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Carbon Footprinting of Combined Passenger Freight Operations in Aviation Networks

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Summary

If CO_2 emissions are taken into account in planning air freight logistics, the IATA RP 1678 method for CO_2 emission computations will give preference to using a dedicated freighter over the belly of a passenger aircraft for transporting cargo in an aviation network. This report quantitatively illustrates that this can lead to unnecessary freighter aircraft movements and additional real world CO_2 emissions compared to the optimal choice from a climate change mitigation perspective. The current carbon footprint methodology for aviation networks, IATA RP 1678, is thus directionally incorrect.

In airline networks freight is transported in two ways: on dedicated freighter aircraft and in the belly space of passenger aircraft. Transporting passengers yields more than transporting freight per unit of weight, so the development of combined passenger and freight airline networks is mostly driven by passenger demand. The dedicated freighter network structure and intensity develop solely due to freight transport demand. Therefore, the most efficient airline network operations would first utilize the available belly freight capacity, and only use dedicated freighters if there is no suitable or sufficient capacity in the passenger networks.

The IATA RP 1678 standard is currently the most widely used method for aviation emission computation and allocation to passengers and freight. The core of the methodological issue is that it assigns emissions to freight and passengers proportionally to their weight, while there is a significant difference in weight capacity between a freight and a passenger version of the same type of aircraft. For example a B747-400 dedicated freighter has a physical payload capacity of 112 tonnes, while a B747-400 passenger aircraft has a physical payload capacity of approximately 54 tonnes. Under the assumption of a 100% load factor this means that 1 tonne of freight on a dedicated freighter “consumes” 0.9% (= 1/112) of the weight capacity, while 1 tonne of freight on a passenger aircraft of the same type (B747-400) “consumes” 1.9% (=1/54) of the of the weight capacity on that flight. Although IATA RP 1678 partly accounts for this capacity difference (the IATA method allocates 100 kg per passenger plus 50 kg per available seat), in the majority of cases, a shipment of a unit of freight on a dedicated freighter gets allocated a smaller portion of the emissions than the same unit of freight on the passenger aircraft.

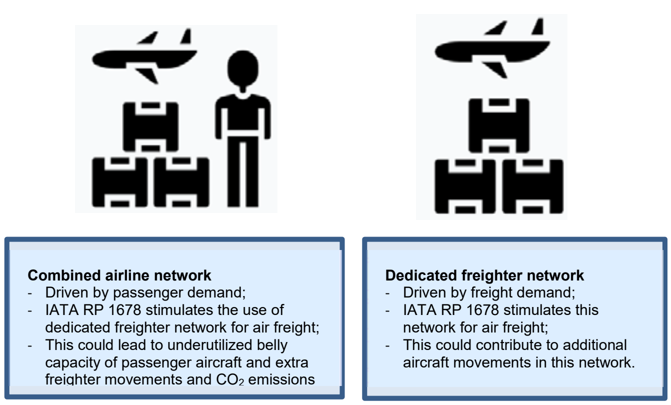

Figure 1: An overview of two options to transport air freight: in the bellies of passenger aircraft or in dedicated freighters.

If carbon footprinting is supposed to stimulate reduction of real-world emissions, the applied methodology must correctly assess the impact of measures that affect these real-world emissions. In this report a number of example cases are assessed to explore the above described methodological issue with IATA RP 1678. For the average situation on two reference routes carbon footprints are calculated for freight carried in passenger aircraft and dedicated freighters. Subsequently an assessment is made of the impact on actual CO_2 emissions of shifting freight from the belly of a passenger aircraft to a freighter. In a third step the impact is assessed of generating an additional freighter flight as a consequence of shifting cargo from multiple passenger aircraft to the dedicated freight network.

As explained the carbon footprint of freight in a passenger aircraft depends on the occupation factor of the passenger aircraft. The assessment confirmed that in the majority of cases the IATA RP 1678 yields a higher carbon footprint for freight in a passenger aircraft than in a dedicated freighter. If, based on these carbon footprint results, freight is shifted from passenger aircraft to freight aircraft the impact on actual CO_2 emissions is found to be negligible as long as no additional flights are generated. But in the end shifting freight from passenger aircraft to freighters will contribute to the creation of an additional aircraft movement, and hence additional CO_2 emissions, while the belly capacity of passenger aircraft on flights already scheduled may go underutilized. We estimate that a complete shift of belly cargo to dedicated freighter on the Shanghai-Amsterdam trade lane may result in a 7,7% increase in total emissions. Thus, the currently most used methodology promotes suboptimal decisions with respect to CO_2 emissions and should be amended.

This report presents two approaches for an improved methodology that are promising to consider seriously for a future amended carbon footprint methodology for air freight. The first approach is capacity-based and takes into account different weight capacities of passenger and freighter aircraft, as well as differences in passenger cabin compositions. The second approach is revenue-based, where aircraft capacity is split proportionally to the revenues generated.
Both approaches require further elaboration and evaluation, but are expected to result in methods that effectively help to reduce real-world emission. Industry acceptance, data availability and the ease of implementation should be considered for a choice between these approaches.

In view of the increasing pressure on the aviation sector to reduce their contribution to global warming, we strongly recommend a timely revision of the IATA RP 1678, since it is important for a carbon footprinting method to stimulate the desired operation and investment decisions from a climate change mitigation perspective. We suggest that industry representatives, such as airlines, freight forwarders and shippers, together with researchers elaborate on a broadly acceptable and implementable method for a standard practice in commercial aviation. This will be a small effort for building a better foundation for improving energy efficiency and reducing CO_2 emissions in commercial aviation.

Contents

1 Introduction

Aviation is an important economic sector and also an important and growing source of CO_2 emissions. It is estimated that global aviation was responsible for 915 million tonnes of CO_2 in 2019[1], which is approximately 2% of the total world-wide human-induced CO_2 emissions. The Dutch aviation sector is responsible for some 13 million tonnes of CO_2 emissions per year[2], which makes it a very important player with respect to greenhouse gas emissions in the country. Therefore, it is important to make sure that the sustainability of the aviation sector is improved.

1.1 Growing cargo space on passenger aircraft could cut CO_2 emissions

Aviation operations are mainly driven by the demand for passenger services. At approximately 80 Eurocent per one tonne-kilometre for passengers, passenger transport yields more than three times as much revenue as freight transport, which yields at around 25 Eurocent per tonne-kilometre in long haul networks. Cargo on passenger aircraft is therefore usually an additional revenue on the route.

