power of engines, the introduction of larger containers and the increasing size of ships (WTO, 2013). For aviation, the introduction of low-cost flights accounts for much of the recent growth of the passenger aviation market in Europe, triggered by the liberalisation of the market, the reduction or eradication of subsidies and increased efficiency due to an increase in competition (EEA, 2016b). These flights cover new destinations, and they have provided significant competition to the traditional carriers. The low-cost carriers' share of total flights increased from 13.7 % in 2005 to 27.5 % in 2014, while traditional scheduled flights fell from 64.2 % to 53.3 %, with business aviation, charters and cargo making up the remaining proportion of the market (EASA et al., 2016). Total numbers of low-cost carriers in the European context are illustrated in Figure 2.6. The data capture the year when the operation began, as well as, for some carriers, the year of closure.

Figure 2.6 **Number of aviation low-cost carriers in Europe**



Source: ICAO, 2017a.

The low-cost operators Ryanair and EasyJet were the two highest GHG emitters in the European aviation sector in 2016, accounting for 8.4 Mt CO_2e and 5.1 Mt CO_2e respectively (EEA, 2017e).

2.2.4 Exemptions and incentives

Fuel used for international aviation purposes is generally exempt from taxation. This preferential taxation regime is linked with the 1944 Chicago Convention on International Civil Aviation (Article 24) — an agreement now more than 70 years old — and, within the EU, with the Energy Taxation Directive (2003/96/EC; EU, 2003). Within the EU alone, the absence of fuel taxation has been estimated to result in a significant reduction in operational costs for airlines, providing an annual revenue saving of between EUR 20 billion and EUR 32 billion per year (Korteland and Faber, 2013). While some Member States do charge value added tax (VAT) on domestic air travel tickets, no VAT is issued on international tickets in the EU. Korteland and Faber (2013) have similarly estimated that if 20 % VAT were to be placed on jet fuel consumption, EU tax revenues would additionally increase by a minimum of EUR 10 billion per year. Airlines can also be offered a number of incentives to operate at certain airports and fly to certain destinations (EEA, 2014a). Further, airports may receive state aid from public authorities, for example to support operations and for new infrastructure investments.

For the maritime sector, there is no international equivalent to the aviation taxation agreement under the Chicago Convention. There are a number of precedents that have established a de facto equivalent tax exemption for international maritime fuels. This includes, within the EU context, the EU's Energy Taxation Directive (2003/96/EC), which prescribes that fuel use for the purposes of navigation within EU waters is exempted from taxation, with exceptions for private pleasure craft and electricity produced on board vessels (EU, 2003).

An analysis by the German Environment Agency concludes that the transport sector receives more environmentally harmful subsidies in Germany compared with many other sectors, particularly because of the tax exemptions for aviation (UBA, 2014).

Such exemptions and incentives can preclude the use of alternative, more environmentally sustainable transport modes such as rail travel, which, although generally also highly subsidised, become financially less competitive.

3 Environmental pressures from aviation

Key messages

- Aviation activities and related support services lead to a number of environmental pressures, including emissions of GHGs and air pollutants, noise pollution, water demand and pollution, and waste generation.
- CO_2 emissions from the aviation sector continue to increase, and it is estimated that they will account for 22 % of global emissions by 2050 if no further action is taken.
- Within the EU, GHG emissions from international aviation have more than doubled since 1990. They were almost 25 % higher in 2016 than in 2000. Emissions from the sector have increased over each of the past 4 years (2013-2016), at an average rate of around 2 % each year.
- Aviation's contribution to EU GHG emissions also becomes increasingly important in absolute terms. This is due to the projected growth in this sector and because the contribution from the road transport sector is expected to decrease due to the anticipated implementation of mitigation measures that will reduce emissions in other sectors.
- While progress is being made in increasing aircraft engine efficiencies and reducing the emission rates from engines, such technological measures are not in themselves expected to be sufficient to reduce the overall emissions of GHGs or air pollutants from the sector.
- Increasing demand for aviation will make achievement of the EU's air quality objectives and goals to reduce noise exposure more challenging.

3.1 Sector summary

Aviation is an integral part of the modern world, facilitating and contributing to economic growth and social benefits (Kandaramath Hari et al., 2015; EEA, 2016b). The foundation of modern commercial aviation stems from the end of the Second World War, when aviation became increasingly accessible as ex-military aircraft were converted to facilitate the reliable and safe transport of people and cargo. Following the introduction into service of the first commercial jetliners in the early 1950s, the aviation sector entered into an era often referred to as the Jet Age. Jet aircraft were capable of faster and longer flights, while simultaneously carrying a larger number of passengers and/or a larger amount of cargo. Further technical advances and developments of alternative aircraft materials have helped increase efficiencies and lower ticket costs, opening up the skies to an ever-increasing number of passengers. Aircraft performance and flight operations have continued to improve with the integration of digital technologies from the 1980s onwards.

Initially, nearly all airlines were state owned and regarded as 'flag carriers'. Such thinking was largely enshrined in the 1944 Chicago Convention, with its first article confirming that each contracting state has complete and exclusive sovereignty over the airspace above its territory. This resulted in a worldwide network of bilateral air services, with countries providing each other with the rights for the operation of air transport between their territories (OECD, 2014). At the European level, the ways in which the international air transport business developed and was being regulated was fundamentally incompatible with the Treaty of Rome (7).

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(7) The Treaty of Rome set up the European Economic Community (EEC), which brought together six countries (Belgium, France, Germany, Italy, Luxembourg and the Netherlands) to work towards integration and economic growth, through trade.

Exemptions therefore had to be made to the treaty for aviation (and shipping). Air transport was effectively excluded from EU policies for 30 years. With the exception of time-limited subsidies for commercial air services in peripheral areas, subsidising air operators directly is not allowed under EU legislation (in contrast to rail transport) (EEA, 2007; Merkert and Williams, 2010).

3.2 Why are activities in the aviation sector important for the environment?

Aviation and its associated activities create various pressures on the environment and climate. Among these impacts are:

- GHG emissions (mainly CO_2) and water vapour;
- air pollutants such as nitrogen oxides (NO_x), sulphur oxides (SO_x), carbon monoxide (CO), unburned or partially combusted hydrocarbons (also known as volatile organic compounds or VOCs), and particulate matter (PM), pollutants formed by the combustion of jet fuels during flight as well as during take-off and landing;
- aviation NO_x emissions when cruising at high altitudes result in an enhancement of ozone (O_3) in the upper troposphere and lower stratosphere, resulting in climate warming (e.g. Søvde et al., 2014);
- noise pollution, especially that caused by airframe and engine noise at or around airports during aircraft take-off, climb-out, approach and landing flight stages;
- pressures on land use and natural habitats derived from the location of airports and the need for access and infrastructure support services around airports;
- other significant pressures from the functioning of the airport, such as energy use, water use, and pollution and waste production (Figure 3.1).

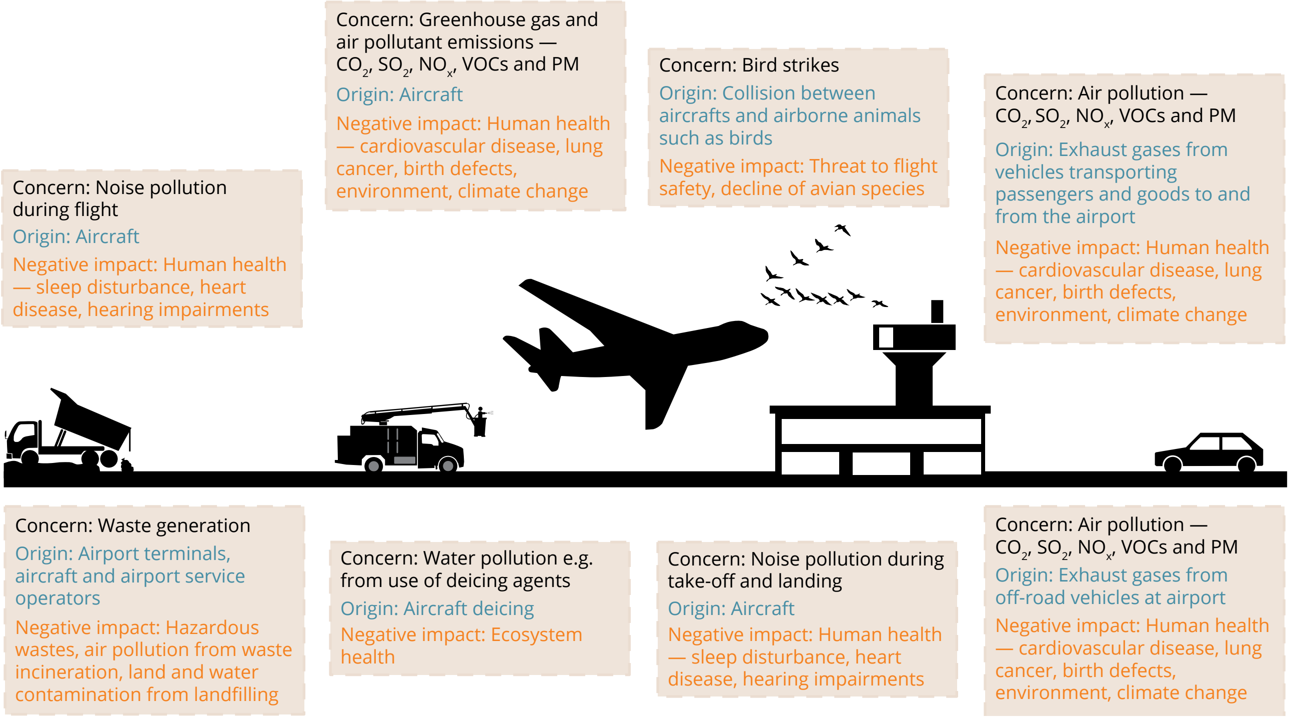
3.2.1 Greenhouse gas emissions

The contribution of aviation to global GHG emissions is approximately 1-2 % of total emissions (Harrison et al., 2015). Emissions from international aviation in Europe have more than doubled since 1990 (increasing by 108 %), despite some reduction in the years following the 2008 economic recession. Emissions from the sector have increased over each of the past 4 years (2013-2016; EEA 2017a, 2017b), at an average rate of almost 2 % each year. Within the EU-28, emissions from aviation accounted for around 13 % of total transport GHG emissions (Figure 3.2) and around 3.3 % of the total EU CO_2 emissions (EEA, 2017a).

Box 3.1 Deregulation of the European aviation market

The deregulation of the domestic aviation market in the United States in 1978 provided the stimulus for the European Commission to propose similar deregulation in Europe. This deregulation took place mainly between 1987 and 1997, through the development of three deregulation packages to liberalise the aviation market (OECD, 2014). The two first policy packages, launched in 1987 and 1990, focused on reducing fare restrictions and capacity constraints, while allowing greater cooperation between airlines. Subsequently, between 1993 and 1997, the final deregulation package removed practically all fare restrictions and granted EU airlines the right to operate within the entire EU as opposed to only their home countries (Regan, 2014). The establishment of a single market in EU air transport led to a wide transformation of the aviation industry in Europe, which is increasingly dominated by competition and commercialisation. Between 1992 and 2000, the number of scheduled airlines nearly doubled. Many of these were low-cost carriers, which benefited from the deregulation and a switch to underused airports. This competition is also reflected in the airports themselves, with increasing levels of privatisation. As of 2016, 53 % of airports in the EU were fully publicly owned, 17 % fully private, and 30 % under some form of mixed ownership (ACI, 2016). The European aviation sector currently supports close to 5 million jobs (EC, 2017a).

Figure 3.1 **Examples of environmental pressures from aviation activities**



Concern: Noise pollution during flight
Origin: Aircraft
Negative impact: Human health — sleep disturbance, heart disease, hearing impairments

Concern: Greenhouse gas and air pollutant emissions — CO_2, SO_2, NO_x, VOCs and PM
Origin: Aircraft
Negative impact: Human health — cardiovascular disease, lung cancer, birth defects, environment, climate change

Concern: Bird strikes
Origin: Collision between aircrafts and airborne animals such as birds
Negative impact: Threat to flight safety, decline of avian species

Concern: Air pollution — CO_2, SO_2, NO_x, VOCs and PM
Origin: Exhaust gases from vehicles transporting passengers and goods to and from the airport
Negative impact: Human health — cardiovascular disease, lung cancer, birth defects, environment, climate change

Concern: Waste generation
Origin: Airport terminals, aircraft and airport service operators
Negative impact: Hazardous wastes, air pollution from waste incineration, land and water contamination from landfilling

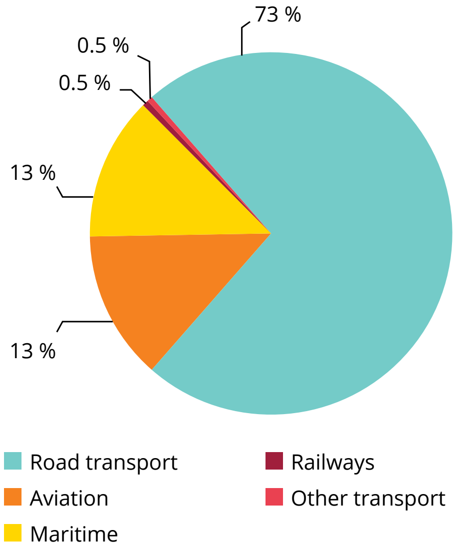
Concern: Water pollution e.g. from use of deicing agents
Origin: Aircraft deicing
Negative impact: Ecosystem health

Concern: Noise pollution during take-off and landing
Origin: Aircraft
Negative impact: Human health — sleep disturbance, heart disease, hearing impairments

Concern: Air pollution — CO_2, SO_2, NO_x, VOCs and PM
Origin: Exhaust gases from off-road vehicles at airport
Negative impact: Human health — cardiovascular disease, lung cancer, birth defects, environment, climate change

Note: CO_2, carbon dioxide; NO_x, nitrogen oxides; PM, particulate matter; SO_2, sulphur dioxide; VOC, volatile organic compound.

Figure 3.2 **Proportions of transport GHG emissions in the EU-28 in 2015**



Note: International aviation, international shipping and maritime navigation are not included in the EU-28 Member State inventories and are thus not included in the total EU-28 numbers. Railways — direct emissions only. Does not include emissions from power plants for electrically powered locomotive stock.

Source: EEA, 2017a (TERM 002 indicator).

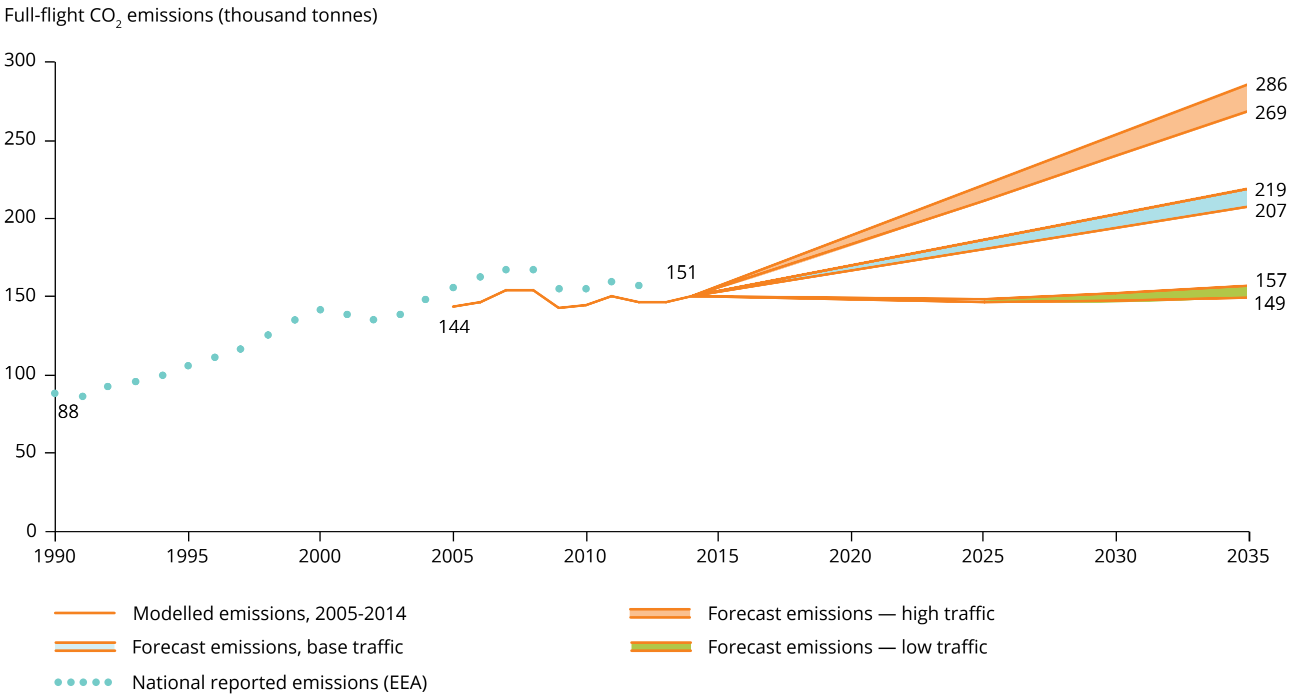
The sector is expected to continue to grow rapidly in the coming decades, with a predicted annual growth in emissions from the European aviation sector of between 1 % and 4 % (Figure 3.3) (EASA et al., 2016). Globally, it has been estimated that aviation may contribute up to 22 % of CO_2 emissions by 2050 if further action to reduce emissions from the sector is not taken (EP, 2015). The objective of the Paris Agreement is to limit global average temperature rise to 2 °C above preindustrial levels, and if possible to 1.5 °C.

To remain below the 2 °C rise, recent research suggests that global aviation emissions in 2030 should not be more than 39 % higher than in 2005, while in 2050 they should be at least 41 % lower than in 2005 (EP, 2015).

3.2.2 Other contributions to climate change

Aviation also contributes to emissions of short-lived climate forcers including NO_x, SO_2 and black carbon (BC), which lead to changes in the radiative forcing of the atmosphere (Box 3.2). Such pollutants can have both indirect global warming and cooling effects, as they undergo complex chemical reactions in the atmosphere, reacting with other GHGs (mainly O_3, methane and sulphate aerosols). Sulphate aerosols

Figure 3.3 **Aviation CO_2 emissions — historical and future forecasts**



Note: CO_2 (carbon dioxide) emissions cover all departures from the EU. Modelled and forecast emissions were estimated by IMPACT, an aviation emissions model (Eurocontrol, 2017).

Source: EASA et al., 2016.

Box 3.2 **Radiative forcing**

Radiative forcing: The change in the amount of light that is absorbed or scattered when it encounters components of the atmosphere such as GHGs and aerosols.

Positive radiative forcing: Leads to atmospheric **warming** and is associated with emissions of GHGs, such as CO_2, and certain other pollutants, such as BC. GHGs absorb and re-emit infrared radiation back to the Earth's surface.

Negative radiative forcing: Leads to atmospheric **cooling** and is associated with certain aerosol particles that may reflect solar radiation.

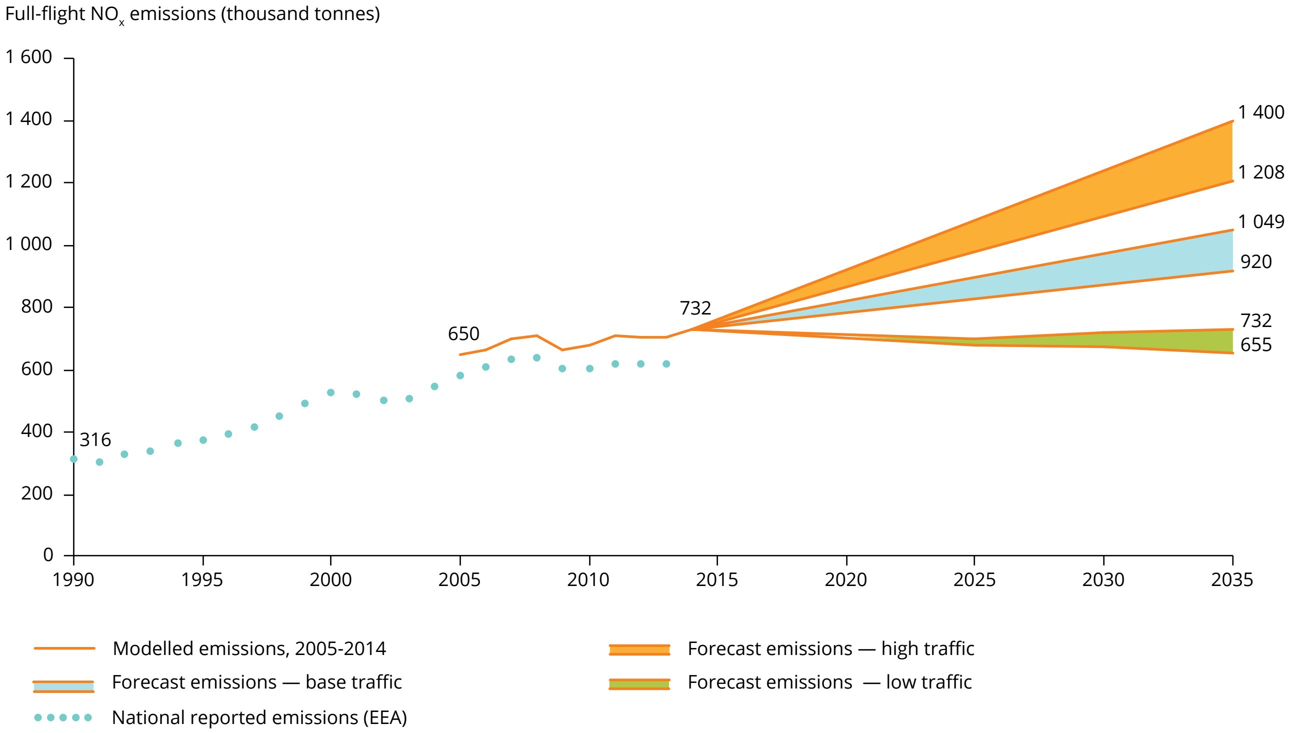
and water vapour can result in contrails and cirrus cloud formation, which can contribute to net climate warming. Estimating the net climate impacts of aviation is complex, and there remain fundamental uncertainties in understanding of the sector's net climate impacts (Brasseur et al., 2016).

3.2.3 Aviation and air pollution

Aviation is a key source of several air pollutants, emitted during taxiing, take-off and landing, and cruising at altitude. In addition, emissions from the numerous ground support services, such as ground vehicles operating at or around runways, airport heating, and transport to and from airports by passengers and freight services, significantly contribute to the emissions of air pollutants.

As seen for GHG emissions, the increasing demand for aviation is leading to increased emissions of air pollutants from the sector. While progress is being made to increase aircraft engine efficiencies and reduce the emission rates from engines, such technological measures are not in themselves expected to be sufficient to reduce the overall emissions from the sector (EASA et al., 2016; Figure 3.4). Further, operational measures such as continuous descent

Figure 3.4 Aviation NO_x emissions — historical and future forecasts



Note: NO_x (nitrogen oxides) emissions cover all departures from the EU. Modelled and forecast emissions were estimated by IMPACT, an aviation emissions model (Eurocontrol, 2017).

Source: EASA et al., 2016.

approaches (CDAs) have also led to decreasing emissions. CDA is a specific way in which an aircraft approaches airports prior to landing, and is designed to reduce fuel consumption and noise compared with other conventional descents.

The health impacts of air pollutants caused by aviation are influenced by several factors, including the altitude at which pollutants are emitted. The largest health impacts are caused by air pollution at ground level due to proximity to human populations, further influenced by local weather conditions and the type of pollutants (e.g. NO_x, O_3 or PM). It is important to note that the climate change impacts of sulphur and PM are more detrimental at higher altitudes.

There is increasing understanding of the health impacts of air pollution, particularly nitrogen dioxide (NO_2) and PM (e.g. Walton et al., 2015; WHO 2013, 2016). Recent research suggests that, globally, aviation emissions could cause 16 000 premature deaths per year because of exposure to particulate matter with a diameter of 2.5 µm or less ($PM_{2.5}$) and O_3 (90 % confidence interval, i.e. 8 300-24 000) (Yim et al., 2015). Of these, 3 700 premature deaths are estimated to occur in Europe (with a range of 2 100-5 500). Emissions from landing and take-off are estimated to account for 49 % of total premature deaths. The monetised cost of the premature deaths due to aviation emissions in Europe has been estimated to be approximately EUR 7.51 to 8.53 billion per year, depending upon the selected discount rate (Yim, et al., 2015).

3.2.4 Noise pollution

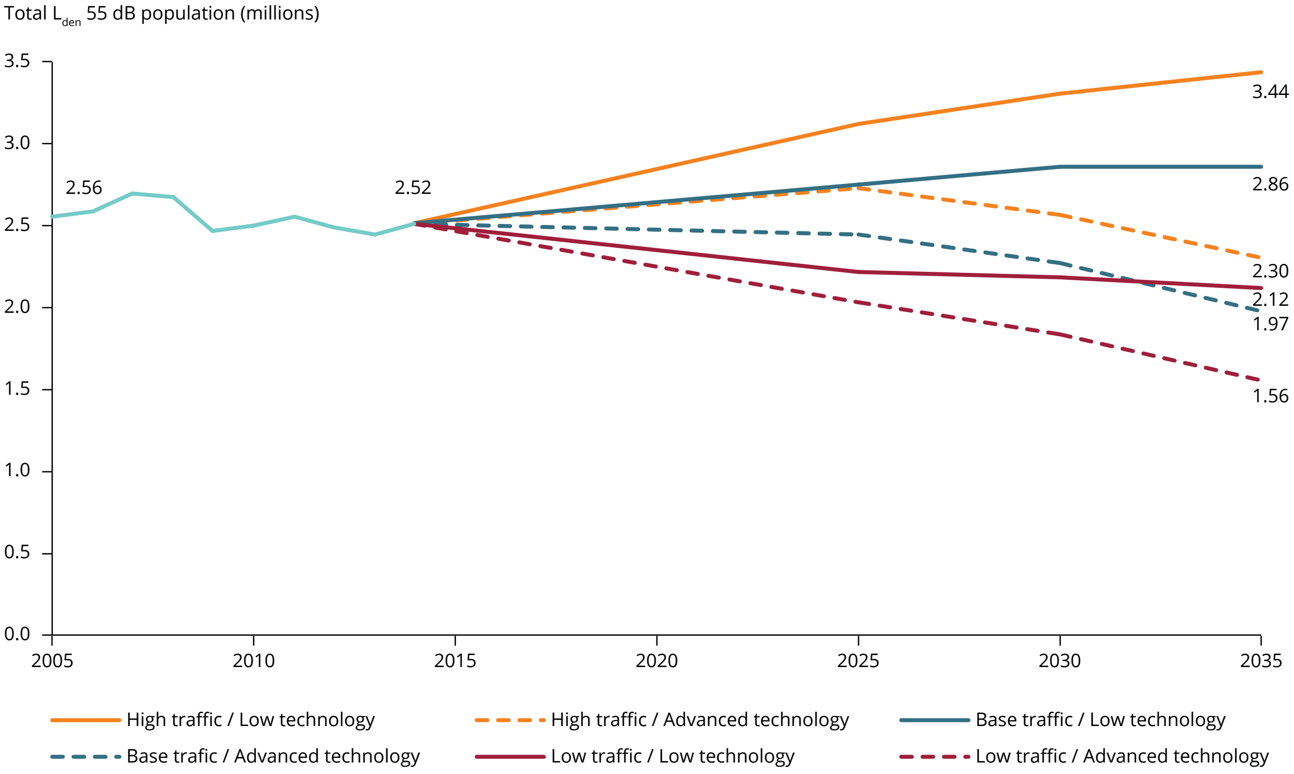
Population exposure to aircraft noise is generally assessed through the calculation of noise contours around airports and the size of the population within these affected areas (Correira et al., 2013). The noise contours represent areas in which noise levels exceed a given decibel (dB) threshold. Recent analysis shows that approximately 4.1 million people in Europe (EEA, 2017c) are affected by exposure to noise above the 55 dB day-, evening- and night-level (L_{den}) indicator, designed to assess annoyance and set under the EU's Environmental Noise Directive (2002/49/EC; EU, 2002). The noise exposure problem is aggravated by the typical growth of the population in the vicinity of airports. Furthermore, past work on noise dose-response curves and health effects shows that aircraft typically generate more annoyance and sleep disturbance than other sources at the same dB L_{den} levels (EASA et al., 2016).

Noise exposure is associated with issues such as sleep disturbance, annoyance, nervousness and increased blood pressure (Correira et al., 2013), as well as with clinical symptoms such as hypertension, cardiovascular diseases and cognitive impairment in children (e.g. WHO, 2011; EEA, 2014b). A 10-20 % higher risk of stroke, heart and circulatory disease in the areas most exposed to aircraft noise was identified through a survey of 3.6 million residents living near Heathrow Airport, London (Hansell et al., 2013). Similarly, a study following 4 000 adults living close to Stockholm Airport (Eriksson et al., 2010) suggested that there was an increased risk of hypertension in men after long-term noise exposure and that participants that identified aircraft noise as an annoyance may be particularly at risk from noise-related hypertension.

The System for Airport Noise Exposure Studies (STAPES) is a multi-airport noise model jointly developed by the EC, EASA and Eurocontrol. Research using the STAPES noise model to quantify noise exposure at 45 large European airports indicates that noise exposure has stabilised in the past 10 years, largely due to technological improvements to engines, fleet renewal, increased air traffic management efficiency and the 2008 economic recession (EASA et al., 2016). Between 2005 and 2014, fleet renewal has resulted in a 12 % reduction in the average noise energy per operation (EASA et al., 2016). However, continuous efforts will be needed to stabilise or reduce noise emissions in the future (Figure 3.5); projections of future population noise exposure are very dependent upon assumptions such as the rate at which new, quieter engine technologies will become available and be implemented in aircraft fleets and on the level of air traffic demand (EASA et al., 2016).

Noise-related operating restrictions at EU airports are addressed in Regulation No 598/2014 (EU, 2014) on the procedures concerning the introduction of noise-related operating restrictions. The Regulation is consistent with international principles on noise management, the 'balanced approach', agreed by ICAO, which comprise four main elements:

Figure 3.5 **Population exposure to aviation noise at 45 large European airports — historical and future forecasts**



Note: dB, decibels; L_{den}, day-, evening- and night-level indicator; STAPES, System for Airport Noise Exposure Studies.

Source: EASA et al., 2016.

- making aeroplanes quieter, for example by setting noise standards;
- managing land use around airports in a sustainable way;
- adapting operational procedures to reduce the noise impact on the ground; and
- introducing operating restrictions.

3.2.5 Additional environmental impacts

The focus in this report is on air and noise pollution and on GHG emissions. However, as the summary below shows, aviation can also directly or indirectly affect ecosystems around airports, primarily through land use pressures, waste production and water pollution.

Land use pressures

The construction and operation of airports have a significant impact on surrounding land use. Impacts stem mainly from development of buildings and transport infrastructure. Changed land use includes altered land use patterns of already developed land, with shifts from residential to commercial land use, as well as degradation of previously undeveloped habitats. Through their large economic impact in the surrounding area and function as major employers, airports can drive urban expansion by inducing various development projects around the airport. However, there are options to manage such expansion through proper land use planning policies (Swangjang and Iamaram, 2011). Green areas in the immediate vicinity of airports can act as buffers, limiting the exposure of noise and air pollution among neighbouring populations. However, overall increases in land use pressures on natural habitats, and in particular wetlands and open plains, can also lead to an increase in incidents such as bird strikes at the airport (DeVault et al., 2013). Regarding land use planning and management, EU Regulation No 598/2014 (EU, 2014) also includes among other things the monitoring of encroachment.

Waste production

Aviation generates large amounts of waste, ranging from the reuse and recycling of disused aircraft to waste generation at airports. Airports can generate amounts of waste similar to those of small cities (Heathrow Airport Ltd, 2011). The environmental impact depends on the type of waste generated, including hazardous waste, and final disposal procedures, such as recycling, incineration and landfill (Fleuti, 2010).

In the EU, waste management practices at airports are regulated in a similar fashion to other large commercial and industrial sectors. Generally, approximately 85 % of waste generated at an airport might come from service partner activities, such as aircraft cleaning, retail and catering, with the remaining waste managed by the airport itself (for example, Heathrow Airport Ltd, 2011).

Water demand and pollution

The establishment of airport infrastructure and public services leads to increased water demand. In addition to the need to adequately manage and treat resulting wastewater, in many parts of Europe the use of de-icing fluids adds further to aviation-related environmental impacts. Such fluids are used in cold climates to remove (and delay the reformation of) snow, ice and frost on aircraft and airport infrastructure. These fluids subsequently fall to the ground either prior to, or during flight, and can be carried into streams, rivers or coastal waters unless properly managed (US EPA, 2012). De-icing fluids used at airports are based on formulations of either ethylene or propylene glycol. They also include additives that consist of metal corrosion inhibitors, rust inhibitors, thickening agents and surfactants, which can be toxic. Urea, a nitrogen-containing compound, is used for runway de-icing in airports in combination with glycols. Decomposition of urea consumes high levels of oxygen in surface waters, and can affect aquatic life by consuming the oxygen available to underwater organisms. Chemical leakages to waterbodies can be reduced through effective drainage systems to capture and treat water contaminated with de-icing fluids (Wallace and Liner, 2011).

3.3 What current monitoring measures are in place?

3.3.1 Greenhouse gas emissions

CO_2 emissions emitted by aviation activities are directly related to the amount of fuel consumed. This includes aviation fuel as well as that used by airport infrastructure, ground vehicles, etc. Current annual reporting of national emission inventories (based on fuel sold at the Member State level) ensures that comparable data from countries is submitted to the United Nations Framework Convention on Climate Change (UNFCCC), and to the EU under the EU Greenhouse Gas Monitoring Mechanism Regulation (MMR) (EU, 2013b).

Within the EU ETS, all flights within the European Economic Area region are required to monitor, report and verify their CO_2 emissions and data in tonnes CO_2 per km, and to surrender allowances against those emissions. Each operator has to submit a monitoring plan and appropriate supporting documentation, with detailed guidance on the monitoring plans provided by the European Commission (for details, see EEA, 2017e).

3.3.2 Air pollution

Pollutant concentrations in the air, e.g. PM and NO_2 levels, are typically measured at air quality monitoring stations located at the airports. Within the EU, minimum air quality monitoring and reporting requirements are set in the EU's Air Quality Directive (EU, 2008). Attributing the locally measured levels of air quality to aircraft, ground equipment and other local sources of air pollution requires further modelling and source apportionment approaches. As highlighted by a study of Amsterdam Schiphol Airport, such analysis can require access to local traffic data to properly disaggregate the impact of aircraft from other sources of air pollution such as road transport (Franssen et al., 2002).

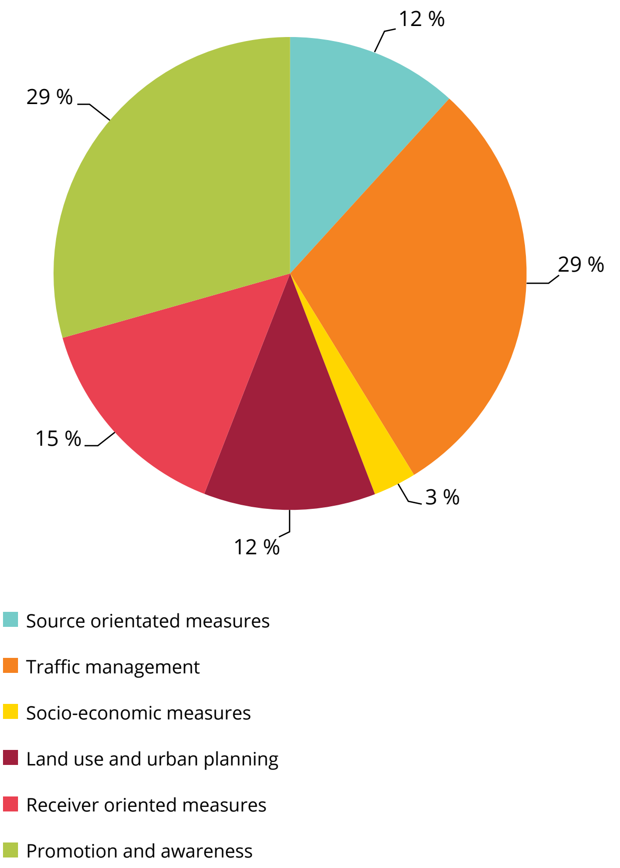
As for GHGs, emissions from landing, take-off and cruising are captured through national emission inventory reporting by Parties to the Gothenburg Protocol under the United Nations Economic Commission for Europe (UNECE) Convention on Long-range Transboundary Air Pollution (LRTAP) (UNECE, 2012), and within the EU under the National Emission Ceilings Directive (EU, 2016a).