The aviation industry also uses dedicated freighters (cargo aircraft), which are aircraft that are fully equipped for freight transport. These aircraft, per definition, only fly because of freight transport demand. Dedicated freighters provide for the possibility to transport certain categories of goods that cannot be transported on passenger aircraft, such as dangerous goods and goods that can only be transported on the main deck as they do not fit or cannot be transported in the bellies, such as machinery and horses. Cargo aircraft provide for more flexibility (e.g. on routes where no sufficient passenger demand is to justify the service by passenger aircraft) and their freight carrying capacity per flight is higher than that of passenger aircraft.

Figure 2: Cargo aircraft, or dedicated freighters, are fully designed and equipped for freight transport.

With the increase in the number of new generation, large twin engine aircraft (the so-called widebody aircraft), the cargo space on passenger aircraft is growing.

[1] https://www.atag.org/facts-figures.html
[2] https://www.cbs.nl/nl-nl/faq/luchtvaart/hoeveel-uitstoot-veroorzaakt-de-nederlandse-luchtvaart

This means that more and more freight shifts – or can potentially be shifted – from the dedicated freighters to passenger flights. The shift of cargo from the dedicated freighters to the passenger aircraft can lead to a decrease in the number of flights of cargo aircraft. Although increased use of passenger aircraft for freight transport increases emissions of those flights due to heavier aircraft and larger fuel burn, this increase is much smaller than the emission savings from fewer dedicated freighter flights. In other words, fewer aircraft movements for the same amount of freight can lead to a less strong growth of aviation's CO_2 emissions. Together with other measures, it can speed up developments leading to a reduction in the total CO_2 emissions in aviation.

1.2 Current IATA CO_2 allocation rules do not promote the use of belly space

The way CO_2 emissions are currently allocated to air freight does however not promote the use of belly space on passenger aircraft. To the contrary: the carbon footprinting rules as described in IATA RP 1678, the current carbon footprinting method for aviation networks, generally allocate more CO_2 emissions to freight transported in passenger aircraft than to freight transported in cargo planes. When following the IATA carbon footprinting rules, shipments may be diverted away from the use of the available belly space on passenger aircraft in favour of using dedicated freighters. As in reality using belly space would cause less CO_2 emissions through fewer aircraft movements, the current IATA CO_2 allocation method inadvertently promotes a less efficient network choice.

1.3 The purpose of this report: to facilitate discussion and propose more sustainable directions

The purpose of this report is to provide some qualitative and quantitative arguments that carbon footprinting rules as described in IATA RP 1678 are not well fit for the purpose of emission reduction and optimization. Although the question of CO_2 allocation is a complex one, this report will show that especially the rules related to allocation of emissions between air cargo and passengers have shortcomings. It is the authors' intention to facilitate a discussion on a better approach, such that both carriers and users of air freight transport can agree on a method that better fits the purpose of promoting emission optimization.

1.4 Reader's guide

This report is structured as follows: Chapter 2 outlines the general principles of carbon footprinting and looks at how IATA RP 1678 methodology computes emissions and allocates them to passengers and freight. Chapter 3 presents estimations of emissions in real world operations on two different routes (Shanghai – Amsterdam and New York Amsterdam) for two different aircraft type in passenger and freighter configurations. The IATA RP 1678 is applied to allocate these emissions to freight and passengers. The results show how different freight carrying capacities of passenger aircraft and dedicated freighters result in allocation of more emissions to the belly freight compared to the same amounts of freight travelling on the dedicated freighters Subsequently the impact on CO_2 emissions is assessed of shifting cargo from passenger aircraft to dedicated freighters. Chapter 4 provides conceptualization on how emissions can be incorporated into the decision making process (route and aircraft choice), and how that may affect decisions. Chapter 5 outlines two promising approaches for a better emission allocation methodology, namely capacity based and revenue based. These two approaches are suggested to be further studies in consultation with the stakeholders.

Note on COVID-19

It is worth noting, that freighter aircraft got an unexpected prominence during the COVID-19 pandemic. With the grounding of the passenger services, a substantial part of the airfreight market capacity, namely belly freight, became unavailable. This led to a spike in airfreight prices that justified the use of passenger aircraft for cargo-only flights. The depth of the medical crisis made acceptable the use of all means possible in order to get the vital supplies. There were a number “cosmetic” conversions done to transform passenger aircraft into freighters, by removal of passenger seats for the main deck cargo space.
This conversion, however, did not include structural strengthening, thus allowing only light-weight freight such as medical equipment and personal protective equipment to be transported[1]. It is expected that after the COVID-19 pandemic, these aircraft will be converted back for the use in passenger services. This implies that the arguments and reasoning presented in this report remain valid. The observed reduction in passenger flights, and hence belly freight capacity, is temporary. The passenger market is expected to rebound when the pandemic ends, therefore, prioritization of the use of belly freight capacity remains an important factor for reduction of CO_2 emissions in airfreight.

2 Carbon footprinting in aviation networks

Internationally, governments and businesses become increasingly aware of the need to reduce greenhouse gas emission (GHG). As a means for monitoring and understanding of GHG emissions and a tool for promoting emission reduction, carbon footprinting gains prominence. Many businesses have made sustainability one of their core values and emission disclosure is often a fixed item in the corporate reports and investor relations data. Hence, getting emission data right is important[3]. It becomes even more important when emission reduction is incorporated into the decision making process: correct decisions can only be made if the underlying methods and data are correct.

Quantification of emissions allows determining the baseline CO_2 emissions and motivates actions that reduce them. The use of appropriate methods and accurate data increases the chances that selected emission reduction measures have a maximum positive effect on the real-world emissions. A properly implemented Carbon Footprint procedure provides for visibility of carbon emissions in supply and logistics chains, thus creating opportunities to identify and estimate reduction potentials, implement effective emission reduction measures and monitor their impact (Figure 3)[4].

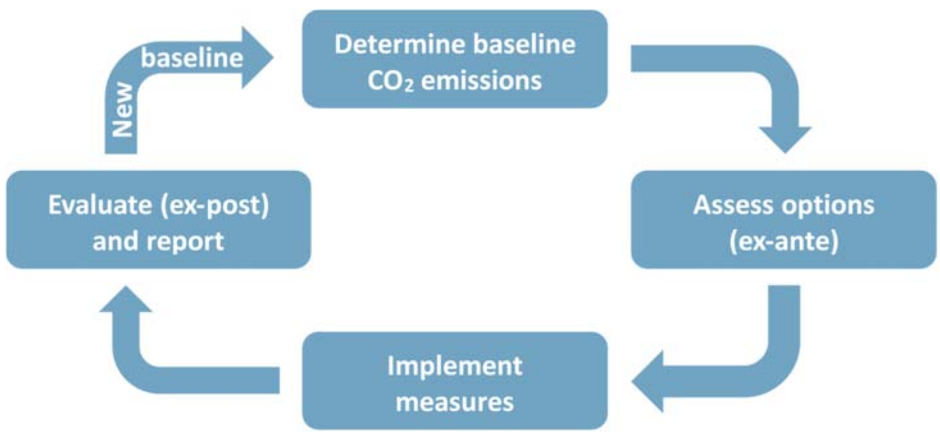

Figure 3: Positive decarbonization loop through complete visibility of emissions.

Decisions related to the transport choice in air freight networks can be made completely dependent on the associated CO_2 emissions, when a shipment is sent by the least emitting option, or only partly dependent on the associated CO_2 emissions by balancing emission minimization with costs and other relevant criteria[5].

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[3] Especially those of the Scope 3 of the GHG protocol: https://ghgprotocol.org/scope-3-technical-calculation-guidance

[4] Davydenko, I., M. Hopman, Gijlswijk BSc, R. N., A. Rondaij (2019). Towards harmonization of Carbon Footprinting methodologies: a recipe for reporting in compliance with the GLEC Framework, Objectif CO_2 and SmartWay for the accounting tool BigMile TM (TNO 2019 R11486)

[5] One of the existing examples, where traditional shipment booking parameters, such as costs and speed, are combined with emission data is RHEGreen tool of Rhenus Logistics, which allows shippers to choose between transport options comparing the CO_2 emissions related to each of the options.

Section 2.1 provides the definition and general principles of carbon footprinting. Section 2.2 elaborates on the current main methodology for carbon footprinting in aviation networks (IATA RP 1678). Section 2.3 explains at an aggregated level how a difference in weight capacity between passenger and dedicated freight aircraft leads to undesired effects of the current methodology. This is issue is explored in-depth in Chapter 3, through the quantitative assessment of two example cases.

2.1 General principles of carbon footprinting methodologies

Carbon footprinting[5] is an analysis of GHG emissions and attribution of these emissions to the activities that cause them. Carbon footprinting feeds the decarbonization process with data on actual emissions (ex-post) and expected emissions (ex-ante) related to proposed improvements. Carbon footprinting provides insights into the impact of activities on GHG emissions and their intensities with the possibility of subsequent actions to reduce them. Carbon footprinting can be performed at different levels, such as at macro (national or regional), meso (collaborative structures, ports, corridors), micro (company or department) and nano levels (specific activities, journeys, shipments). Carbon footprinting of logistic activities always includes decomposition of complex transport and logistics chains into transport chain elements or transport service categories, which can be further supplemented with in-depth analyses.

With respect to allocation of CO_2 emissions there is always some degree of arbitrariness present in all carbon footprinting methodologies[6]. Important criteria for developing a carbon footprinting methodology are accuracy of the results, directional correctness, fairness of allocation, feasibility and ease of implementation and broad acceptance.

Accuracy of the results is important when they are used for taking decisions, as shown in Chapter 3. Directional correctness refers to a system of outcomes where a lower *computed* or *estimated* emission footprint reflects less emissions *in practice*. As we show further in this chapter, the current IATA RP 1678 is generally not directionally correct when applied to the choice of shipping freight in the belly of passenger aircraft or by dedicated freight aircraft. In other words: there is generally no incentivisation of decisions that lead to fewer emissions for the scope of aircraft choice.

Fairness of allocation is a perception-based factor that is important for the acceptance by stakeholders[7]. For emission allocation, a fair allocation is a key factor for a wide uptake of the method. It stipulates that the actions that cause emissions get emissions allocated to the extent that those actions cause them. It also stipulates that there is no free-riding in the system and no entities or actions get assigned more emissions than their actual (or fair) share.

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[6] Davydenko, I., M. Hopman, Gijlswijk BSc, R. N., A. Rondaij (2019). Towards harmonization of Carbon Footprinting methodologies: a recipe for reporting in compliance with the GLEC Framework, Objectif CO_2 and SmartWay for the accounting tool BigMile TM (No. TNO 2019 R11486). TNO.

[7] The theory of fairness is an incentive theory put forward by American psychologists in the 1960s.

A crucial aspect of a carbon footprinting methodology is feasibility and ease of implementation, as it should be practically possible to implement it on the side of carriers as well as the users of transport, such as shippers, consignees, freight forwarders and freight consolidators. Availability of and access to the necessary data is an important aspect of the feasibility of implementation. Luckily, air transport industry has developed a system of strict accountancy of the passengers and freight carried. This data exists and should be accessible to the carriers, and the users of air transport have data on their shipments.

Broad acceptance is necessary for a successful implementation of a method. As such implementation can face resistance due to business sensitivity of the data. For example, disaggregated fuel burn data, load factors as well as financial data are considered commercially sensitive information.

As carbon footprinting may affect the competition between networks and between companies, changing an existing method may also be expected to encounter some resistance, even if the proposed amendments constitute scientifically proven improvements. As IATA RP 1678 already exists, the carriers may have some vested interests not to change it[8].

2.2 Current carbon footprinting methodology for aviation networks (IATA RP 1678)

The emissions of the aviation sector are not regulated by the Paris[9] climate agreement. Nonetheless, the sector takes some actions to limit the growth of CO_2 emissions in aviation. For instance, the Carbon Offsetting and Reduction Scheme for International Aviation (CORSIA[10]) is intended to limit the aviation emissions at the 2020 level (currently at the level of 2019 due to COVID-19 impact on the baseline emissions). For the emissions that exceed the base level, the airlines will have to buy emission offsets.