3.3.3 Noise pollution

The EU's Environmental Noise Directive (EU, 2002) defines a common approach intended to avoid, prevent or reduce on a prioritised basis the harmful effects, including annoyance, due to exposure to environmental noise, and to provide a basis for developing measures to reduce noise emitted by the major sources, including aircraft (EEA, 2014b). To achieve that aim, it requires the following actions to be implemented:

- the determination of exposure to environmental noise, through noise mapping, by methods of assessment common to the Member States;
- ensuring that information on environmental noise and its effects is made available to the public;
- adoption of action plans by the Member States, based upon noise mapping results, with a view to preventing and reducing environmental noise where necessary and particularly where exposure levels can induce harmful effects on human health, and to preserving environmental noise quality where it is good.

Figure 3.6 **Reported noise action plan measures relevant to major airports**



Source: EEA, 2017c.

More specifically, every 5 years, strategic noise maps are reported by Member States, including for major airports (i.e. every civil airport that has more than 50 000 movements — take-offs and landings — per year). Action plans provided by Member States identify the initiatives designed to manage noise issues, including where necessary for major airports. Figure 3.6 shows an example of the information reported by Member States, an overview of the types of measures included in noise action plans.

3.4 What current and future policy measures are in place?

3.4.1 Greenhouse gas emissions

Due to the global nature and inter-dependencies of the aviation industry, many mitigation policy options are negotiated and agreed within international fora rather than being set by the EU itself. ICAO develops mitigation policies in the aviation sector, among other things, in relation to the Kyoto Protocol. By the end of the Protocol's first commitment period in 2012, very little progress in terms of the introduction of concrete mitigation measures had been achieved, although an 'aspirational' goal of 2 % annual fuel efficiency improvement had been introduced in 2010 (Bows-Larkin, 2015; ICAO, 2016).

Reflecting this limited progress at the international level, more proactive action was taken at the European level. Since January 2012, CO_2 emissions from aviation have been included in the EU ETS, although flights to and from non-European Economic Area countries were subsequently excluded from the scope of the ETS under a 'stop the clock' provision, agreed to enable a global agreement on aviation emissions. An analysis of the aviation emissions accounted for under the ETS is included in EASA et al. (2016).

In October 2016, ICAO agreed to establish a global market-based measure (GMBM) to offset international aviation CO_2 emissions (ICAO, 2016), referred to as the Carbon Offsetting and Reduction Scheme for International Aviation (CORSIA). CORSIA aims to offset the CO_2 emissions generated by international aviation activities above 2020 levels, by requiring emitting airlines to buy and surrender 'emission units' generated by projects in the aviation and other sectors to offset CO_2 emissions. The first two phases of CORSIA (pilot and first phase) will run from 2021 to 2027 and will be voluntary.

Following the adoption of CORSIA, the European Commission has published a proposal for amendments to aviation emissions covered by the ETS. The proposal suggests that the current reduced scope should be

Box 3.3 The Carbon Offset and Reduction Scheme for International Aviation (CORSIA)

CORSIA sets out to cap emissions by 2020 and enable carbon-neutral growth beyond this baseline (ICAO, 2016). CORSIA will be initiated through a voluntary period from 2021 onwards and becomes mandatory from 2027. The initiative builds on initial work carried out by the international aviation sector to reduce net aviation CO_2 emissions by 50 % by 2050, from a 2005 baseline, through five key areas (ACI et al., 2010):

- improved technology;
- efficient infrastructure;
- efficient operations;
- economic measures;
- sustainable alternative fuels.

While CORSIA is the first global scheme of its kind covering an industrial sector, the final ambition level associated with the initiative has come under scrutiny for a number of reasons.

- Its reliance on cheaper carbon offsetting in other sectors, rather than reducing emissions from the sector itself, is primarily due to the high abatement cost in the aviation sector (Harvey, 2016; Scheelhaase, et al., 2016). Such a development could arguably reduce pressures to develop alternative technologies and fuels within the aviation sector itself.
- It covers only international aviation, and thus the 38 % of global aviation emissions contributed by domestic aviation is not covered by the agreement (World Bank, 2016) (8).
- Research suggests costs will be significantly less than underlying price volatility of jet fuel and, as a result, it is unlikely that CORSIA will provide a sufficient incentive for airlines to improve their fuel efficiency above that already achieved by fuel prices.
- It will be essential to ensure that any carbon offsets are of high environmental integrity, i.e. demonstrate that the activity producing the offset is 'additional', and can advance sustainable development goals (SEI, 2016).

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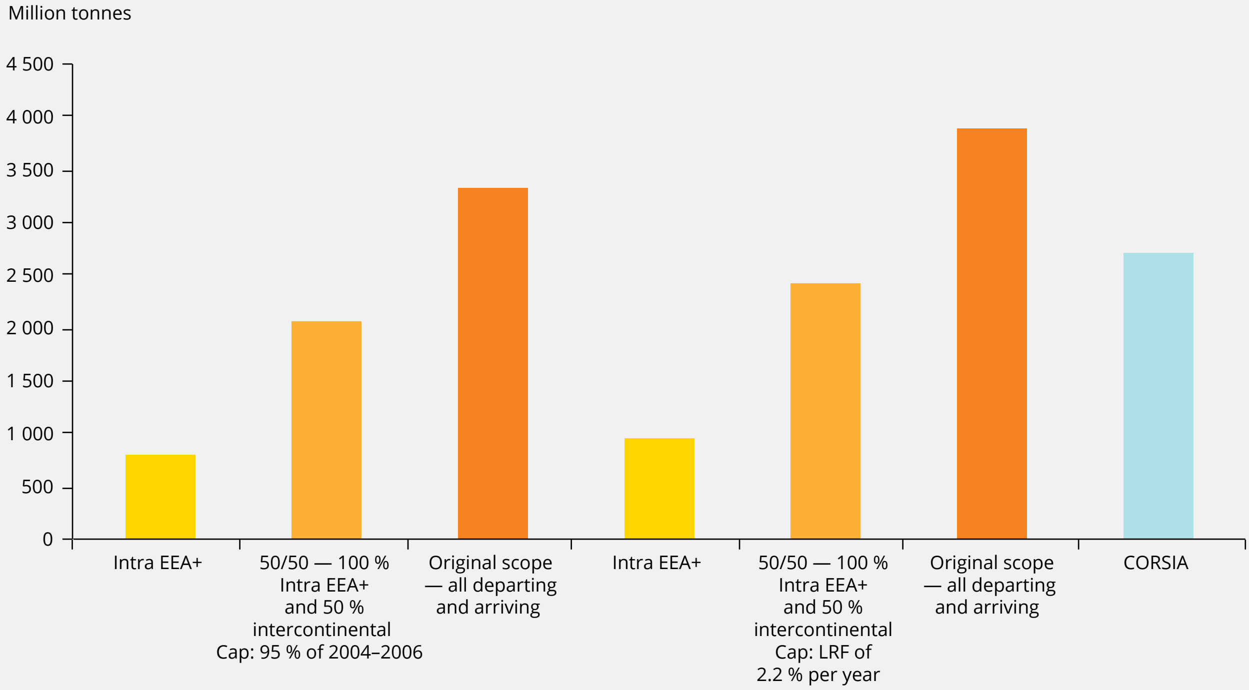
(8) However, the National Determined Contributions within the Paris Agreement covers emissions by domestic aviation.

Box 3.4 Comparison between EU ETS and CORSIA

Comparisons between EU ETS and CORSIA depend in particular upon the assumptions used with regard to the level of cap set and the chosen geographical coverage. Results from a recent analysis undertaken by CE Delft (2016) are shown in Figure 3.7 for three different scenarios. If the current cap for EU ETS is kept constant, the demand for European emission allowances (EUAs) under the ETS over the period 2021-2035 will vary depending on the geographical range (from 796 Mt CO_2e for intra-European Economic Area flights including Switzerland (European Economic Area+, EEA+), to 3 323 Mt if all flights are considered as per the ETS original scope).

If the cap is altered and a linear reduction factor of, for example, 2.2 % per year is applied, as is proposed for stationary ETS emission sources, the results would again vary depending on the geographical range. The demand for allowances would increase to 956 Mt for the intra- EEA+ scenario, and 3 888 Mt if all flights are considered (as per the ETS's original scope). These outcomes need to be set in the context of the demand for allowances for CORSIA of 2 711 Mt.

Figure 3.7 Estimated demand for allowances under the ETS and CORSIA



Note: EEA+, European Economic Area including Switzerland. LRF, Linear reduction factor.

Source: Based on CE Delft, 2016a.

continued while the details of CORSIA are developed by ICAO (EC, 2017b). The European Parliament and Council are presently negotiating the proposal, with the aim of reaching an agreement by the end of 2017.

ICAO also recently agreed to adopt a new CO_2 standard for aircraft emissions to improve aircraft fuel efficiency. Agreed in March 2017, the standard will apply to new aircraft type designs from 2020 onwards, and to aircraft type designs already in production as of 2023. Production of those aircraft that do not meet the standard by 2028 will no longer be permitted, unless their designs are sufficiently modified (ICAO, 2017b).

3.4.2 Air pollutant emissions and air quality

Air quality at and around airports, along with other air pollutant sources, is regulated by the EU through the establishment of air quality standards for relevant pollutants (EU, 2004, 2008). EU air legislation follows a twin-track approach of implementing these local air quality standards as well as source-based mitigation controls. These source-based mitigation controls include binding national limits for emissions of the most important air pollutants (EU, 2016a). They address aircraft landings and take-offs (but exclude 'cruise' emissions above 3 000 feet or 914 metres), as well as a number of emission sources at airports. These sources include aircraft and the associated support equipment. The passenger and road freight movements can contribute significantly to local levels of the two air pollutants most responsible for harm to human health, PM and NO_2.

ICAO emission certification standards help to regulate emissions from aircraft engines, including NO_x (EASA et al., 2016). To improve fuel efficiency, engine pressures and temperatures can be increased, which can lead to higher NO_x emissions. NO_x limits have been introduced to help mitigate the potential trade-off with fuel burn improvements. The limits were developed and agreed by ICAO's Committee on Aviation Environmental Protection (CAEP), the body that assists the main ICAO Council in formulating new policies and adopting new standards and recommended practices related to aircraft noise and air pollutant emissions, and more generally to aviation environmental impacts. Since January 2013, all in-production engines must meet the so-called CAEP/6 standard.

3.4.3 Noise abatement

As noted in the preceding section on noise, key sources of environmental noise, including those from aviation, are addressed under the EU Environmental Noise Directive (END) (EU, 2002). This includes requirements for Member States to develop noise maps and action plans.

Accompanying the END, Regulation (EU) No 598/2014 lays down rules, where a noise problem has been identified, on the process to be followed for the introduction of noise-related operating restrictions on an airport-by-airport basis (EU, 2014). To help improve noise levels and to limit or reduce the number of people significantly affected by potentially harmful effects of aircraft noise, this regulation introduced the principle of a 'balanced approach' to aircraft noise management at airports, in line with relevant ICAO guidance (ICAO, 2008). The focus, once a noise-related issue has been identified under the END, is on reducing noise exposure where it is excessive and above national noise limits. Out of the 79 major airports in the EU, 28 have so far implemented a noise action plan (EASA et al., 2016). These plans cover operational measures (e.g. optimised flight procedures) as well as operating restrictions (e.g. airport night-time restrictions) and measures focused on those impacted by the noise, such as house insulation. The balanced approach also highlights the importance of stakeholder engagement.

3.5 What current mitigation options exist?

The following sections address opportunities to mitigate the environmental impacts of aviation through the 'avoid, shift and improve' framework

3.5.1 Avoid

Reducing air travel demand is challenging. Constraining demand is viewed as politically unpopular and there is minimal reference to this potential mitigation measure in government literature (Bows-Larkin, 2015). To date, developing more sustainable travel policies by attempting to change cultural or societal practices has primarily targeted road transport rather than aviation and commuting and business travel rather than leisure activities (Holden and Linnerud, 2011). This is illustrated by a continued high level of air travel among individuals otherwise defining themselves as 'pro-environmentalists', who do not abstain from air travel despite a relatively high awareness of environmental issues (Alcock et al., 2017). However, improved online technologies have facilitated the use and accessibility of videoconference and remote online meetings for many organisations, helping reduce to some extent the need for certain business-related travel. Further, if avoidance is not an option, carbon offset information and schemes can influence consumer behaviour by providing individuals or businesses with environmentally friendly options. Carbon offsetting is essentially a way to balance out consumers' carbon footprints by funding a reduction of an equal amount in some other part of the world, for example via projects investing in renewable energy or a reduction in deforestation.

3.5.2 Shift

The adoption of alternative modes of transport such as rail, and high-speed rail in particular, are in line with the current policy priorities of the EU. However, additional policies need to be adopted to make such modes available and more competitive in the face of, for example, low-cost airfares.

Table 3.1 **Top 10 European airports (EEA member countries) in 2016 — ranking in terms of passenger traffic**

Rank	Airport	City	Country	Passengers in 2016
1	Heathrow Airport	London	United Kingdom	75 714 970
2	Charles de Gaulle Airport	Paris	France	65 935 748
3	Amsterdam Airport Schiphol	Amsterdam	Netherlands	63 618 867
4	Frankfurt Airport	Frankfurt	Germany	60 786 937
5	Istanbul Atatürk Airport	Istanbul	Turkey	60 011 454
6	Adolfo Suárez Madrid-Barajas Airport	Madrid	Spain	50 400 442
7	Barcelona El Prat Airport	Barcelona	Spain	44 131 031
8	London-Gatwick Airport	London	United Kingdom	43 136 047
9	Munich Airport	Munich	Germany	42 261 309
10	Leonardo da Vinci-Fiumicino Airport	Rome	Italy	41 738 662

Source: ACI Europe, 2017.

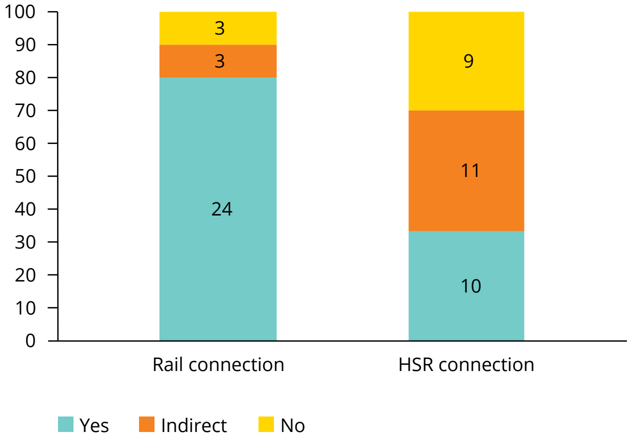
In terms of their potential to replace aviation, the competitiveness of other forms of transport generally depends on the distance travelled, time and cost. On the one hand, high-speed rail in the form of a fully integrated European network has the potential to effectively change the current European transport regime, especially through the elimination of short-haul routes such as those between Amsterdam and Brussels, Dusseldorf and Frankfurt, and Paris and London (EEA, 2014a). On the other hand, high-speed rail is considered competitive with aviation only for relatively short to medium distances (e.g. < 1 000 km) (EC, 2011). It also requires a high energy intensity for the related infrastructure. Shifting demand from aviation to rail could lead to an increase in overall noise exposure, as train noise tends to affect larger populations. In addition, there is an ongoing reliance on relatively short-haul connecting flights in the European hub network.

Improved integration of airports and the wider rail network, and high-speed rail in particular, would further enable passengers to undertake part or all of their journey via such travel modes. Information on the current rail connectivity of the 30 largest airports in Europe is provided in Figure 3.8. Many smaller airports are not as well connected, for example they might be accessible only via bus routes. The 2011 European Commission White Paper (EC, 2011) outlines the integration of airports into the wider travel network, with an ambition to connect all core network airports in Europe to the rail network by 2050.

Currently, non-aviation transport modes mainly dominate shorter distance travel, often for reasons of convenience and/or cost-competitiveness. However, for journeys greater than approximately 1 000 km, non-aviation transport modes would need to offer substantial advantages to compete with the time and cost savings offered by aviation. These advantages could include improved comfort such as dining and

Figure 3.8 **Airport accessibility by rail at the 30 largest airports in Europe**

Airport rail connections at 30 largest airports in Europe (2017) (%)



Note: HSR, high-speed rail.

Source: Based on ACI-Europe in Reichmuth et al. (2010) and updated for 2017. Note that during this period, London Luton overtook Prague Václav Havel as the 30th biggest airport in the EEA+ area.

Table 3.2 **Competitiveness of non-aviation forms of transport compared with aviation, and potential barriers to continued transition**

Travel distance	Example	Competitiveness	Potential barriers to transition
0-400 km	Brussels-Amsterdam Vienna-Budapest	Conventional rail usually faster than air travel and provides better opportunities for teleworking through internet access and greater working time availability compared with planes	Resilience in terms of ability to deal with disruptions and cost of rail transport
0-1 000 km	London-Paris Rome-Milan	High-speed rail enables a significant modal shift	Cost, especially for leisure travellers at short notice Location of airports can be more accessible to certain travellers
> 1 000 km	Madrid-Milan Warsaw-Zürich	Limited competitiveness by non-aviation transport modes. Would require other advantage such as significantly lower cost or comfort. Examples include long-range high-speed trains such as the Frecciorossa 1000, designed to challenge airlines through business-class-like amenities and a private five-seat meeting room (Trenitalia, 2015)	Rail infrastructure resilience issues, cost of rail transport, and geographical barriers

Source: Based on UK Committee on Climate Change (2009).

sleeping facilities, efficient boarding, internet access and remote working opportunities.

3.5.3 Improve

Fuel can be a substantial part of an airline's operating costs (approximately one third) and can therefore act as a strong incentive for airlines to manage their fuel consumption (ICCT, 2017). Historically, driven by operator incentives to increase profitability, aircraft energy efficiency has improved without any policy drivers. However, the extent of efficiency improvements has reduced over time, from an initial 3-6 % per annum in the 1950s, as new aircraft were introduced, to around 1 % currently (ICCT, 2017). Increasing lead times required to develop, certify and introduce new technology has been identified as one possible cause for the decreasing rate of improvement (Kivits et al., 2010).