For the users of air transport, there are methods and models for estimation and/or computation of emissions, such as IATA RP 1678 and the GLEC Framework. The use of these methods should enable shippers to choose the most emission-efficient options. Several aviation businesses have started taking actions for emission reductions, such as the KLM biofuel programme[11] and BurnFAIR at Lufthansa[12]. An example of shipper-directed sustainability efforts is RHEGREEN[13], a tool developed by Rhenus Logistics, that estimates shipment-level emissions and presents shippers with different options on how to fly their cargo.

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[8] Implementation of improved allocation methods would probably assign more emissions to passengers, which may not be beneficial from the PR point of view. The freighter operators will lose the advantage of relatively smaller per tonne or per tonne-km emissions in their networks. Operators that phase-out dedicated freighters can benefit from the improved allocation methods.

[9] Paris Agreement, 12 December 2015, https://treaties.un.org/pages/ViewDetails.aspx?src=TREATY&mtdsg_no=XXVII-7-d&chapter=27&clang=_en

[10] https://www.icao.int/environmental-protection/CORSIA/Pages/default.aspx

[11] https://www.klm.com/travel/nl_en/prepare_for_travel/fly_co2_neutral/all_about_sustainable_travel/biofuel.htm

[12] https://www.icao.int/environmental-protection/GFAAF/Pages/Project.aspx?ProjectID=24

[13] https://www.rhenus.com/en/nl/our-solutions/air-ocean/about-us/rhegreen/

Some companies have started to include CO_2 emissions in their operational and investment decisions. They do this, for example, by choosing transport options that emit the lowest amount of CO_2 emissions, or by adding a fictive price of CO_2 emissions to the internal calculation of actual operating costs. These companies and decision makers need a methodologically sound and evidence-based support framework for making correct decisions.

The IATA Cargo Services Conference[14] adopted the Recommended Practice 1678[15] for CO_2 Emissions Measurement Methodology in March 2014. Developed by the IATA Air Cargo Carbon Footprint (ACCF) working group, the document establishes a methodology to compute the CO_2 emissions generated by air cargo at shipment level based on ex-post (i.e. past) emission intensity data. The emission intensity data is at the core of the IATA RP 1678 methodology for allocation of airline-specific emissions to the shipments.

IATA RP 1678 defines a leg-based emission factor (kgCO_2/tonne) as the average CO_2 emissions generated by the transportation of one tonne of cargo on a given city-pair (origin-destination). The leg-based emission factor is computed by the carrier on the basis of the measured (i.e. real) fuel burn and the actual payload. It is computed as:

$$Leg\_based\ Emission\ Factor\ \left(\frac{kgCO2}{tonne}\right) = \frac{Total\ fuel\ burn\ for\ the\ leg\ (in\ tonnes) * 1000}{Total\ payload\ for\ the\ leg\ (in\ tonnes)} * 3.15$$

(1)[16]

The emission factor is computed per leg (i.e. city pair) and is based on the tank-to-wheel (TTW) CO_2 content of the fuel, which is 3,15 kg CO_2 per kg of kerosene.

For dedicated freighters payload in equation 1 is defined as follows:

Total Payload Weight (tonne) = Total Cargo and Mail Weight (tonne) (2)

For the passenger flights, the payload in equation 1 is defined as follows:

Total Payload Weight (tonne) =
Total Passenger Weight (tonne) + Total Freight Weight (tonne) (3)

Where:

Total Passenger Weight (tonne) =
((Number of Seats * 50kg) + (Number of Passengers * 100kg))/1000 (4)

[14] https://www.iata.org/en/programs/cargo/sustainability/carbon-footprint/

[15] https://www.iata.org/contentassets/34f5341668f14157ac55896f364e3451/rp-carbon-calculation.pdf

[16] Note that for the network carriers, the IATA RP 1678 stipulates computing network-based emission factor as kg CO_2 / tkm. This means that for the network carrier, the denominator should be the sum of shipment weights multiplied by the Great Circle Distance (GCD) (or GCD distance plus fixed manoeuvring term) over which each shipment is displaced. For the purpose of this report, we discard the distance component, as we analyse emission allocation between passengers and cargo on the basis of individual flights.

Using:

Fictive Passenger Weight (tonne) = Total Passenger Weight (tonne) / Number of Passengers (5)

The emissions can be allocated to passengers and freight as follows:

Emission per passenger =Leg-based Emission Factor * Fictive Passenger Weight (6)

Emission per tonne of freight = Leg-based Emission Factor * 1 (7)

These allocation rules mean that the per flight allocation of emissions is on the basis of weight, and that the cargo weight is used directly for the allocation (kilo-for-kilo). For passengers the allocation of emissions is based on a fictive allocation weight accounting for the total extra weight related to the carriage of passengers. This includes 100 kg per transported passenger and their baggage, plus 50 kg per available seat to account for the weight of passenger-related items such as seats, catering, cabin crew, etc. as part of the payload. This fictive allocation rule means that when 100% of seats are occupied, each passenger gets 150 kg allocation weight. Under a realistic passenger load factor of 89%, each passenger gets an allocation weight of 156 kg (= 100 + 50 * 100/89).

2.3 Difference in weight capacity leads to undesired allocation effects

The main methodologies (IATA RP 1678, GLEC Framework[17]) allocate emissions by weight[18]. But there is a significant difference in weight capacity between a freight and a passenger version of the same type of aircraft. For example a B747-400 dedicated freighter has a physical payload capacity of 112 tonnes, while a B747-400 passenger aircraft has a physical payload capacity of approximately 54 tonnes (see Figure 4), in other words the freighter has more than twice as much weight payload capacity than the passenger variant of the aircraft. Under the assumption of a 100% load factor[19] this means that 1 tonne of freight on a dedicated freighter is allocated 0.9% (= 1/112) of the CO_2 emissions, while 1 tonne of freight on a passenger aircraft of the same type (B747-400) is allocated 1.36% (=1/73.7 = 1/(12.5 + 408 * 0.15)) of the CO_2 emissions of that flight under IATA RP 1678 allocation rules.

[17] The GLEC Framework generally follows the IATA RP 1678 methodological rules.

[18] The emissions are allocated to freight proportionally to the transport work (or transport activity). In simple cases, transport activity can be measured in tonnes transported, in most cases though, transport activity is measured in tonne-kilometres transported. For a single flight weight-based allocation and tonne-kilometre based allocation lead to the same result as the kilometre component is the same for all shipments.