ICCT (2017) suggests that the rate of fuel efficiency can (depending on the investment in research and development) be increased from the current 1.0 % to 2.2 % through the adoption of technologies that improve engine efficiency, reduce aerodynamic drag and trim empty weight. However, there exists a gap between market-driven fuel efficiency improvements and those that take into account fuel price projections. The latter provide an opportunity for further reductions in CO_2 emissions.

The projected GHG emission reductions from the possible future use of biofuels, as assumed by the aviation industry, vary widely (e.g. ICAO, 2016; Sustainable Aviation, 2012 for the UK context) depending on the assumptions made for other reduction options, which include energy efficiency, improved operation and trading emission permits. If produced sustainably, biofuels could reduce fossil fuel dependency and associated GHG emissions. In 2011, the European Advanced Biofuels Flightpath (EABF) was developed to help drive the increased uptake of biofuels in Europe's aviation sector. The EABF had a goal of producing 2 million tonnes of sustainable biofuel for civil aviation by 2020. This is unlikely to be achieved, however, because of both the competition in demand for such alternative fuels and the lack of dedicated biomass-to-liquid production facilities in Europe. Further, concerns over indirect land use changes from sustainable aviation fuels are also under discussion. Presently, the projected supply of biofuels into the aviation sector in 2020 is just 0.05 million tonnes (EASA et al., 2016).

One key challenge to this target is current production capacity. For example, while North America has a relatively high availability of the feedstock to produce sustainable fuels, development is constrained by cost and time to commercialisation (ICCT, 2017). Furthermore, the high cost of aviation biofuels in the context of the low projected cost of carbon offsets mean that CORSIA alone will be unlikely to provide sufficient incentive for uptake of sustainable biofuels (ICCT, 2017).

3.5.4 Airports as cities

Airports can be considered similar in nature to small cities rather than just transport terminals (Robey, et al., 2010; Conventz and Theirstein, 2014), reflecting the economic and geographical scale of airports and their impact on their surrounding regions in terms of employment. Through the kind of services provided by airports, ranging from accommodation to religious facilities, the large demand for resources such as energy, fuels, water and food, and the scale of waste generation, airports share many similarities with their neighbouring urban areas. For example, a single large-scale catering company in the aviation sector might employ more than 800 members of staff and produce 25 000 meals daily (Jones, 2007).

At the 2015 Paris Climate Change Conference of the UNFCCC, the European airport industry pledged to operate 50 carbon-neutral airports by 2030. Since the launch of the Airport Carbon Accreditation scheme in 2009, 28 European airports are currently accredited for achieving carbon neutrality, representing 19.6 % of European air passenger traffic (ACA, 2017). However, recent reports have also pointed to the lack of transparency over what carbon offsets are being used by certain airports to achieve CO_2 'neutrality', highlighting the risk that the project credits being used would not be allowed under the EU ETS and have a low likelihood of delivering real, measurable and additional GHG reductions (Transport & Environment, 2017).

There is also the potential for lessons to be learnt and exchanged with the Sustainable Cities agenda, including work by C40 Cities (9) and the Global Covenant of Mayors for Climate and Energy (10), which are working at the city level to take forward action on climate change. Measures at the airport level raise interesting questions on how governance and action could come from the 'bottom up' rather than 'top down', moving away from a reliance on action at the international level.

Box 3.5 Case study of El Prat Airport — Bus on demand system

As for urban transport systems in cities, airports can implement smart transport systems. In 2014, Barcelona-El Prat Airport, Spain, unveiled its 'bus on demand' system. Serving air travellers, as well as 18 000 airport workers, the system allows passengers to request bus services by pressing a button at the bus station or by logging onto a website; this connects the city park area with the airport. Through this development, the local municipality aims to increase bus usage among air travellers and airport workers to and from the airport (ARC, 2014).

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(9) C40 is a network of the world's megacities committed to addressing climate change.

(10) In 2016, the United Nations' Compact of Mayors and the Covenant of Mayors announced the Global Covenant of Mayors for Climate and Energy, a newly merged initiative to bring these two efforts together.

4 Environmental pressures from shipping

Key messages

- Shipping activities lead to significant emissions of greenhouse gases and air pollutants, noise and water pollution.
- Global shipping CO_2 emissions could be 17 % of all CO_2 emissions by 2050 if no further action is taken.
- Existing policy measures at the international level, for example in the form of the Energy Efficiency Design Index, could result in a CO_2 emission reduction of about 17 % of the estimated 2050 level.
- Increasing shipping demand will make air, noise and water pollution objectives more challenging to achieve.
- Ballast water poses a threat to marine life, as it can contain alien species that are released to new environments during discharge.
- Dismantling of old ships can release materials such as polycyclic aromatic hydrocarbons, heavy metals, oil, asbestos and toxic paints to air and water, resulting in negative health impacts, even fatalities, among workers, and it can disrupt local biodiversity.

4.1 Sector summary

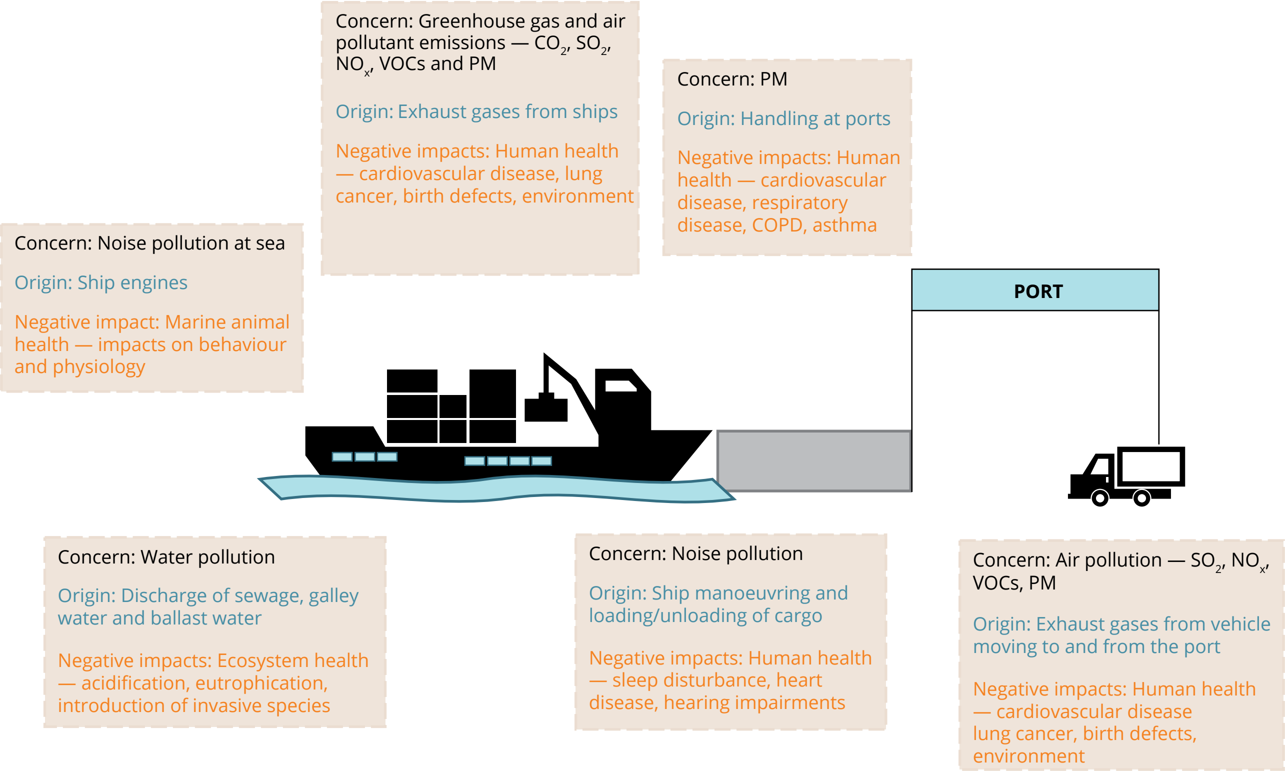
The shipping sector has grown significantly in recent decades, due to economic development in a number of emerging economies such as China and India, and in general increased globalisation of trade. World trade is highly dependent on shipping, with 75 % of EU goods by weight being transported by sea in 2013, with a value of EUR 1 733.7 billion (SHEBA, 2015). Food and energy security around the world therefore relies on the distribution of goods by international shipping. It is also an important source of employment, with 4.2 million jobs related to maritime activities and seafaring worldwide (Narula, 2014).

In the EU-28 in 2015, 3 838 million tonnes of goods were handled in ports and 2 224 608 vessels visited the main ports (Eurostat, 2017b). Three European ports are among the world's 20 largest container ports: Rotterdam is 11th, Antwerp 14th and Hamburg 18th (World Shipping Council, 2017).

Dry cargo and oil, gas and petroleum products make up much of global ship cargo, approximately two thirds and one third respectively (Narula, 2014). Merchant ships now make up 21% of the European fleet (EC, 2017c). In 2016, the EU-28 controlled 37 % of the world's merchant fleet and of the EEA member countries, Spain, Germany and Norway controlled most merchant ships (with 4 439, 3 456 and 1 605 respectively).

The United Nations Convention on the Law of the Sea (UN, 1982) emphasises that the flag state has jurisdiction over its vessels on the high seas (the open sea beyond the territorial control of a country). The term 'flag of convenience' refers to ship owners registering their ship(s) in a country other than the home country. Globally, the use of flags of convenience (open registries) is growing, as they are associated with more favourable tax policies, lower labour and environmental standards and an easier registration process (Artuso et al., 2015). Currently about 70 % of ships fly a flag that does not belong to the country where the owner is a citizen (George, 2013). At the EU level, action has been taken to address the potential consequences of this. A ship that does not comply with EU legislation or international conventions may be detained. After

Figure 4.1 Examples of environmental pressures from shipping activities



Concern: Greenhouse gas and air pollutant emissions — CO_2, SO_2, NO_x, VOCs and PM

Origin: Exhaust gases from ships

Negative impacts: Human health — cardiovascular disease, lung cancer, birth defects, environment

Concern: PM

Origin: Handling at ports

Negative impacts: Human health — cardiovascular disease, respiratory disease, COPD, asthma

Concern: Noise pollution at sea

Origin: Ship engines

Negative impact: Marine animal health — impacts on behaviour and physiology

Concern: Water pollution

Origin: Discharge of sewage, galley water and ballast water

Negative impacts: Ecosystem health — acidification, eutrophication, introduction of invasive species

Concern: Noise pollution

Origin: Ship manoeuvring and loading/unloading of cargo

Negative impacts: Human health — sleep disturbance, heart disease, hearing impairments

Concern: Air pollution — SO_2, NO_x, VOCs, PM

Origin: Exhaust gases from vehicle moving to and from the port

Negative impacts: Human health — cardiovascular disease lung cancer, birth defects, environment

Note: CO_2, carbon dioxide; COPD, chronic obstructive pulmonary disease; NO_x, nitrogen oxides; PM, particulate matter; SO_2, sulphur dioxide; VOC, volatile organic compound.

multiple detentions the ship is denied access to the ports concerned (PMoU, 2017).

4.2 Why is this important for the environment?

Maritime activities are dependent on fossil fuel combustion and therefore contribute to both climate change and air pollution (Figure 4.1). In port regions, around 55 % to 77 % of total air pollutant emissions can come from ships (Cullinane, 2014). There are hotspot areas in Europe where the contribution of shipping to air pollutant emissions can be up to 80 % for NO_x and SO_2 and up to 25 % for primary $PM_{2.5}$ (EEA, 2013).

Emissions originate from a wide range of sources, including the ship's boiler, the main engine and auxiliary engines, and can occur when a ship is at sea, when it is manoeuvring and when it is in port. The challenges posed by emissions, however, vary with location. When at sea, the main concern is the impact on the marine environment and the contribution of shipping emissions to background air pollution and releases to water. When closer to or in port, the main concerns are negative impacts on water quality and the contribution to poor local and regional air quality and thus negative impacts on human health (e.g. Cullinane, 2014).

4.2.1 Greenhouse gas emissions

CO_2 emissions from international shipping are currently 2.5 % of the global total (EC, 2016c). Since 1990, EU-28 emissions of GHGs from international shipping have increased by 22 %, the second highest increase of any sector, exceeded only by international aviation. In 2015, GHG emissions from the maritime sector comprised around 13 % of the EU's total GHG emissions from the transport sector (Figure 3.2). Emissions have decreased since their peak in 2007-2008, following the global economic crisis, with levels in 2015 being around the same as those reported by Member States in 2000.

In comparison with 2015, EU GHG emissions from international shipping decreased by 1.1 % in 2016 (EEA, 2017b). However, they will need to further decrease by more than 28 % by 2050 to meet the target of a 40 % reduction in emissions from 2005 levels, set in the 2011 Transport White Paper (EC, 2011). With shipping activity expected to increase in the future, driven by increasing globalisation and trade, it will be a challenge to keep emissions from the sector on a downward trajectory. To remain below the 2 °C objective of the Paris Agreement, recent research suggests that global emissions of the shipping sector in 2030 should be 13 % lower than in 2005. In 2050 they should be 63 % lower than in 2005. If the additional non-CO_2, climate change-relevant emissions are taken into consideration, these reductions would need to be even higher (EP, 2015).

4.2.2 Other contributions to climate change

As for aviation, shipping also contributes significantly to emissions of various short-lived climate forcers, including NO_x, SO_2 and BC. For shipping overall, the net impact of emissions is estimated to have a negative radiative forcing effect due to high emissions of NO_x and SO_2, which have a negative forcing effect due to aerosol formation. However, the uncertainties are large and encompass both positive and negative forcing (EEA, 2013). Therefore, as knowledge in this area improves, it is uncertain whether or not the overall impact of non-CO_2 emissions will be a net warming or cooling (EEA, 2013).

4.2.3 Air pollutant emissions

Figure 4.2 shows that in the EU-28, international shipping contributes a significant proportion of air pollutant emissions, for example 16 % of NO_x, 4 % of particulate matter with a diameter of 10 µm or less (PM_{10}), 7 % of $PM_{2.5}$ and 16 % of the SO_x emissions (EEA, 2017d).

In particular, PM, NO_x and SO_2 emissions from shipping contribute to poor air quality and thus have negative impacts on human and ecosystem health (Eyring et al., 2010; EEA, 2013; WHO, 2013, 2016). For global emissions of sulphur and nitrogen oxides (SO_x and NO_x), the shipping sector is among the top emitters and contributes up to 8 % and 15 % to the respective global totals (Maragkogianni et al., 2016). It is expected that the relative contribution from international shipping to air pollutant emissions will increase until 2020 as land-based reductions in emissions occur at a faster rate. This could result in NO_x emissions from shipping equalling those from land-based sources by 2020 (EEA, 2013). The total PM released is lower, but it is considered to have more severe impacts on health. Emissions are estimated to increase over the period 2006-2020, with $PM_{2.5}$ emissions increasing by 45 % in the Mediterranean Sea and by up to 15 % in the North Sea, the Baltic Sea and surrounding coastal areas (Aksoyoglu et al., 2016).

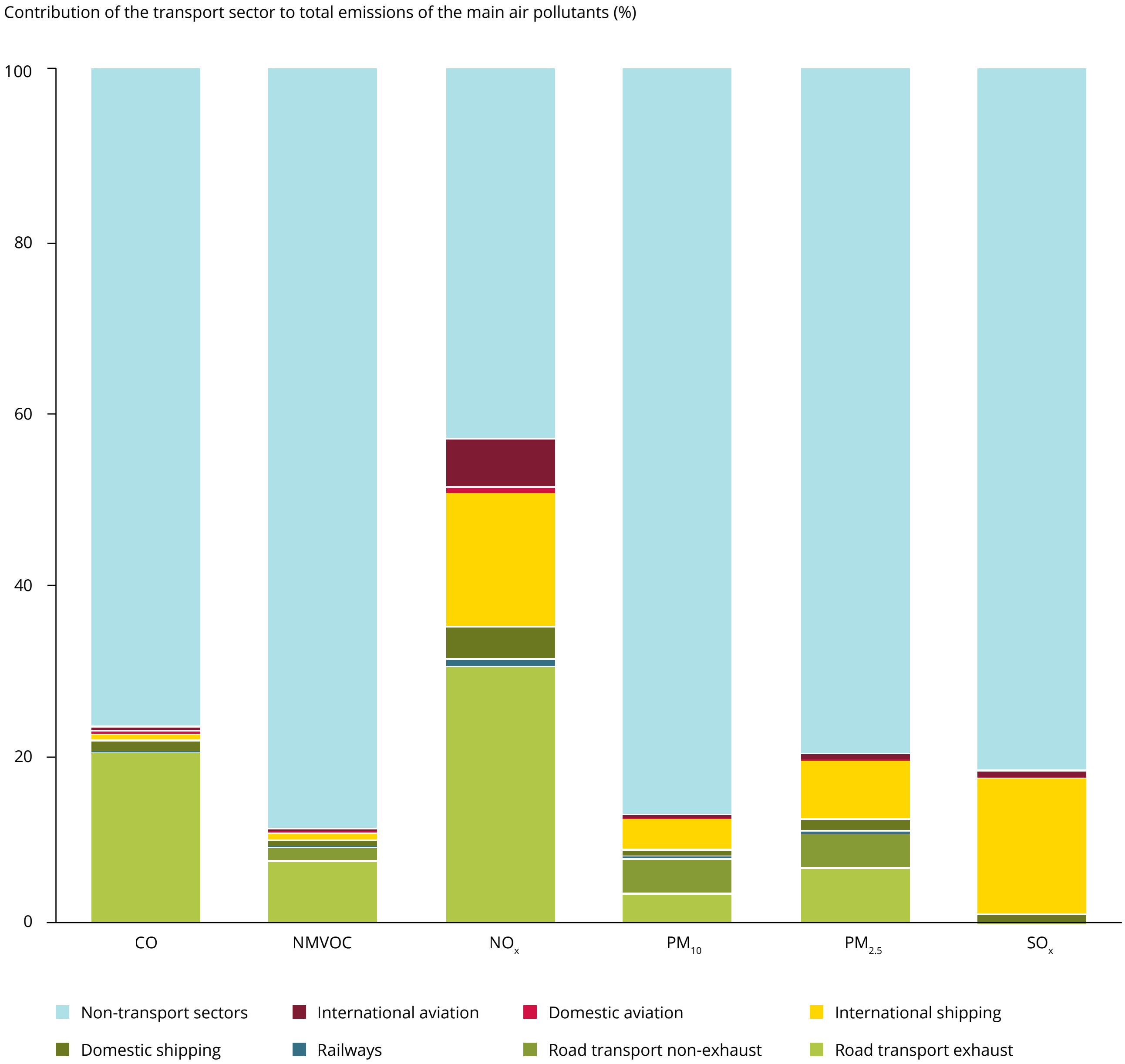
Despite the international nature of shipping, most air pollutant emissions occur close to the shore and thus have an impact on coastal areas. On average, 70 % of emissions are released within a distance of 400 km of the coast, and thus can have significant air quality impacts on coastal regions, contributing to so-called background air pollution (Viana et al., 2014). The reasons are increased shipping traffic near ports, vessels running auxiliary engines when at berth, increased emissions from loading and unloading activities, and a higher engine load when manoeuvering. In Europe, a larger than average proportion of emissions occurs close to the shore — 97 % of North Sea emissions are released within 100 nautical miles of the shore (Viana et al., 2014; Maragkogianni et al., 2016).

A review by Viana et al. (2014) concluded that, in European coastal areas, shipping emissions contribute 1-7 % of ambient air PM_{10} concentrations and 1-14 % of $PM_{2.5}$ levels. Contributions from shipping to ambient NO_2 concentrations range between 7 % and 24 %, with the highest values being recorded in the Netherlands and Denmark. Impacts from shipping emissions on SO_2 concentrations were reported for Sweden and Spain. Shipping emissions not only affect the levels and composition of particulate and gaseous pollutants, but they may also enhance secondary particulate matter formation processes in urban areas.

Modelling results also suggest that emissions from international shipping in Europe increase $PM_{2.5}$ concentrations in the air, for example, during all seasons of the year but particularly in summer (Aksoyoglu et al., 2016). The highest increases were modelled for the summer months; 20-25 % in the north around the English Channel and 40-50 % in the western Mediterranean. Elevated $PM_{2.5}$ levels were predicted not only around shipping routes but also over coastal areas. Particulate ammonium nitrate increased by about 10-20 % around the Benelux area and in northern Italy, where land-based ammonia emissions, mainly from agriculture, are high (Aksoyoglu et al., 2016).

PM emissions from ships are estimated to be responsible for around 600 000 premature deaths annually from cardiopulmonary disease and lung cancer in coastal areas of Europe, East Asia and South Asia (Maragkogianni et al., 2016). Air pollution in ports also has a high external cost on the city when health impacts are monetised (OECD, 2010). In the port of Bergen the monetised impacts of air pollution released from ships at berth is estimated to be between

Figure 4.2 **Contribution of the transport sector to total emissions of main air pollutants in the EU-28 in 2015**



Note: CO, carbon monoxide; NMVOC, non-methane volatile organic compound; NO_x, nitrogen oxides; $PM_{2.5}$, particulate matter with a diameter of 2.5 µm or less; PM_{10}, particulate matter with a diameter of 10 µm or less; SO_x, sulphur oxides.

Source: EEA, 2017d (TERM 003 indicator).

EUR 10 and EUR 20 million annually (MacArthur and Osland, 2011). In a study on 13 Spanish harbours, overall external costs of air pollution from shipping activities were estimated to be almost EUR 206 million (Castells Sanabra et al., 2013).

Ship emissions also contribute to negative impacts on ecosystem health caused by the deposition of sulphur and nitrogen compounds, which can lead to acidification and eutrophication of both water and soil (e.g. EEA, 2014c).

In addition to the above, BC, a component of PM, is also emitted by ships, mainly due to incomplete combustion of diesel fuel. Studies of short-term health effects suggest that BC is a better indicator of harmful particulate substances from combustion sources than undifferentiated PM mass (WHO, 2012). BC releases in Arctic shipping routes magnify its positive climate-forcing effect — when BC is deposited on snow and ice surfaces, it reduces the reflection of sunlight, causing further warming and increasing the rate of melting (e.g. US EPA, 2016).

Near shipbreaking yards, air pollution by toxic chemicals such as persistent organic pollutants (POPs) and polycyclic aromatic hydrocarbons (PAHs) can be very high, producing negative impacts on human health and the environment (see summary in EC, 2016e). Those yards are mostly located outside Europe. The Chittagong area in Bangladesh, for example, accounted for 22 % of shipbreaking activities worldwide in 2014. Workers on those yards, often also children, are exposed to levels of air pollution that are often far above World Health Organization (WHO) carcinogenic risk limits.

4.2.4 Noise pollution

There are two main concerns with noise: the impact on humans in areas near ports, and the impact on marine animals. WHO guidelines set limits for noise exposure and these vary between night and day (e.g. WHO, 2009). Environmental noise, defined as the summary of noise pollution from outside, caused by transport, industrial and recreational activities, can have health impacts including sleep disturbance, heart disease and hearing impairments. Noise originates from, for example, day- and night-time handling at ports, and an activity that is increasing across Europe (Murphy and King, 2014). A study addressing the Port of Dublin found that surrounding residential areas were exposed to night-time noise that exceeded the guideline limits set by the WHO and potentially causing negative health issues.

Underwater noise is also a concern for the health of marine life, although this is currently not monitored and still not well understood. Underwater noise can have a range of impacts on marine animals, from subtle behavioural changes to injuries and death in extreme cases (EEA, 2015). Many marine animals use sound for navigation, communication and hunting, as sounds travels well through water. While they have evolved to cope with natural noise, human-induced noise is now a major source and is exposing these animals to very high-level and ongoing sounds. The coping strategies of marine life appear to be limited, especially among long-lived species, and therefore there are harmful impacts on animal behaviour and physiology (Simmonds et al., 2014).

4.2.5 Additional environmental impacts

Shipping also poses a threat to water quality. Eutrophication of water bodies can occur through direct discharge and leakage of substances from a ship, and indirectly through air emissions that are subsequently deposited to land and sea surfaces (e.g. Moldanova and Quante, 2016). Polluting substances are often the result of multiple onboard operations. For example, the total amount of nitrogen that can contribute to eutrophication is the sum of nitrogen from exhaust emissions, wash water discharge (e.g. from gas scrubbers) and ballast water discharge (Moldanova and Quante, 2016).

Ballast water can also pose a threat to marine life, as it can contain alien species that are, when discharged, released to new environments. In fact, shipping is considered the main pathway of bio-invasion. In the Mediterranean, shipping traffic through the Suez Canal is an important source (EEA, 2015).

Another key source of water pollution is oil spills. In ports these can come from port run-off, loading and unloading of oil tankers, removal of bilge water and leakages (OECD, 2010). Although tanker accidents are often named as a key source of water pollution, estimates indicate that day-to-day shipping operations can actually be responsible for over 70 % of the oil entering the sea from marine transport (OECD, 2010). Oil spills can harm or kill marine mammals such as whales, dolphins, seals and sea otters. Even when marine mammals escape the immediate effects, an oil spill can cause damage by contaminating their food supply.

Port activities also produce waste, especially from oil terminals, fuel deposits and dry-dock operations. Cruise ships are also a notable contributor to the overall amount of waste generated by the shipping sector; although they comprise less than 1 % of the global fleet, they produce 25 % of all waste associated with the sector (Miola et al., 2009).

Shipbreaking and ship recycling yards are not only major sources of air pollution. Mainly located outside Europe, they also contribute significantly to water pollution and waste issues. The Alang-Sosiya shipbreaking yard in India, for example, is one of the largest in the world. It accounts for nearly half of the shipbreaking and recycling activities worldwide (see summary in EC, 2016e). Pollutants such as heavy metals and small plastic fragments threaten marine biodiversity in the area. The beaches of Alang on the western coast of India have become the world's largest 'graveyard' for ships.

4.3 What current monitoring approaches are in place?

In the EU, annually reported national emission inventories, which include shipping activities, are compiled by Member States within the context of the UNFCCC and the MMR (EU, 2013b) for GHGs, and for air pollutants under the UNECE LRTAP Convention and the National Emissions Ceiling (NEC) Directive (EU, 2016a). However, these data are considered to be of high uncertainty, as emissions for international shipping are typically prepared on the basis of international bunker fuel statistics, and they are not linked to actual fuel used by shipping in the territorial waters of each Member State (see Box 4.1).

Future reporting initiatives should help improve the quality of the available emissions data from shipping. An EU-wide framework for monitoring, reporting and verification (MRV) of CO_2 emissions and other key information from maritime modes was developed through the MRV Shipping Regulation adopted in April 2015 (EU, 2015). From 1 January 2018, the regulation requires all large ships (over 5 000 gross tonnes) that call at European Economic Area ports to monitor their CO_2 emissions from and between EEA ports of call and when in EEA ports. It will also enable the EU to contribute to international developments, as in 2016 the IMO reached an agreement on the requirements for a global data collection system for 2019 onwards, but for which only aggregated anonymised data will be publicly available.

In terms of timescales for key deliverables within the EU framework (EU, 2015), companies managing ships of more than 5 000 gross tonnes (volume), calling at ports in the EU, are responsible for the following:

- A monitoring plan will need to be submitted by 31 August 2017 to an accredited verifier, using template documents provided by the EU.
- From 1 January 2018, companies shall, based on the monitoring plan assessed in accordance with Article 13(1), monitor CO_2 emissions. The reporting will cover vessels' CO_2 emissions, fuel consumption and further relevant parameters including distance, cargo carried and time at sea.
- From 2019, and by 30 April each year, a satisfactorily verified emissions report for each relevant ship should be submitted to the European Commission and to the authorities of the flag states concerned, by the companies.
- From 2019, and by 30 June each year, all relevant ships shall carry a document of compliance, which may be subject to inspections by Member States' authorities.

4.4 What current and future policy measures are in place?

4.4.1 Greenhouse gas emissions

At the global level, an Energy Efficiency Design Index (EEDI) was made mandatory for new ships, and the Ship Energy Efficiency Management Plan (SEEMP) for all ships, from 2013 onwards, as a result of amendments in 2011 to Annex VI of the International Convention for the Prevention of Pollution from Ships (MARPOL). The EEDI is an index that quantifies CO_2 (g) per cargo carried (tonne-mile). The regulation requires that the majority of new ships were 10 % more efficient at the start of

Box 4.1 Bunker fuels

Bunker fuel is a generic term for fuel used on a ship to power its engines. It is usually a type of liquid fuel, which is fractionally distilled from crude oil. The fuel can be broken down into various categories based on its chemical composition, intended purpose and boiling temperature. In comparison with other petroleum products, bunker fuel is extremely crude and highly polluting.

In accordance with the Intergovernmental Panel on Climate Change guidelines for the preparation of GHG inventories and the UNFCCC reporting guidelines on annual inventories, emissions from international maritime transport (also known as international bunker fuel emissions) should be calculated as part of the national GHG inventories of Parties. However, they should be excluded from national totals and reported separately. These emissions are not subject to the limitation and reduction commitments of Annex I Parties under the Convention and the Kyoto Protocol. For small countries with large international ports, there can thus be a big difference between the emissions in territorial waters and the total emissions of the fuel sold (e.g. UNFCCC, 2017).

2015, and they will be 20 % more efficient by 2020 and 30 % more efficient from 2025. There is, however, a concession that individual flag administrators could defer mandatory EEDI requirements for up to 4 years before the due implementation date. The CO_2 savings from the introduction of the EEDI depend on whether or not this deferment is used and, if so, to what extent. Under a 'no deferment scenario', reductions of around 17 % for global shipping emissions are possible by 2050. With deferment, estimated reductions of around 10 % are possible by 2050 (based on Figure 1 in ICCT, 2011). The SEEMP requires all ships and shipping companies to develop and maintain a plan to maximise operational efficiency; this can include planning, implementation, monitoring, evaluation and improvement. It is recognised that neither the EEDI nor the SEEMP will stop or reverse the growth in absolute CO_2 emissions from the shipping sector. However, they are expected to slow the overall rate of growth to 37-44 % from the 83 % estimated under a base-case scenario (ICCT, 2011).

At the EU level, the European Commission set out a strategy in 2013 to integrate the mitigation of maritime emissions into the EU's policy for reducing domestic GHG emissions (EC, 2013). The strategy consists of three steps:

- monitoring, reporting and verification of CO_2 emissions from large ships;
- GHG reduction targets for the maritime transport sector; and
- further measures, including market-based measures, in the medium to longer term.

The monitoring, reporting and verification of CO_2 emissions has been addressed in the preceding section. Market-based measures (MBMs) put a price on GHG emissions and in turn provide an economic incentive for the maritime sector to reduce fuel consumption, and also allow offsetting in other sectors. This report does not include an analysis, but research results suggest that it is feasible to implement such a scheme (CE Delft, 2010), and that it has the potential to reduce emissions cost effectively. It does not require extensive legal activity and could address environmental, social and economic concerns (Ben-Hakoun et al., 2016; Franc and Sutto, 2014).

Action at the global level, however, has been slow. While the IMO recognises that MBMs are required as part of a comprehensive package of measures to reduce GHG emissions from international shipping, despite work since 2008 its Marine Environment Protection Committee has not yet delivered a study assessing the impacts of proposed MBMs for the sector, whether emissions trading or alternative measures. Development work on a new 'roadmap' has commenced, however, with the IMO aiming to agree an initial 'strategy' for this roadmap in 2018, an action that has arguably been undertaken as a response to the increasing calls from many stakeholders for unilateral or regional action undertaken independently by governments.

Therefore, while a global scheme is the preferred mechanism and there are industry concerns with regard to impacts of regional schemes on potential competitiveness, the EU will monitor closely the progress achieved at the IMO towards an ambitious emission reduction objective. The EU will also monitor accompanying measures to ensure that the sector duly contributes to the efforts needed to achieve the objectives agreed under the Paris Agreement.

4.4.2 Air pollutant emissions and air quality

At the global level, the IMO also addresses air pollution through the MARPOL Convention's Annex VI. This currently limits emissions from NO_x, SO_x, ozone-depleting substances and VOCs.

For sulphur, the IMO's Marine Environment Protection Committee has revised Annex VI by reducing the global sulphur limit of marine fuels from 4.5 % to 3.5 %, and incrementally, to 0.5 % from 1 January 2020. In the EU, Directive 2016/802 (EU, 2016b) regulates the sulphur content of fuels and abatement equipment on board ships. Sulphur limits in dedicated Emission Control Areas (ECAs) in EU waters are at 0.1 % from 2015 onwards. There are currently two ECAs in Europe, one in the Baltic Sea and the second covering the North Sea, including the English Channel. To help achieve compliance with these new limits, operators can use low-sulphur fuel, install onboard filters (scrubbers), or adopt alternative fuel technologies; the last is often considered in new vessels, reflecting the modifications required (EC, 2016c). To reduce emissions, port authorities may also decide to invest at local level in shore-side electricity for ships calling at their ports. In Denmark and the Netherlands, for example, monitoring of air quality close to ports has shown 20 % to 60 % lower SO_2 concentrations in recent years, compared with the 2014 levels (DCMR, 2015; Miljø- og Fødevareministeriet, 2016).

MARPOL Annex VI also sets limits for NO_x. Different levels, known as tiers, apply depending on the ship's construction date. Within any particular tier, the actual limit value is determined from the engine's rated speed. Tier I applies to marine diesel engines with a power output of more than 130 kW, on ships constructed on or after 1 January 2000, Tier II applies to ships constucted on or after 1 January 2011, and Tier III applies to ships constructed on or after 1 January 2016 and which operate in the so-called NO_x Emission Control Areas (NO_x ECAs) (11).

For NO_x, the difference between Tier I and Tier II is approximately a 20 % reduction, and between Tier II and Tier III it is approximately a 75 % reduction. Tier II standards are expected to be achieved through optimisation of the combustion process, which can include fuel injection and exhaust valve timing. The Marine Environment Protection Committee has agreed to limit NO_x emissions from ship exhausts in the Baltic Sea and North Sea countries. Further, the committee decided that the global limit of the sulphur content of ships' fuel oil will be 0.50 % m/m, which is the percentage mass of SO_2 gas in the total mass of the emission, from 1 January 2020. Proposals to designate the North Sea and the Baltic Sea as NO_x ECAs have been under discussion and would potentially take effect from 1 January 2021.

4.4.3 Water pollution

Concerning water pollution, a key international measure for environmental protection, which aims to stop the spread of potentially invasive aquatic species in ships' ballast water, entered into force on 8 September 2017. The International Convention for the Control and Management of Ships' Ballast Water and Sediments (BWM Convention) was adopted in 2004 (IMO, 2017) to introduce global regulations to control the transfer of potentially invasive species. With the treaty now in force, ships need to actively manage their ballast water.

Accidental oil spills and cleaning operations are a major source of water pollution from ships. The EU's Emergency Response Coordination Centre ensures a coordinated response to this kind of pollution event (EC, 2017c). Further, the European Maritime Safety Agency (EMSA) provides marine pollution preparedness and response services.

4.5 What current mitigation options exist?

4.5.1 Improve

For the shipping sector, options to reduce emissions are closely linked to improving efficiencies, whether through operational efficiency, improved ship efficiency, new ship designs or the use of alternative fuels (for on-board or onshore power).

Slow steaming/speed reduction

The reduction of sailing speed, or 'slow steaming', has become increasingly common around the world since the economic downturn, which also saw sharp increases in fuel prices. These economic changes encouraged innovation as a means of achieving more economically efficient methods of ship operation. Slow steaming achieves a dual benefit by reducing both fuel consumption and emissions. By 2011, it was estimated that 93 % of ships on the Asia-North Europe route had implemented slow steaming, with speed reductions of 20 % estimated to result in savings of USD 3 billion annually in fuel (fuel costs can make up at least half of a ship's operating costs) (Maloni et al., 2013; Woo and Moon, 2014). Unlike other potential solutions for reducing emissions, slow steaming offers immediate results. Combined with the optimisation of ships for slower speeds (e.g. through modification of the engines), this approach can reduce power requirements and therefore also increase the proportion of power that could potentially be supplied by renewable energy (Bows-Larkin, 2015). The global shipping sector is still recovering from the economic downturn, but slow steaming is still being implemented because of its ability to cut costs. Therefore this innovation is still delivering benefits for the environment, but whether such practices will continue as economic activity grows remains to be seen.