[19] Note that under the assumption of a lower and equal load factor, the allocation proportions will be the same.

Figure 4*:* Two examples of weight payload capacity for both a dedicated freighter and a passenger aircraft of the same type. Based on KLM data[20] and data of other carriers.

Obviously the freighter aircraft in the above example has a higher total weight and thus a higher fuel burn on the same leg compared to the passenger aircraft. The extent to which IATA RP 1678 allocation rules lead to a higher carbon footprint for freight in the belly of a passenger aircraft thus also depends on the ratio of fuel burns of the two options. The standard average fuel consumption factors as used in the GLEC Framework v 1.0 (see Figure 5) do suggest that the IATA RP 1678 method leads to a higher carbon footprint for belly freight. Figure 5 shows that for flights over 1000 kilometres the amount of kerosene attributed by GLEC to a tonne-kilometre is higher for belly freight in passenger aircraft than it is for cargo in dedicated freighters. For example, to transport 1 tonne on a flight of 5000 km an amount of 1055 (= 1*5000*0.211) kg kerosene is allocated when the cargo is transported with a dedicated freighter, while 1750 (= 1*5000*0.350) kg kerosene is allocated when it is transported as belly freight.

		Kg kerosene (Jet A1 or Jet A)/tkm
Air	**Air freight only**	
	Up to 1000km	0.691
	1000 to 4000km	0.500
	4000 to 7000km	0.211
	Over 7000km	0.172
	Combined (Belly Freight)	
	Up to 1000km	0.610
	1000 to 4000km	0.526
	4000 to 7000km	0.350
	Over 7000km	0.306

Figure 5: Fuel consumption factors of air freight (GLEC Framework v 1.0).

The impact on CO_2 emissions of decisions to move shipments from bellies of passenger aircraft to dedicated freighter aircraft then depends on the additional fuel burn associated with the additional freighter aircraft movements and the fuel saved on the passenger aircraft movements due to their lower weight.

This is explored in depth in Chapter 3, which provides computations of the fuel burn for flights of comparable passenger and freight aircraft. The assessments confirm that that under real-world load factors the use of the IATA RP 1678 methodology leads to more CO_2 emission being allocated to freight on passenger aircraft than to freight on dedicated freighters. The calculations also show that the consequence of additional flight movements of dedicated freighters and reduced capacity utilization of belly space on passenger flights is higher real-world CO_2 emissions. This means that the IATA RP 1678 method is not directionally correct.

3 Application of IATA RP 1678 in two examples

If carbon footprinting is supposed to stimulate reduction of real-world emissions, the applied methodology must correctly assess the impact of measures that affect these real-world emissions. Chapter 2 illustrates on a high level that using IATA RP 1678 for decision support in aviation networks could lead to undesired effects: an increase of real-world emissions. Chapter 3 elaborates two detailed examples to support the high level statement in Chapter 2.

This chapter consists of the following sections:

- Definition of the two example cases (section 3.1);
- Fuel consumption model used for the emission calculations (section 3.2);
- Emission calculations for both example cases (section 3.3 and 3.4);
- Analysis and discussion of the results (section 3.5);
- Conclusion on freight emission computation and allocation (section 3.6).

3.1 Definition of the two example cases

This chapter presents emission computations on two routes[21] and shows the results of how emission allocation rules of the IATA RP 1678 distribute emissions between passengers and freight. For the Shanghai – Amsterdam and New York – Amsterdam routes, we compute flight-level emissions of dedicated freighters and passenger aircraft for typical load factors of freight and passengers, for two aircraft types, Boeing 777 and Boeing 747. Based on emission data, this chapter looks into what would happen if the outcomes are followed and least polluting options, as stipulated by IATA RP 1678 are preferred. For illustrational purposes, emissions are computed and allocated on the basis of single flights. Aggregation of a number of flights on the same route or inclusion of roundtrips would lead to the same conclusions, but would make the examples more complex.

3.1.1 The routes

For the illustration of the IATA RP 1678 allocation method and the possible impact of decisions based on the outcome of applying the method, two routes have been selected:

1. From Shanghai to Amsterdam (PVG → AMS)
2. From New York to Amsterdam (JFK → AMS)

There are two reasons for the selection of these two routes. The first reason is the duration of flights and the fuel burn on the segments. New York - Amsterdam is a relatively short long-haul segment, which is flown in the Eastern direction (tailwinds) with an average B747 flight time of 6 hours and 23 minutes. This relatively short flight duration means that the amount of fuel needed to carry for later stages of the flight is relatively small. An average flight from Shanghai to Amsterdam takes 11 hours and 20 minutes, where the non-linear effects of fuel burn are more profound.

[21] These routes can also be referred to as trade lanes.

The second reason for selection of the specific examples is the difference in load factors. Figure 6 shows that in 2019 the passenger load factor across the long-haul network of KLM was 89% on average, and its variation was small. For the passengers, therefore, the load factor on both trade lanes is assumed to be 89% in the example cases. On the other hand Figure 6 shows that the load factor for cargo[22] operations in 2019 varied significantly depending on the part of the network. Although the average cargo load factor was 64,5% for KLM's total cargo operations in 2019, the load factor for North America was 59% whereas for Asia it was 82%.

Cargo	Traffic			Capacity			Load factor	
In million cargo ton-km	2019	2018	% Change	2019	2018	% Change	2019 %	2018 %
Route areas								
Europe & North Africa	11	13	(17.0)	366	377	(3.0)	3.0	3.4
North America	994	1,019	(2.5)	1,675	1,640	2.1	59.3	62.1
Central and South America	1,251	1,316	(5.0)	1,876	1,851	1.3	66.7	71.1
Asia	1,454	1,504	(3.4)	1,767	1,745	1.3	82.3	86.2
Africa	752	767	(2.0)	1,101	1,125	(2.2)	68.3	68.2
Middle East	127	125	1.8	180	201	(10.4)	70.7	62.2
Caribbean and Indian Ocean	90	105	(13.9)	289	300	(3.6)	31.3	35.0
Total	4,678	4,849	(3.5)	7,253	7,239	0.2	64.5	67.0

Figure 6: KLM cargo load factor[23] per continent[24] in 2019, adapted from KLM's annual report.