There are, however, operational risks and challenges associated with slow steaming that must be carefully balanced with the benefits. For emissions, slower is generally always better; however, below 14 knots this becomes economically detrimental because of increased

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(11) Currently there are two NO_x ECAs, the North American and the US Caribbean Sea, whereas there are four SO_x ECAs, including in the Baltic Sea and the North Sea in Europe.

pipeline (in-transit) costs (12). The optimal speed for balancing economic and environmental benefits is around 18 knots (Maloni et al., 2013; Woo and Moon, 2014). There is also a risk of increased operating costs due to longer shipping times, higher stock at sea, higher insurance costs and greater pipeline costs (Maloni et al., 2013; Ben-Hakoun et al., 2016). Slower speeds are clearly also a challenge for perishable goods or goods with a short life cycle, such as food. These costs therefore need to be balanced, and economic and environmental benefits must outweigh the costs for slow steaming to be a viable option.

Weather routing

Weather routing is the process of choosing the course for a voyage based on weather conditions, such as wind, wave height and currents, to save time, maximise safety and maximise energy efficiency (Cui et al., 2016). Weather routing can optimise efficiency, and more sophisticated methods are being developed as technology and weather-forecasting methods improve.

Improving ship efficiency

Vessel efficiency can be improved through several pathways, including via energy efficiency technologies such as waste heat recovery systems and auxiliary power. New ship designs can also substantially improve efficiencies.

1. *Waste heat recovery*
   Heat is lost to surrounding areas during thermal processes, such as the burning of fuel. By recovering this energy, a vessel can potentially save 5-9 % in fuel (Maersk, 2014; Baldi and Gabrielli, 2015; Singh and Pedersen, 2016). There is a range of options for implementing waste heat recovery systems. Where financial resources are limited, simple waste heat recovery systems can be implemented that have relatively low efficiency and can use waste heat from the exhaust funnel to provide auxiliary power on board. This involves the modification of a current exhaust gas economiser and is therefore considered to be a relatively simple, cheap option. Alternatively, if resources are readily available, high temperature cooling as a source of waste heat is recommended, especially if this can be linked with a retrofit of the shaft generator to be used as a shaft motor. Although this is an expensive measure, the long-term savings are larger and the power produced can potentially be used for propulsion (Baldi and Gabrielli, 2015).

2. *Wind assistance technologies*
   Wind assistance technologies can help harness wind energy for vessel propulsion. There are three options:

- sails;
- Flettner rotors;
- kites.

These options can reduce the fuel consumption of a ship, as less power needs to be generated from the engine. Therefore, the higher the wind speeds, the higher the fuel consumption savings. The fuel savings achieved by wind assistance technology rely on ship design (especially the rig and hull), operating speed, and wind speed and direction (variable over routes and seasons). When modelled for a range of wind speed and ship designs, it was found that fuel savings could range from 10 % to 60 % (Rehmatulla et al., 2017). Exploratory studies have estimated that if 10 700 bulk carriers and tankers were to have wind propulsion systems installed by 2030, this would provide CO_2 savings of approximately 7.5 million tonnes CO_2 (0.7 % of global shipping emissions), as well as 8 000 direct jobs and 10 000 indirect jobs (Nelissen et al., 2016). There is clear potential for wind assistance technologies in the field of sustainable shipping; to date, however, there have been few real-life sea trials.

3. *New ship design*
   Improvements can be made to ship design to make the vessel more efficient and decrease emissions and operating costs. Two key improvements can be made, which aim to reduce energy loss and reduce resistance. First, the main engine of a ship can be adapted to facilitate energy recovery so that it can recover waste heat and electrical power. This can then be used for auxiliary engines (Perera and Mo, 2016) that reduce fuel consumption and GHG and air pollutant emissions. Second, fuel consumption can also be decreased by reducing the ship's resistance through the water and thus reducing the amount of power required to move the ship. Resistance can be minimised through design changes to hull shapes and improved cleaning and maintenance regimes for the hull and propellers, facilitated by more frequent vessel dry-docking (Perera and Mo, 2016).

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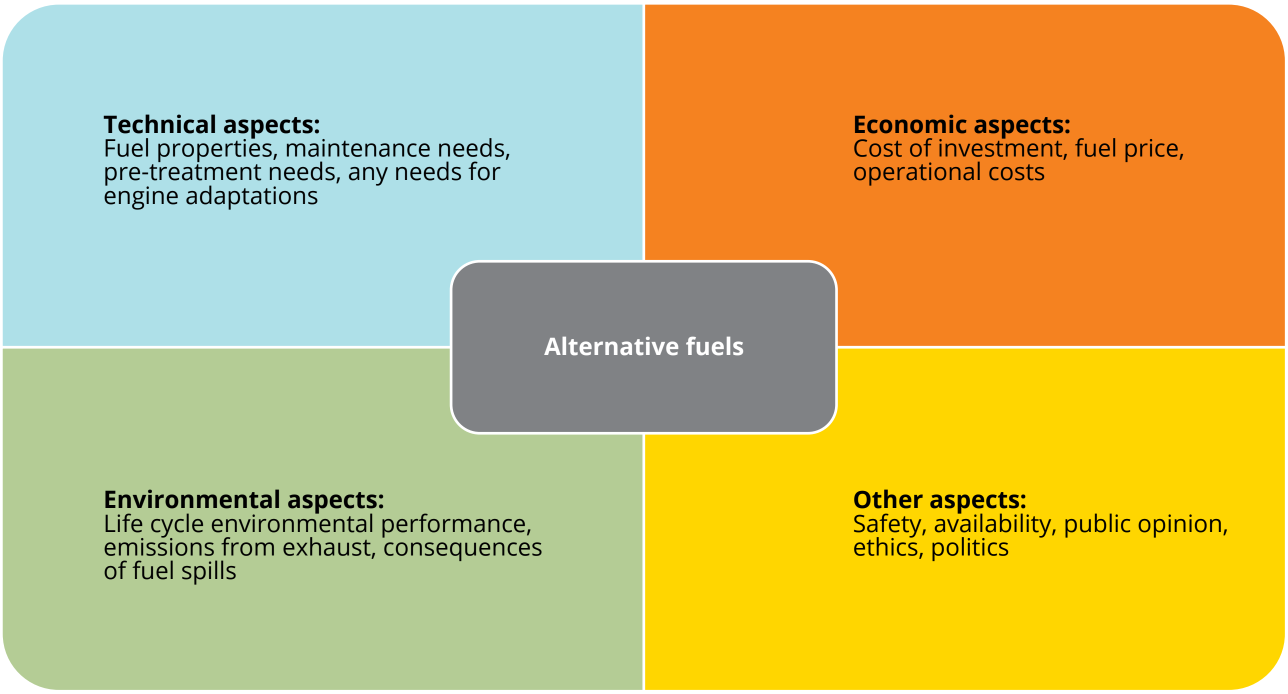
(12) The in-transit inventory carrying cost depends upon the amount of inventory in the transport pipeline and the number of days in the pipeline.

Alternative fuels

Currently, most ships are powered by heavy fuel oil (HFO). This is a cost-effective but polluting fuel, as high levels of asphalt, carbon residues, sulphur and metallic compounds combined with a high viscosity and low volatility mean that HFO produces significant air pollutant and GHG emissions (NO_x, SO_x, CO, CO_2) during the combustion process. MARPOL limits for levels of NO_x and SO_x, for example, and the 0.1 % limit effective since January 2015 in defined ECAs effectively precludes the normal uncontrolled combustion of HFO and has resulted in ships either implementing emissions abatement technologies or using alternative fuels (Burel et al., 2013; Anderson et al., 2015). The restriction on emissions can facilitate innovation on low-emission fuels. Alternative fuel options include liquefied natural gas (LNG) (Box 4.2, Box 4.3), liquefied biogas (LBG), methanol and bio-methanol. There are various technical, economic and environmental aspects that need to be considered when choosing a fuel (Figure 4.3).

Figure 4.3 Considerations for use of alternative fuels in shipping



Technical aspects:
Fuel properties, maintenance needs, pre-treatment needs, any needs for engine adaptations

Economic aspects:
Cost of investment, fuel price, operational costs

Alternative fuels

Environmental aspects:
Life cycle environmental performance, emissions from exhaust, consequences of fuel spills

Other aspects:
Safety, availability, public opinion, ethics, politics

Source: Based on Brynolf et al., 2014.

Box 4.2 Alternative fuels: liquefied natural gas

LNG is now increasingly used as a marine fuel for shipping propulsion. There are plans to build more fuelling infrastructure to facilitate use of LNG along major shipping routes. MARPOL Annex VI sets limits for NO_x and SO_x emissions from ships, and the use of LNG fuel is one method for attaining the limits.

Benefits

One of the main benefits of using LNG are the reductions in NO_x, SO_x and CO_2 emissions that can be achieved, compared with HFO:

- NO_x emissions reduced by 80-85 %;
- very low SO_x emissions, as LNG has a very low sulphur content;
- low primary PM emissions; and
- CO_2 emissions reduced by 20-30 %.

The reduction in emissions from these sources means that investment in expensive abatement technologies can be minimised. Payback times can be between 2 and 4 years. In terms of cost, LNG, on a per tonne basis, can provide a viable alternative to HFO.

Challenges

While the environmental benefits of using LNG are obvious, there are some challenges that will need to be overcome before LNG can deliver a large-scale benefit in terms of lower environmental impacts from fuel emissions:

- There is a need for better awareness of safety issues and staff training — there are safety issues that come with the storage and use of gas energy. Measures to ensure safety will need to be implemented on ships and staff will need to be trained to understand the fuel and the associated risks.
- There is a need for changes in ship design — LNG requires specially designed tanks to keep the gas cold; installing these incurs a cost and they take up additional space. It is possible to retrofit ships that currently run on HFO. However, changes to the hull structure may be necessary to accommodate the tanks and this limits the scope of uptake for some vessels.
- Methane slip — methane can be emitted during the combustion of LNG with levels of around 7 g/kg LNG at higher engine loads, increasing to 23-36 g/kg LNG at lower loads. Methane is a potent GHG with a global warming potential that is 28 times higher than that of CO_2. Measures to address methane slip are therefore required, for example through careful timing of the injection of pilot fuel and the use of after-treatment systems.
- Emissions of total hydrocarbons and CO — emissions of both these substances are higher for LNG than for the marine fuel oils currently used.
- There is a 'chicken and egg' situation whereby ship owners may be reluctant to invest in new vessels ahead of the installation of new fuelling infrastructure, and fuel suppliers may be reluctant to install new infrastructure ahead of new demand.

Sources: Burel et al., 2013; EC, 2013; Anderson et al., 2015; Fridell et al., 2016; Yoo, 2017.

Box 4.3 Liquefied natural gas terminal in Bulgaria

At present, there is no infrastructure for LNG supply in Bulgarian seaports. However, Bulgaria has already built a small-scale LNG terminal on the Danube, with a total volume of 1 000 m^3, which is now being used for the storage of LNG, the bunkering of inland vessels and fuelling of trucks, as well as the further distribution of LNG in the region. The terminal is located in the port area in Ruse, on the grounds of a former heavy machinery factory.

The terminal offers facilities for the loading/unloading of inland LNG carriers, the bunkering of inland vessels and the fuelling of trucks using LNG. The fuelling station is connected to the facility for loading trucks to distribute LNG to various customers around the country. The LNG storage facility is connected to the existing terminal for hazardous cargo with its own pontoon. The same pontoon will be used for the bunkering of inland vessels running on LNG. Loading/unloading operations are performed via customised hoses at the pontoon and fixed pipelines connecting the pontoon to the storage facility. Both flexible hoses and pipelines have special insulation to transport the cryogenic LNG gas.

Shore side power

While in port, ships require electricity to supply power for activities such as lighting, ventilation and the operation of cranes. Typically, ships continually run auxiliary engines to generate power on board. However, using onshore electricity supplies instead of the onboard auxiliary engines can deliver important benefits, the most significant being a reduction in pollution and noise (Barregård et al., 2014; Yiğit et al., 2016).

One key consideration, however, is how the electricity is generated on land. The greatest environmental benefit will not surprisingly be obtained when onshore electricity generation is from renewables (Barregård et al., 2014). The future may come in the form of smart grids that involve two-way energy flows between the ship and the port. The national electricity grid would supply energy to the ship while in port. The ship could also supply energy to the grid from energy storage units and onboard renewable sources during peak hours when demand is high (Yiğit et al., 2016). This option could offer maximum environmental and economic benefits, while also aiding integration between port and city.

4.5.2 Ports as cities

As with airports, port complexes can potentially also be considered as small cities. Many of the world's largest cities also have the largest ports, which may make up a substantial part of these cities (Table 4.1). For example, one third of the city of Antwerp consists of its port (OECD, 2010). Ports can act as extensions of cities, for example offering opportunities for residential moorings and development. Ports offer employment opportunities, and on average one million tonnes of port throughput are associated with 800 jobs (OECD, 2010). Ports also offer opportunities for business innovation, especially in maritime-related fields such as ship operations, petroleum and hoisting.

Ports therefore have a role to play in taking forward sustainable shipping initiatives. In addition to monitoring and ensuring compliance, many port authorities now use voluntary incentive schemes to help reduce emissions, including the use of slow steaming and encouraging use of alternative fuels, cleaner ships, truck retirement and modal shift (OECD, 2010). Ports can also introduce differentiated port dues, based on an environmental ship index. The Port of Amsterdam, for example, gives a rebate on port fees which ranges from EUR 200 to EUR 1 400 depending on the size of the vessel.

Table 4.1 The top 10 container ports in Europe in 2016

	Port	Country	1 000 TEU in 2016
1	Rotterdam	The Netherlands	12 385
2	Antwerp	Belgium	10 037
3	Hamburg	Germany	8 910
4	Bremerhaven	Germany	5 587
5	Algeciras	Spain	4 760
6	Valencia	Spain	4 722
7	Felixstowe	United Kingdom	3 745
8	Piraeus	Greece	3 675
9	Marsaxlokk	Malta	3 064
10	Gioia Tauro	Italy	2 797

Source: PortEconomics, 2017.

Note: TEU, 20-foot equivalent unit (used to measure a ship's cargo carrying capacity).

5 Transitions towards improving the environmental sustainability of the aviation and shipping sectors

For Europe to achieve its 2050 vision of 'living well within the limits of the planet' (EU, 2013a), there is increasing recognition that long-term, multi-dimensional and fundamental changes to European societal systems will be required (EEA, 2016a). Any type of 'transition' towards sustainable aviation and shipping will necessitate changes to interdependent social systems across multiple levels. Transitions or transformations in core systems are understood to be 'long-term, multi-dimensional and fundamental processes of change', based on 'profound changes in dominant practices, policies and thinking' (EEA, 2016c).

Transitions researchers have developed a variety of theories to explain how socio-technical systems are structured and the ways that these systems can be reorganised to deliver better outcomes (Markard et al., 2012). One of the most widely used approaches is the 'multi-level perspective'. The multi-level perspective characterises socio-technical systems as being structured and stabilised by a 'regime' comprising factors such as knowledge, investments, policies, institutions, skills and cultural values.

Innovative technologies and practices can be the key to systemic change but they often struggle to make impacts, as businesses and consumers are locked into established ways of producing and consuming. For innovations to emerge, two things are needed: 'niches' and forces that can disrupt the regime (for definitions and details, see Box 5.1).

Transitions cannot be comprehensively managed. There is much complexity and uncertainty (e.g. interplay of social and technological responses), but governments and other societal stakeholders can help catalyse and steer transitions, for example by creating niches in which experimentation and innovation can flourish.

Box 5.1 Transitions terminology

Transitions or transformations in core systems are understood to be 'long-term, multi-dimensional and fundamental processes of change', based on 'profound changes in dominant practices, policies and thinking' (EEA, 2015).

Transitions researchers have developed a variety of theories to explain how socio-technical systems are structured, and the ways that these systems can be reorganised to deliver better outcomes (Markard et al., 2012). One of the most widely used approaches is the **'multi-level perspective'.**

The multi-level perspective characterises socio-technical systems as being structured and stabilised by a **'regime'** comprising factors such as knowledge, investments, policies, institutions, skills and cultural values. Innovative technologies and practices are seen as holding the key to systemic change but they often struggle to have any impact because businesses and consumers are **locked into** established ways of producing and consuming.

For innovations to emerge and alter the dominant system, two things are needed. One is **'niches'**: protected spaces below the regime level, where innovators can develop, nurture and experiment with new technologies or practices without immediate or direct pressure from the regime (Raven et al., 2010). There is an emphasis on social innovations — new practices and behaviours that enable society to meet its needs more sustainably. Such changes are sure to entail adjustments in policies, norms and values.

The second requirement looks at forces that can disrupt the regime, creating windows of opportunity for new innovations to establish themselves. Such forces come from the external **'landscape'** of long-lasting structures and large-scale socio-economic, demographic, political and international trends, which can both constrain and enable regime change (Raven et al., 2010). For example, global megatrends, such as demographic and economic growth, and associated demand for resources (e.g. fossil fuels), can create pressure on the energy system (EEA, 2015).

Source: Based on EEA, 2016c.

5.1 Lock-ins

5.1.1 Lock-ins and barriers to future changes

Even when opportunities are identified, it may not be straightforward to fully exploit them, as specific factors may exert strong incentives for avoiding the fundamental changes that are required. Depending on specific circumstances, different barriers and lock-ins may occur on different pathways towards sustainable mobility. Barriers are existing challenges that hamper a successful transition towards sustainable mobility but can be overcome (EEA, 2016a). Lock-ins refer to additional elements that hamper change from previous choices that have 'locked' the system into a certain state or technology (Box 5.1). For example, existing infrastructure and associated expansion plans can be considered lock-ins, as they can generate overcapacity resulting in their being used to yield benefits or recover investments. This lock-in can result in ongoing market and policy failures that can delay the spread and use of more sustainable technologies (Unruh, 2000).

5.1.2 Existing infrastructure and systems

Airports and ports form a resource of existing infrastructure and in themselves may form lock-ins, for example by reducing opportunities for a modal shift to rail transport (e.g. for travel distances of less than 1 000 km).