Passenger	Passenger kilometers			Seat kilometers			Load factor	
In millions	2019	2018	% Change	2019	2018	% Change	2019 %	2018 %
Route areas								
Europe & North Africa	20,047	19,433	3.2	22,960	22,508	2.0	87.3	86.3
North America	23,666	23,045	2.7	26,474	25,795	2.6	89.4	89.3
Central and South America	15,989	15,939	0.3	17,798	17,645	0.9	89.8	90.3
Asia	28,625	27,668	3.5	31,398	30,318	3.6	91.2	91.3
Africa	11,545	11,698	(1.3)	12,935	13,243	(2.3)	89.3	88.3
Middle East	2,957	3,205	(7.7)	3,574	3,896	(8.3)	82.7	82.3
Caribbean and Indian Ocean	6,645	6,688	(0.6)	7,313	7,410	(1.3)	90.9	90.3
Total	109,476	107,676	1.7	122,452	120,815	1.4	89.4	89.1

Figure 7: KLM passenger load factor per continent in 2019, adapted from KLM's annual report.

For the of purpose of this illustration, the cargo load factor in the Shanghai – Amsterdam trade lane is assumed to be 80% and on the trade lane of New York – Amsterdam it is assumed to be 55%, in line with both the KLM data as well as IATA data that cover the whole airfreight market (Figure 8)[25].

[22] Airline statistics, unfortunately, do not provide for a split between dedicated freighters and belly cargo

[23] Royal Dutch Airlines Annual Report 2019, https://www.klm.com/travel/nl_en/images/KLM-Jaarverslag-2019_tcm542-1063986.pdf

[24] For the Europe and North Africa part of the network, the cargo load factor is around 3% mostly due to the fact that this part of the network is flown with narrow body aircraft that generally do not carry out significant volumes of commercial freight

[25] Note that for this report, the 2019 data is considered to be representative. Due to the COVID-19 pandemic, in 2020 the capacity of air networks decreased substantially, leading to much higher load factors due to air cargo "chasing" limited freight capacity when transport demand substantially exceeded transport capacity.

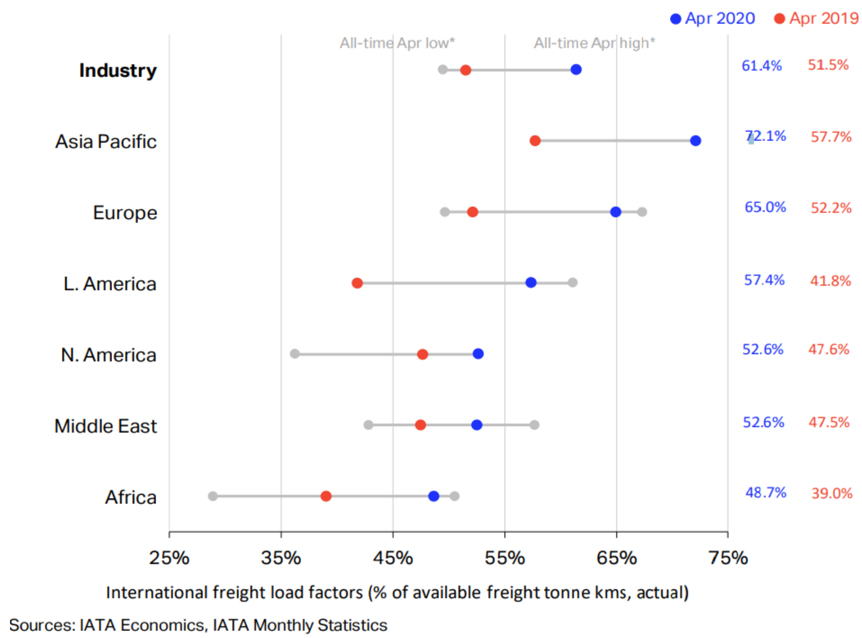

Figure 8 Cargo load factors[26] per part of the world, adapted from IATA Air Cargo Market Analysis.

3.1.2 *Types of aircraft*

Emissions are computed for two types of aircraft: the Boeing 777-200[27] and the Boeing 747-400. These types of aircraft are available as passenger aircraft and as full freighters. Selection of aircraft types for which both configurations are available makes comparison and understanding of differences in emission allocation easier.

The passenger aircraft have different seating arrangements. For both aircraft types computations have been made assuming typical KLM seating arrangements (408 seats). For the Boeing 747-400 also a variant with British Airways configuration has been modelled. This variant has a large number of business class seats, and hence, a smaller total number of seats (275 seats). Although British Airways do not fly these routes, we included estimations of fuel burn and made emission allocations in accordance to IATA RP 1678 as if BA aircraft flew the routes. This is done to show the impact of the passenger seat arrangements on emission allocation.

The technical aircraft specifications, including the number of seats, are used as inputs in the emission model described in section 3.2 in order to model flight-level emissions and for the allocation of those emissions to freight and passengers.

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[26] Air Cargo Market Analysis, April 2020, https://www.iata.org/en/iata-repository/publications/economic-reports/Air-Freight-Monthly-Analysis-Apr-2020/

[27] The passenger aircraft type used is the Boeing 777-200ER; its freighter type equivalent is the Boeing 777-200F. Although it is the same aircraft type, emission computations account for the fact that the freighter variant is built on the Boeing 777-300ER shrink platform.

Figure 9: Freight capacity per aircraft type, adapted from Air France – KLM aircraft specifications.

3.2 Fuel consumption model used for the emission calculations

To illustrate emission allocation in accordance to IATA RP 1678, an aircraft emission model was constructed to estimate flight-level emissions[28]. Modelling is necessary due to the fact that flight-level emissions are strongly influenced by the weight of the payload and fuel, and hence by the length of the flight segment. There is not one standard emission factor in kgCO_2 per kilometre to calculate flight-level emissions.

The fuel consumption model is constructed on the data from the flight planning and performance manuals provided by the aircraft manufacturers. The manuals present the data on hourly fuel flow for a given aircraft weight[29]. The model goes backwards in flight time, starting with the last moment of flight, with the landing weight, which includes empty aircraft weight, payload and fuel reserves[30]. Based on the landing weight, one can estimate the amount of fuel burned in the last hour of the flight.

[28] The modelling can be done using flight planning software, which the authors of this report do not have access to. Therefore, for the purpose of this report generalized modelling techniques were used in order to estimate flight-level fuel burn and CO_2 emissions.