The lock-in of existing infrastructure can be compounded through airlines being offered incentives to operate at certain airports and destinations; these incentives often form part of the charge-setting strategy of airports (Allroggen et al., 2013). However, research suggests that EU-funded investment in airports does not always generate the anticipated results (ECA, 2014) in terms of delivering a positive economic impact on the local area, and therefore it has been categorised as poor value for money. Inadequate planning and forecasting were identified as key issues, with some of the airports being sited too close together. In 2017, the European Parliament (EP), has similarly called on the European Commission to review the EU's current approach to aviation connectivity, stressing that the connectivity should be aimed at joining remote and disadvantaged regions of the EU and that it is essential that this is done in conjunction with more sustainable alternatives, including cross-border, overnight trains.

For shipping, existing and emerging technologies can be limited by existing port infrastructure and institutional practices:

- For slow steaming, the current institutional framework often penalises late arrival at destination ports (Köhler et al., 2017).
- Cargo handling by cranes can conflict with most wind propulsion technologies, since cranes may be hampered by high masts (Rojon and Dierperink, 2014).
- ICT (information and communications technology) capabilities need to be developed, particularly weather-routing systems to gain maximum benefit from wind technologies (Mander, 2017; Rehmatulla et al., 2017).

Alternative fuels for aviation and shipping often require the introduction of new infrastructure. There can be an unwillingness of operators to invest in alternative fuel technologies, and associated vessels and aircraft with a limited alternative fuel supply infrastructure, while investments in new alternative fuelling stations are less attractive without an increasing demand for such fuels.

5.1.3 Lifespan of vessels

Aeroplanes and vessels have long lifespans, typically spanning several decades (e.g. an aircraft can have a lifetime of about 20-25 years). Current aircraft and vessel designs, and associated technologies, are therefore being locked into the longer term. While energy efficiency standards are frequently in place, more could be achieved. For example, it has been estimated that an extensive uptake of lighter weight composite materials could help achieve 14-25 % of the aviation industry's GHG emissions reduction targets, as well as contributing to a reduction in NO_x emissions (Timmis et al., 2015). Greater improvements, for example in terms of the energy efficiency of new ships, are also possible (Faber and 't Hoen, 2015). Concerning the use of alternative fuels, while modifications to existing designs can allow use of these fuels, it is often more cost-effective to incorporate this into new vessels than to retro-fit new technology into existing ships (e.g. EC, 2012). Differences between design and operational 'real-life' efficiency also need to be considered, with EEDI concerned with only the former (Scott et al., 2017).

One challenge for the shipping sector is the current oversupply of vessels, which corresponds to around one quarter of the world fleet in 2015 (ITF, 2017). Replacement and turnover of the fleet may be more challenging as a result of this surplus stock. Reasons for the imbalance in the market include negative economic shocks but also structural characteristics in the industry, including the impact of time lags of between 2 and 3 years from order to delivery (ITF, 2017).

5.1.4 Resistance from incumbent transport operators

Aviation and shipping are often seen as conservative industries (e.g. Mander, 2017). For example, the culture of the shipping industry has historically been careful not to take risks (Rojon and Dieperink, 2014), which results in ship owners being reluctant to be the first movers in terms of adopting new technologies. For aviation and shipping, dominant operators can have little incentive for change, whether it is investing in new technologies, sharing data or engaging in cooperation with other modes. New operators can act as facilitators for change, for example low-cost airlines' greater adoption of newer, more fuel-efficient planes compared with traditional carriers (Figure 5.1).

The fragmented nature of the shipping industry can also cause problems. For example, slow steaming can increase voyage time, which can affect the timeliness of the supply chain. Carriers can benefit from slow steaming through reduced fuel consumption, but these benefits may not be passed on to shippers whose supply chains are affected. For slow steaming to be more widely accepted, there needs to be greater transparency over the financial benefits, with carriers and shippers working to share these benefits (Mander, 2017).

5.1.5 Lock-ins in other sectors

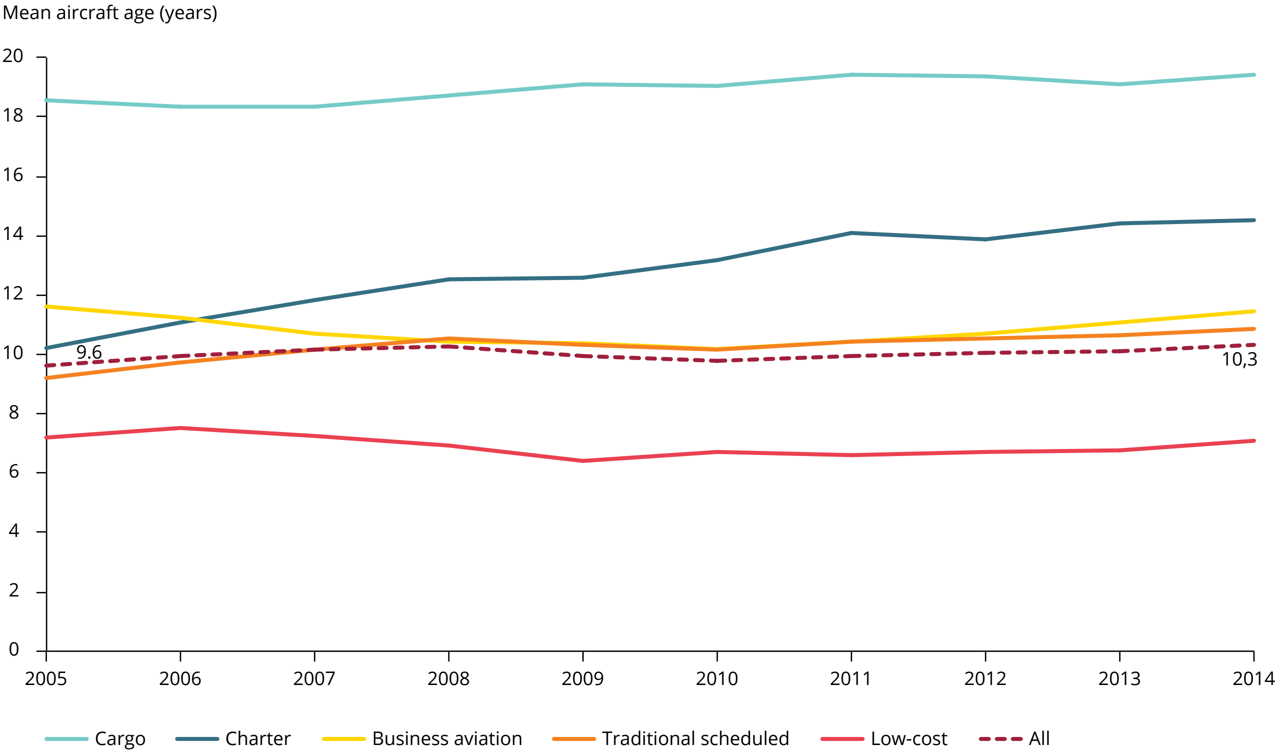
A sustainable transport system is intertwined with broader systems. The use of sustainable biofuels in the aviation sector needs to be seen in the context of competing uses, for example in the road transport sector (particularly in heavy-duty vehicles) and in terms of food availability, as well as broader, potentially negative sustainability impacts on biodiversity (Popp et al., 2014). The absence of sustainable second-generation feedstock supply has historically been seen as a key challenge in terms of biofuel use in the aviation sector (Gegg et al., 2015), together with limited production facilities in Europe (EASA et al., 2016).

5.2 Barriers

5.2.1 Existing interests

The interests of incumbent industries can often stand in the way of necessary changes to the transport

Figure 5.1 Mean aircraft age per flight



Source: EASA et al., 2016.

system (Sharmina et al., 2017). For the shipping sector, short-term priorities, for example issues with local and sulphur-related pollution, were prioritised over global and longer term carbon 'pollution', which potentially locked out low-carbon measures. The fragmented nature of the sector may also play a role, as the ships in the world fleet are in the possession of many owners. Furthermore, perception is important, with wind propulsion technologies that could help improve fuel economy being viewed as a nostalgic 'thing of the past', and not in line with the modern economic system (Rojon and Dieperink, 2014).

Studies have stressed that 'innovation champions' or 'change agents' in general play an important role with regard to disruptive changes (Howell et al., 2005; Benn et al., 2006). Environmental leadership by big shipping companies can also be emphasised, whereby their environmental actions have resulted in others following suit (Scott et al., 2017).

5.2.2 Governance

International agreements are required to transition towards sustainable aviation and maritime transport. However, the speed of international negotiations is often slower than that which can be achieved within the EU alone (EEA, 2016a). Shipping is regulated by the IMO and aviation by the ICAO. Reflections on their current approaches are identified in Chapters 3 and 4. The timescales to which these organisations work are also challenging. For shipping, concrete measures to reduce emissions will probably be agreed only in 2023, with an initial GHG emissions strategy to be adopted in 2018. Globally, visions of how the sector will reduce emissions are yet to be developed. Efforts to reduce emissions, and associated policies such as fuel taxation, are less meaningful if not decided at an international level and result in progress towards reductions in GHG emissions (EEA, 2016a).

5.2.3 Costs

The high cost of developing, purchasing and producing new technologies and fuels can be a key barrier. High production costs have been identified as a major block to the development and use of biofuels in aviation (Gegg et al., 2014). This high production price translates into a higher fuel cost. Aviation biofuels are estimated to be between two and four times the price of fossil jet fuel (Hamelinck et al., 2013). The price premium over fossil jet fuel (EUR 762 per tonne renewable jet fuel) and emission mitigation cost (EUR 242 per tonne CO_2 avoided), averaged over 2020-2030, are relatively high compared to other mitigation options (de Jong et al., 2016). This price premium is expected to persist beyond 2030. Suggestions for a structural financing mechanism to foster early adoption and production of renewable jet fuel are needed. Economic analysis suggests that a surcharge of EUR 0.9-4.1 per passenger departing from an EU airport would be sufficient to finance a 5 % uptake of renewable jet fuel by 2030 (de Jong et al., 2016).

In terms of cost, it is important to take into consideration the subsidies and energy tax exemptions that conventional aviation fuels benefit from, and place the cost of biofuels in this context. For example, research suggests that for Germany a kerosene tax is an important environmental protection measure; an excise duty rate of EUR 0.65 per litre, as set out in the German 2006 Energy Tax Act, could be levied on aviation fuel (Köder et al., 2014). With aviation jet fuel prices at around EUR 0.40 per litre, an excise duty rate of this size would effectively double the cost, providing a more level playing field for aviation biofuels.

Pricing can therefore provide important incentives towards making transport more sustainable, as supported by the 2011 Transport White Paper (EC, 2011). When prices better reflect the real-world external costs caused by passenger and freight transport, consumers and producers must start to take these costs into account. Pricing will affect transport not only directly, but also indirectly. An example is the demand for leisure travel (and the ensuing effect on the tourism sector) and discretionary goods.

Who pays and who benefits from costs and investments can also be a key issue. Split incentives can be a key barrier in the shipping sector (Mander, 2017), when those who pay for energy efficiency improvements (e.g. ship owners) do not financially benefit. Instead, the benefits would usually accrue to operators (Rojon and Dieperink, 2014). Short contracts between ship owners and charterers therefore have an impact on opportunities for payback on the required timescales. For example, more than 90 % of time-charter contracts last for less than 2 years, and this would not be long enough for payback on wind technology investments (Rehmatulla et al., 2017).

A lack of investment and challenges in accessing funding can also act as a barrier. For aviation biofuels, uncertainty around the technology and legislative support can hinder investment. The importance of de-risking the investment, for example through government-backed loans and the availability of government funding, has also been identified (Gegg et al., 2014). For the shipping sector, the reluctance to try new technologies and the lack of evidence to prove their economic benefits can make attracting investment particularly difficult. New technology companies therefore often have to rely on their own equity or on public funding to test and promote their products (Nelissen et al., 2016; Rehmatulla et al., 2017). The economic crisis of 2007-2008 and the subsequent economic downturn has been identified as having negatively affected both the aviation and shipping sectors, with operators struggling for commercial survival and lacking the financial resources to invest in new technologies (Rojon and Diepering, 2014).

To help address existing interests and cost barriers, there is therefore a need to look for action across the sectors encompassing a range of actors — owners, operators, engineers, regulators, banks and finance companies.

5.2.4 Environmentally harmful subsidies

Environmentally harmful subsidies can be defined as being the 'result of a government action that confers an advantage on consumers or producers, in order to supplement their income or lower their costs, but in doing so, discriminates against sound environmental practices' (Withana et al., 2012). For the aviation and maritime sectors, the tax exemptions for fuels used are identified as key subsidies. However, when compared with railway transport, these exemptions have to be put into perspective, with massive subsidies granted for the latter.

Research by Germany's Environment Agency (Köder et al., 2014) found that the transport sector receives a greater amount of subsidies than other sectors, and this was identified as being mainly due to aviation subsidies. The impact in terms of loss of potential revenue can be significant. Analysis undertaken for Germany suggests that, for domestic flights alone, the tax exemption of fuel resulted in a tax shortfall of EUR 680 million in 2010 (Köder et al., 2014). Taking into account international flights through analysis of the tax exemption of fuel used for foreign travel results in a subsidy of EUR 6.91 billion (Köder et al., 2014).

The European Parliament (2017) has emphasised that fuel taxation must be introduced for the aviation sector, highlighting that this sector is far from internalising its external costs. The need for interim action is also highlighted, for example the role of the removal of VAT exemption on international air passenger tickets. The particular fiscal system of air transport, which has no fuel taxes and where VAT is applied only in a minority of European countries, is identified as a barrier to modal shift to rail. However, an economic concern is, for example, that the European aviation sector is under very high competition pressure from carriers from the Middle East and Turkey. Isolated European action could lead to adverse effects on the European aviation industry, if not carried out in a concerted way.

The absence of subsidies to take forward mitigation opportunities is also identified. Research by Gegg et al. (2015) found a lack of aviation biofuel incentives, especially within the EU. Harmonising such financial incentives for sustainable jet fuels as well as road biofuels, on both a European and a national level, could increase uptake (Kousoulidou and Lonza, 2016).

5.2.5 Knowledge needs and dissemination

Further research requirements and the current limited dissemination of existing data are identified as key barriers for the aviation and shipping sectors. For example, a lack of research into biofuel is considered a barrier in terms of the development and, in turn, uptake of aviation biofuels (Gegg et al., 2014).

For the shipping sector, data from trusted sources are required to better understand the impacts of new technologies. Currently, technology providers are the key source, but the potential for bias is recognised and trust in the information therefore reduced (Rojon and Diepering, 2014). In terms of onboard data collection, information on average fuel consumption in real-world conditions is often not publicly available in a detailed and transparent format. As a result, ship owners may be more reluctant to invest in new technology, reflecting the absence of clear, independent data on vessel performance (Faber and 't Hoen, 2015).

Collecting these data is also difficult because of the large number of factors that affect fuel consumption (e.g. weather, hull design and draught) and the difficulties in isolating these impacts. A shift to a more comprehensive method of continuous data collection is occurring. However, the rate of uptake is limited by installation costs (Mander, 2017; Rehmatulla et al., 2017). The EU's recently adopted Regulation on the monitoring, reporting and verification of shipping emissions (EU, 2015) will ensure that information on operational emissions becomes publicly available. But it will not provide sufficient information on the extent of the technologies being implemented (Rehmatulla et al., 2017), i.e. it will be difficult to discern the impact of individual technologies. Positive examples of information dissemination do exist. Maersk, a pioneer of slow steaming, has shared 'letters of no objection' from engine manufacturers with the operators of its ships, helping to disseminate knowledge more widely among the navigation industry, and contributing to taking slow steaming forward (Mander, 2017).

Visions and goals can play a key role in taking forward transitions. Here, there is the potential for further considering the role of technology roadmaps, for example building on the visions set out in the European Commission's Maritime Transport Strategy (EC, 2009).

5.3 Landscape change

Forces can also disrupt the regime, facilitating windows of opportunity for innovations to establish themselves. These forces come from the external 'landscape', which encompasses socio-economic, political and international trends. These can constrain and enable change (e.g. Raven et al., 2010). Relevant forces in the external landscape identified in the shipping and aviation literature are discussed below.

5.3.1 Oil prices

For the transport sector, when oil prices are high, there is more of an incentive to invest in energy efficiency measures (Nelissen et al., 2016; Mander, 2017; Rehmatulla et al., 2017), with oil prices being identified as the most important driver for investment in energy efficiency in shipping (Rojon and Dieperink, 2014). For aviation, drivers for biofuels include jet fuel prices and fuel security concerns (Gegg et al., 2015). Fuel can be a proportionally larger part of airline costs, and in 2016 they represented approximately 19 % of airlines' operating costs (IATA, 2017). These landscape changes could provide the industry with a strong incentive to explore alternative fuel solutions and improve efficiencies (ACI et al., 2010). The extent of these incentives will depend on the fuel price and the potential for substantial change over short time scales. Steps to ensure that aviation fuel prices better reflect environmental externalities, and that taxation reflects this in terms of VAT on international flights and taxation on aviation fuel, may also facilitate the uptake of more sustainable fuels.

5.3.2 Social responsibility

The social responsibility agenda can also act as an agent for landscape change (Mander, 2017), causing businesses to consider their supply chains, including how they ship their goods. The example of the airport GHG accreditation scheme was mentioned earlier in this report, one outcome of the increasing pressure on the aviation sector to disclose and improve its environmental credentials (Koç and Durmaz, 2015).

Data from the shipping MRV will be made available to a range of stakeholders, including service purchasers, regulators and non-governmental organisations (NGOs). NGOs may play a particular role in driving forward sustainability from the social responsibility perspective, helping raise awareness among consumers.

5.3.3 Regulatory measures

In terms of developing niches and changes in the current regime, the importance of policy interventions through, for example, strict regulation or MBMs has been identified (EEA 2016c; Geels, 2016). Regulation can provide a strong impetus for change. For instance, the introduction of marine fuel sulphur limits (maximum sulphur content of fuels reduced from 1.0 % to 0.1 %) in the North Sea and the Baltic Sea has resulted in air quality improvements, with reductions of ambient sulphur concentrations of 50 % and more having been reported (CE Delft, 2016b).

As discussed in Chapters 3 and 4, regulations for shipping and aviation in the longer term will focus on MBMs. While these are potentially cost-efficient mechanisms for reducing emissions, concerns have also been raised. For the aviation sector, for example, there are questions over whether the carbon costs involved will be sufficient to facilitate uptake of the required energy-efficient measures, and whether the coverage will be adequate to achieve the required emission reductions when it does not cover domestic aviation. As a result, options to potentially limit the current aviation EU ETS exemptions of flights to and from Europe until 2021 are under political discussion. For the shipping sector, timescales will be a major challenge. According to the roadmap agreed at the IMO, concrete measures to reduce emissions seem to be expected to be adopted only in 2023. However, there seems to be general support at the IMO for early action by way of short-term measures to be adopted between 2018 and 2023.

5.3.4 Disruptive events

There is the potential for lessons to be learnt when disruption is sudden and unexpected. One such example is the volcanic ash cloud released into the atmosphere during the eruption of the volcano Eyjafjallajökull in April 2010, which impacted flights across Europe. It is estimated that more than 100 000 flights and 10 million passenger trips were cancelled (Eurocontrol, 2010). Surveys of those travellers stranded raised interesting questions around journey planning, with original destination choice being linked to the ready availability of cheap, short flights (Guiver, 2012). This emphasises the role that pricing could play in terms of constraining demand. In terms of revised options, the accessibility of different, closer destinations was identified as key and needs to be linked into the potential for broader societal changes around travel needs.

5.4 Niches

Niches are effectively a protected space for emerging innovation, and for enabling and nurturing experimentation in alternative technologies and practices (Raven et al., 2010; EEA, 2016c). Niches can occur through deliberate actions (for a definition, see Box 5.1). Governments, for example, can use a number of mechanisms to develop niches, including investment in research development, product standards and subsidies (EEA, 2016c). Businesses and civil society actors can also provide significant opportunities to create niches and promote innovation. EU-funded research and civil society initiatives are explored below, discussing, where appropriate, how barriers and lock-in have been overcome.

5.4.1 Research initiatives

Aviation — biofuels

The Initiative Towards sustAinable Kerosene for Aviation (ITAKA) project was a collaborative EU initiative that aimed to facilitate the transition towards sustainable aviation biofuels. The project started in 2012 and finished in 2016. The niche space allowed the demonstration of the use of a biojet blend mixed with conventional airport fuel systems (including tanks, pipelines, hydrants) during conventional airport operation (ITAKA, 2017). Since the end of 2015, all flights departing from Oslo Airport (Gardermoen) have used a biojet fuel blend (below 3 %) thereby contributing to the evidence base concerning biofuel and kerosene blending and to achieving fuel quality standards.

The ITAKA project involved the production of camelina oil (an aviation biofuel). The production of the fuel covered more than 15 000 hectares, with the land chosen having a low risk for the potential for indirect land use change (ILUC) (13). The outcomes of the project suggest that 2.1 million hectares could be available for camelina oil production in the EU, of which 25 % is in Spain. This would produce 700 000 metric tonnes of camelina and substitute more than 1 % of the jet fuel consumption in the EU. A further challenge, however, is that camelina oil is classified as an ILUC-generating oil crop for which the Renewable Energy Directive proposal suggests limiting broader production (EC, 2016d).

The project demonstrated the declaration of the use of biojet fuel in the ETS and how aviation biofuel can be accounted for in national renewable energy targets. The ITAKA project also focused strongly on dissemination of information across multiple stakeholders — farmers, biofuel and aviation sectors, and air passengers.

Electric aviation

Electric aviation currently mainly occupies an early-stage innovation niche, and is far from replacing conventional aircraft (see for example Figure 5.2). However, it enables and nurtures experimentation and use of alternative technologies and practices in the wider aircraft industry.

In 2014, European aircraft manufacturer Airbus demonstrated its initial all-electric E-Fan prototype aircraft, using onboard lithium batteries to power its motors. The aircraft made a successful flight across the English Channel in 2015, and it was initially developed for niche markets such as pilot training. However, because of a number of factors, including range requirements and other developments in the electric aviation industry, the project has since moved towards the use of hybrid-electric engine configurations and larger and more powerful aircraft. One such model, the E-Fan X, is currently to be developed by 2020 (AE, 2017; Airbus, 2017).

Figure 5.2 Example of an electric aircraft

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(13) While biofuels are important in helping the EU meet its targets for reducing GHG emissions, biofuel production typically takes place on cropland that was previously used for other agriculture, such as growing food or feed. Since this agricultural production is still necessary, biofuel production may be partly displaced to previously non-cropland such as grasslands and forests. This process is known as indirect land use change (ILUC).

Additional research will be required to develop electric engines that generate sufficient thrust and to improve the energy density of batteries. To extend their range, electric aircraft would have to rely on alternative technologies such as solar panels. An example of such a development includes the Swiss solar-powered aircraft project Solar Impulse, which in 2016 completed a circumnavigation of the Earth using only solar power.

At present, several alternative aircraft designs have been identified as potential ways to reduce emissions, including blended truss-braced ([14]) and box wing aircrafts (Somerville et al., 2016). However, more research is needed before such technologies can be adopted on a larger scale.

5.4.2 Civil society initiatives

Civil society groups can also promote the emergence of niches (EEA, 2016c). One way is by advocating and organising preferential treatment of particular goods or services, for example those that are environmentally beneficial. Civil society groups can also help create the space for discussion around required behaviour change, including questioning the need to travel, as illustrated in the case study in Box 5.2.

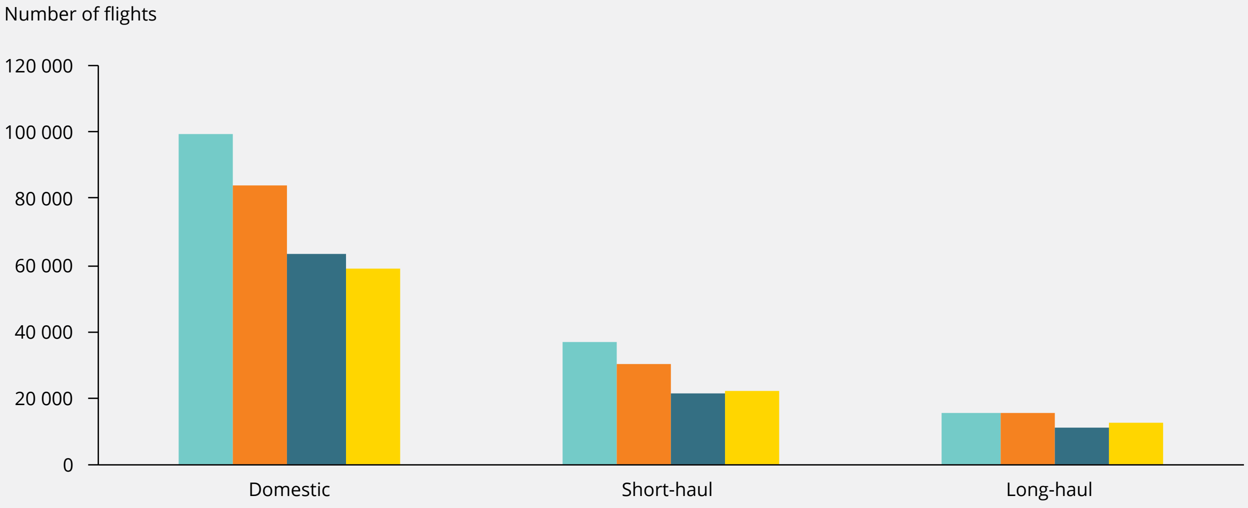
Apart from reduced flight expenditures and GHG emissions, participating organisations also reported additional co-benefits from participating in the challenge, such as better work/life balance for employees, improved reputation and public relations,

Box 5.2 Case study: the One in Five Challenge

In July 2009, the World Wide Fund for Nature (WWF) UK launched the 'One in Five Challenge', a guided programme to help businesses and government reduce air travel demand by 20 % within 5 years. Framing potential for increasing business efficiencies and financial savings alongside potential carbon savings, the 'One in Five Challenge' developed a business case for reducing business travel. By 2012, six of the 12 organisations that joined the challenge in 2009 had reduced their number of flights by 38 % and flight expenditure by 42 % (WWF, 2012) (Figure 5.3).

The savings achieved through the project in such a short amount of time suggest the presence of 'low-hanging fruit', or non-essential flights that the organisations can do without, whereas additional savings become increasingly difficult to achieve.

Figure 5.3 The One in Five Challenge: flight numbers by flight type



Note: Different kinds of organisations participated in the challenge, including public sector organisations and private sector companies. By 2012, each of the organisations participating in the challenge had saved an average of EUR 2.45 million and avoided a total of 59 000 flights (WWF, 2012).

Source: Based on WWF, 2012.

([14]) In aeronautics, (truss) bracing utilises additional structural elements below the main wing, which stiffen the functional airframe. Among other things, this provides a stronger, lighter structure than one that is unbraced.

improved staff safety, and increased collaboration with colleagues, clients and suppliers (WWF, 2012). A mixture of measures was used to achieve the reductions, including those that facilitated demand reduction by questioning the need to travel, and reducing flight budgets to facilitate modal shift through replacing flights with rail travel and increasing the use of video- and audioconferencing.

5.4.3 Business stakeholders

Business stakeholders can contribute to the development of niches, for example through developing innovative business models. There is increasing interest in the circular economy. In contrast to the linear economy, which uses a 'take, make, dispose' mode of production, a circular economy aims to reduce the production of waste through product design or reuse, to circulate materials in the production system for continued use (Ellen MacArthur Foundation, 2015).

The circular economy will have an essential role to play in terms of the design of aircraft, vessels and their parts to facilitate reuse and recycling. This is a monumental task, with a modern commercial aircraft such as the Airbus A380 consisting of approximately 4 million individual components, produced by more than 1 500 companies from 30 countries (Airbus, 2016).

High-performance requirements for aircraft have caused the sector to rely on rare and expensive materials such as titanium, rhenium, hafnium and beryllium to improve performance (Spence, 2012). This has been highlighted by, among others, the European Commission's Joint Research Centre, stressing that a shortage of such metals could become a threat to Europe's climate goals. This reflects their use in, for example, batteries for electric vehicles (Moss, et al., 2011).

Such dependence is increasingly becoming a challenge for the aviation industry, leading to new, alternative business models, including increased reuse and recycling of materials, especially to produce the more expensive parts such as landing gear and aircraft engines.

The European Ship Recycling Regulation (EU, 2013c) requires ships registered in the EU to use 'green' listed recycling facilities and requires all ships calling at ports in the EU to have a hazardous material inventory (EC, 2016e). This allows for tighter control on hazardous materials and an effective ban on beaching facilities (Domini and Metall, 2014). On 19 December 2016, the European Commission adopted the first version of the 'European list of ship recycling facilities'. The first 18 shipyards on the list are all in the EU and will have exclusive access to ships that fly the flags of Member States. Applications to join the list have been received from additional yards in non-EU countries. The Commission will decide later this year with regard to their inclusion, once the applications have been reviewed and verified in full.

5.5 Summary

This chapter has provided examples of some existing lock-ins and barriers affecting a potential transition to more sustainable aviation and shipping sectors, as well as niches and landscape change. Lock-ins and barriers can be grouped around three key themes:

1. financial aspects;
2. knowledge needs; and
3. stakeholder interests.

Financial aspects include historical investment in existing infrastructure, the cost of new fuels and technologies, and fuel subsidies. Knowledge needs relate to the importance of data on the viability of new technologies, while stakeholder interests relate to existing interests, including resistance to change from transport operators.

The role of niches is very much to provide protected operating space within a sector to allow innovations to develop and flourish, rather than being overcome by existing barriers and lock-ins. For example, research initiatives (whether government or business led) can help reduce the cost of development of new fuels and technologies. Therefore, they help to address financial challenges; they can also provide data on the viability of new fuels and technologies, addressing knowledge needs, which in turn can provide reassurance with regard to the viability of this change and contribute to realigning stakeholder interests. Civil society initiatives can help develop the broader conversations around reductions in demand and movements to more sustainable lifestyles.

A number of challenges dominate despite the contribution of niches. These include the impact of subsidies, existing interests and resistance from operators. Landscape change therefore has a key role to play. Regulatory measures can provide clear signals to operators with regard to the steps required for change, overcoming resistance and facilitating uptake of new technologies and fuels. Understanding disruptive events and the impact they have on behaviour can improve the knowledge base with regard to the potential for change.

6 Concluding remarks

Transport, including aviation and shipping, continues to be a significant source of air pollutants. It is also the main source of environmental noise in Europe, and it contributes to pressure on ecosystems and thus biodiversity in sensitive habitats.

As other sources of GHGs decline, emissions from aviation and shipping are increasingly significant. While still comprising a relatively small proportion of total GHG emissions, those from international aviation have more than doubled since 1990 and were almost 25 % higher in 2016 than in 2000 (EEA, 2017f). Between 2000 and 2015, the transport sector significantly reduced emissions of the main air pollutants SO_x, NO_x and primary PM. With the exception of international aviation, all modes of transport contributed to the decrease.

The impact assessment accompanying the European Commission's 2011 Transport White Paper sets, for example, the ambitious goal of a 70 % reduction in transport oil consumption by 2050 compared with 2008 (EC, 2011). Even though the EU was on the target path until 2014, it exceeded the projected downward target trend in 2015 because of increased diesel fuel consumption in road transport and international marine bunkers. Transport oil consumption will need to fall by more than two thirds to meet the 70 % goal by 2050.

For the aviation and shipping sectors to contribute to 2050 decarbonisation goals and broader sustainability objectives, systemic change is required, going beyond simple efficiency gains. While a range of technological and operational measures exists, which can improve efficiency and therefore reduce emissions, implementation and adoption of these measures is currently limited. In terms of modal shift for aviation, the shift to rail, where feasible (e.g. for distances < 1 000 km), offers potential, although a number of barriers have been identified. Mitigation through avoiding the need to travel receives limited consideration for shipping and aviation.

Transitions to sustainable aviation and shipping therefore need to be considered. Here, an understanding of lock-ins and barriers to change is key. This report identifies three key themes that act as obstacles to change in the shipping and aviation sectors — financial aspects, knowledge needs and stakeholder interests. This understanding can in turn help to identify the mechanisms through which, and the extent to which, these barriers and lock-ins can be overcome through existing initiatives.

Transitions involve a great deal of complexity and uncertainties. However, governments and other societal stakeholders, such as civil society and business stakeholders, can help catalyse and steer transitions, for example by creating niches in which experimentation and innovation can flourish. A number of EU and international initiatives provide niches to facilitate the required transitions. In addition, technology and innovation developments in other transport modes could cause a change in travellers' behaviour. For example, one could assume that people will be more inclined to travel long distances in self-driving cars. Framing niches within the three key themes of financial aspects, information needs and stakeholder interests highlights the role that they can play in addressing certain barriers and lock-ins. For example, improvements in the scientific knowledge base are starting to be made. However, a newly configured regime has yet to be formed. Correspondingly, these niche innovations are not yet fully embedded in the system.

Niches have a key role to play in transitioning to a more sustainable aviation and shipping sector, creating space for the development and uptake of innovation. However, a number of challenges will remain, such as the impact of aviation subsidies and the long lifespan of vehicles. Changes at the landscape level, in the form of stronger regulatory and fiscal measures, will therefore be required to overcome these barriers. A number of stakeholders have also called for further action in the shorter term, for example through taxation of air passenger tickets and removal of fuel subsidies.

More broadly, it is clear that innovations within current niches are mostly linked to 'improve' aspects of the 'avoid, shift and improve' framework. This includes the development of alternative fuels and design improvements in both sectors. The abatement potential for these options can be significant. However, increased understanding of the mechanisms that ensure opportunities to avoid travel is also required. This reflects the fact that behavioural, as well technological, change in these sectors will be necessary to move us towards 'agreed objectives on a better environmental performance of the transport sector'. In terms of the 'avoid' aspect, increased understanding of the cultural and behavioural shifts necessary to reduce demand for travel and goods is required, for example to address the attitude-action gap whereby environmental awareness does not translate into reductions in flight demand. It is important to learn from disruption to existing practices, for example from the 2010 Eyjafjallajökull volcanic ash cloud, to understand how travel practices are formed and how they are influenced by underlying societal and economic factors.

Related to this, there will be a need for wider conversations around the types of lifestyle that will help enable sustainable mobility. A change in consumption habits regarding material goods will be particularly relevant for the shipping sector. This will include evaluating and addressing existing incentives, with the purpose of achieving more sustainable demand. These range from the impact of advertising on cultural and social norms to the need for increased durability and serviceability of goods. The latter ties in with the emerging work on the importance of the circular economy.

7 Abbreviations, units and symbols

7th EAP	Seventh Environment Action Programme
BC	Black carbon
CAEP	Committee on Aviation Environmental Protection
CO	Carbon monoxide
CO_2	Carbon dioxide
CO_2e	Carbon dioxide equivalent
CORSIA	Carbon Offset and Reduction Scheme for International Aviation
dB	Decibels
EABF	European Advanced Biofuels Flightpath
EASA	European Aviation Safety Agency
EC	European Commission
ECA	Emission Control Area
EEA	European Environment Agency
EEDI	Energy Efficiency Design Index
EU	European Union
EU-28	The 28 Member States of the European Union
ETS	Emissions Trading System
GDP	Gross domestic product
GHG	Greenhouse gas
HFO	Heavy fuel oil
IATA	International Air Transport Association
ICAO	International Civil Aviation Organisation
ILUC	Indirect land use change
IMO	International Maritime Organisation

ITAKA	Initiative Towards sustAinable Kerosene for Aviation
LBG	Liquefied biogas
L_{den}	Day-, evening- and night-level indicator
LNG	Liquefied natural gas
LRTAP	Long-range Transboundary Air Pollution (Convention)
LRF	Linear Reduction Factor
MARPOL	International Convention for the Prevention of Pollution from Ships
MBM	Market-based measure
MMR	Monitoring Mechanism Regulation
MRV	Monitoring, reporting and verification
Mt	Megatonnes
NO_2	Nitrogen dioxide
NO_x	Nitrogen oxides
O_3	Ozone
PM	Particulate matter
$PM_{0.1}$	Particulate matter with a diameter of 0.1 μm or less
$PM_{2.5}$	Particulate matter with a diameter of 2.5 μm or less
PM_{10}	Particulate matter with a diameter of 10 μm or less
SEEMP	Ship Energy Efficiency Management Plan
SO_2	Sulphur dioxide
SO_x	Sulphur oxides
TERM	Transport and Environment Reporting Mechanism
UNECE	United Nations Economic Commission for Europe
UNFCCC	United Nations Framework Convention on Climate Change
VAT	Value added tax
VOC	Volatile organic compound
WHO	World Health Organization
WTO	World Trade Organization
WWF	World Wide Fund for Nature

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