[29] For the Boeing aircraft considered in this report, the hourly fuel flow is very well approximated by a constant multiplied by the aircraft weight at any given moment, and under the condition of the long range cruise speed, near optimal flight level and ISA atmospheric conditions. These conditions can be considered as the average flight conditions.

[30] The reserve fuel is the usable fuel that remains after landing. The reserves are determined by legal requirements, flight conditions, locations of diversion airports, contingency fuel, crew discretion and airline models. For the majority of flights, the reserve fuel is enough for flying for 60 to 120 more minutes.

Once the fuel consumption of the last hour of the flight is computed, the weight of this fuel burn is added to the aircraft weight. This weight is again used to compute fuel burn in the hour preceding the last hour. The fuel burn of this hour is again added to the aircraft weight. The procedure is repeated until the first hour of the flight. In addition the fuel burn related to the Landing and Take Off (LTO) cycle and the climb and descend cycle is accounted for in the model. The extra hourly fuel burn during the climb phase is partly compensated by a lower hourly fuel burn during the descend phase, the model compensates for the average excess hourly fuel burn in this cycle.

The model does not take into account taxi in and taxi out fuel burn. The taxi fuel burn is very dependent on the operational conditions at the airport, length of taxi, airline policies (e.g. engine out taxying) and is difficult to model. The modelling choice has been not to add a fixed amount of fuel for taxi as it does not improve modelling quality: for long haul flights taxi represents a small portion of the total fuel burn.

This fuel burn model is considered to be sufficiently accurate for the purpose of estimating emissions under average conditions. The estimated averages may differ from the actual fuel burn on specific flights due to deviations from the optimal flight altitudes, the use of other than long range cruise speeds, differing atmospheric and temperature conditions, or the specifics of the airframes used (e.g. wear and tear, specific aircraft weight). Further, the flight fuel burn is computed based on the average flight duration. Actual flight durations vary depending on the winds, flight speed selection, congestion on route and during approach.

3.3 The Shanghai – Amsterdam example

Using the emission model described in section 3.2 the emissions from five flights on the Shanghai – Amsterdam route were calculated (Table 1). For these flights, a passenger load factor of 89% (if applicable) and a cargo load factor of 80% were assumed, in accordance with the numbers presented in section 3.1.1.

Table 1: Overview of five flights for emission calculation on the Shanghai – Amsterdam trade lane.

	Route	Type	Configuration	Aircraft Type
1.	Shanghai – Amsterdam	Passenger	KLM	Boeing 777-200 ER
2.	Shanghai – Amsterdam	Freighter	Generic	Boeing 777-200 Freighter
3.	Shanghai – Amsterdam	Passenger	KLM	Boeing 747-400
4.	Shanghai – Amsterdam	Passenger	BA	Boeing 747-400
5.	Shanghai – Amsterdam	Freighter	Generic	Boeing 747-400 Freighter

For determining the relative difference between the carbon footprint of cargo transported on passenger vs. freight aircraft, the generic freighter flights (number 2 and number 5) are considered as the benchmark for the respective type of aircraft concerned (Boeing 777 and Boeing 747 respectively). The results of the computation, together with the basic modelling parameters, are summarized in Table 2.

Table 2: Modelling and allocation of emissions on the Shanghai – Amsterdam trade lane.

	Flight number in Table 1	1.	2.	3.	4.	5.
Parameters per aircraft type	Type	KLM B777-200ER (pax)	Generic B77F	KLM B744 (pax)	BA B744 (pax)	Generic B744F
		Boeing 777-200 ER	Boeing 777-200 Freighter	Boeing 747-400	Boeing 747-400	Boeing 747-400 Freighter
	DOW (dry operating weight)	145.0	144.0	186.0	186.0	164.0
	MTOW (max take-off weight)	297.0	347.0	390.0	390.0	396.0
	Average flight time	11:40	11:30	11:20	11:20	11:20
	Pax capacity (number)	320	0	408	275	0
	Pax load factor (%)	89.0	0.0	89.0	89.0	0.0
	Pax load (number)	285.0	0.0	363.0	245.0	0.0
	Cargo capacity (tonnes)	13.0	102.0	12.5	12.5	112.0
	Cargo load factor (%)	80.0	80.0	80.0	80.0	80.0
	Cargo load (tonnes)	10.4	81.6	10.0	10.0	89.6
	ZFW (zero fuel weight)	183.9	225.6	232.3	220.5	253.6
	Reserves (tonnes)	9.2	11.3	11.6	11.0	12.7
Outcome aircraft emission model	Fuel burn (tonnes)	77.0	91.4	110.8	105.2	123.1
	CO_2 TTW (tonnes) (3.15 kg CO_2 per kg fuel)	242.6	287.9	349.0	331.4	387.8
	Allocation weight, (tonnes), IATA RP 1678	54.9	81.6	66.7	48.3	89.6
Carbon footprint based on IATA RP 1678	CO_2 per pax (kg), IATA RP 1678	662.7	0.0	784.9	1030.2	0.0
	CO_2 per ton allocated freight (kg), IATA RP 1678	4418.0	3528.3	5232.7	6868.0	4327.7
	CO_2 per tkm freight (kg), IATA RP 1678	0.496	0.396	0.587	0.771	0.486
	Relative difference in allocated emissions to cargo per ton (or ton-kilometre) freight	**+25%**	**-**	**+21%**	**+59%**	**--**
	Marginal CO_2 emissions of additional freight (kg/tonne)	**1320**	**1277**[31]	**1502**	**1502**	**1502**

[31] The 777 freighter burns marginally less fuel per hour as it has newer engines than 777-200ER, and flies slightly faster. Modifying the fuel burn data for the freighter version to match that of the pax version results in an equal marginal fuel burn for both aircraft configurations, similar to the 747 case.

The input to the calculations are the aircraft type and empty weight (DOW), flight duration, aircraft capacity (passenger-wise and cargo-wise), and load factors for the passengers and cargo. Based on these inputs, the landing weight is estimated, which includes fuel reserves. The fuel burn model, described in section 3.2, takes these parameters as input and estimates the fuel burn per flight. The output of the computations are the flight-level CO_2 emissions. These CO_2 emissions are allocated to the passengers and freight in accordance with the IATA RP 1678 principles, which assign emissions proportionally to the allocation weight (kilo-for-kilo for freight and for a 89% passenger load factor a 156 kg allocation weight per passenger), as described in section 2.2. Application of this allocation results in CO_2 emissions per tonne and tonne-kilometre of freight and per passenger, as shown in Table 2.

The modelling of aircraft emissions and the IATA RP 1678 emission allocation to cargo on the trade lane Shanghai-Amsterdam leads to the following conclusions per aircraft type (under prevailing load factors and average flight and aircraft characteristics):

1. KLM Boeing 777-200: freight travelling on the passenger flight gets 25% more emissions per tonne (or tonne-kilometre) assigned than freight travelling on the dedicated freighter.
2. KLM Boeing 747-400: freight travelling on the passenger flight gets 21% more emissions per tonne (or tonne-kilometre) assigned than freight travelling on the dedicated freighter.
3. BA Boeing 747-400: freight travelling on the passenger flight gets 59% more emissions per tonne (or tonne-kilometre) assigned than freight travelling on the dedicated freighter.

3.4 The New York – Amsterdam example

The same computations were performed to estimate the emissions from five flights on the New York – Amsterdam route. As in the previous example, the passenger load factor is assumed to be 89%. The cargo load factor for the JFK-AMS route is set to 55%, in line with section 3.1.1.

Table 3: Overview of five flights for emission calculation on the New York – Amsterdam route.

	Route	Type	Configuration	Aircraft
1.	New York – Amsterdam	Passenger	KLM	Boeing 777-200 ER
2.	New York – Amsterdam	Freighter	Generic	Boeing 777-200 Freighter
3.	New York – Amsterdam	Passenger	KLM	Boeing 747-400
4.	New York – Amsterdam	Passenger	BA	Boeing 747-400
5.	New York – Amsterdam	Freighter	Generic	Boeing 747-400 Freighter

For determining the relative difference between the carbon footprint of cargo transport on passenger and freight aircraft the generic freighter flights (number 2 and number 5) are considered as the benchmark for the respective type of aircraft concerned (Boeing 777 and Boeing 747 respectively). Table 4 summarises the results of the computation, together with the basic modelling parameters.

Table 4: Modelling and allocation of emissions on New York – Amsterdam trade lane.

	Flight number in Table 3	1.	2.		3.	4.	5.
Parameters per aircraft type	Type	KLM B777-200ER (pax)	Generic B77F		KLM B744 (pax)	BA B744 (pax)	Generic B744F
		Boeing 777-200 ER	Boeing 777-200 Freighter		Boeing 747-400	Boeing 747-400	Boeing 747-400 Freighter
	DOW (dry operating weight)	145.0	144.0		186.0	186.0	164.0
	MTOW (max take-off weight)	297.0	347.0		390.0	390.0	396.0
	Average flight time	06:32	06:28		06:23	06:23	06:23
	Pax capacity (number)	320	0		408	275	0
	Pax load factor (%)	89.0	0.0		89.0	89.0	0.0
	Pax load (number)	285.0	0.0		363.0	245.0	0.0
	Cargo capacity (tonnes)	13.0	102.0		12.5	12.5	112.0
	Cargo load factor (%)	55.0	55.0		55.0	55.0	55.0
	Cargo load (tonnes)	7.2	56.1		6.9	6.9	61.6
	ZFW (zero fuel weight)	180.7	200.1		229.2	217.4	225.6
	Reserves (tonnes)	9.0	10.0		11.5	10.9	12.7
Outcome aircraft emission model	Fuel burn (tonnes)	39.6	42.6		56.9	53.8	54.6
	CO_2 TTW (tonnes) (3.15 kg CO_2 per kg fuel)	124.6	134.2		179.1	169.4	172.0
	Allocation weight (tonnes), IATA RP 1678	51.7	56.1		63.6	45.1	61.6
Carbon footprint based on IATA RP 1678	CO_2 per pax (kg), IATA RP 1678	361.8	0.0		422.6	563.1	0.0
	CO_2 per ton allocated freight (kg), IATA RP 1678	2412.1	2392.0		2817.5	3754.2	2792.0
	CO_2 per tkm freight (kg), IATA RP 1678	0.413	0.409		0.482	0.642	0.478
	Relative difference in allocated emissions to cargo per ton (or ton-kilometre) freight	**+1%**	**--**		**+1%**	**+34%**	**--**
	Marginal CO_2 emissions of additional freight (kg/tonne)	**679**	**661**[32]		**782**	**782**	**782**

[32] See footnote 31

The modelling of aircraft emissions and IATA RP 1678 emission allocation to cargo on the trade lane New York – Amsterdam leads to the following conclusions (under prevailing load factors and average flight and aircraft characteristics) per aircraft type:

1. KLM Boeing 777-200: freight travelling on the passenger flight gets 1% more emissions per tonne (or tonne-kilometre) assigned than freight travelling on the dedicated freighter.
2. KLM Boeing 747-400: freight travelling on the passenger flight gets 1% more emissions per tonne (or tonne-kilometre) assigned than freight travelling on the dedicated freighter.
3. BA Boeing 747-400: freight travelling on the passenger flight gets 34% more emissions per tonne (or tonne-kilometre) assigned than freight travelling on the dedicated freighter.

3.5 Impact of the passenger occupation factor

The emissions allocated to freight on passenger aircraft according to IATA PR 1678 depend on the total payload, which besides the fright weight depends on the passenger load factor as explained in section 2.2. The examples analysed above indicate that the carbon footprint of freight in passenger aircraft calculated according to IATA PR 1678 is higher than the footprint for freight in dedicated freight aircraft. To check whether that conclusions is generally valid for all passenger load factors, Figure 11 shows how CO_2 emissions on the route Shanghai -- Amsterdam allocated to one tonne of freight (under the assumption of an 80% freight load factor) depends on the passenger load factor. The results are based on the estimated fuel burn of the KLM 777-200ER aircraft for each passenger load factor and total weight. This analysis shows that the emission allocated to a tonne of freight are quite sensitive to the passenger load factor, but also that for all load factors the footprint of freight in the belly of a passenger aircraft exceeds that of freight in a dedicated freighter.

It should be noted that the passenger load factor is mostly outside of the control or consideration of the freight shippers.

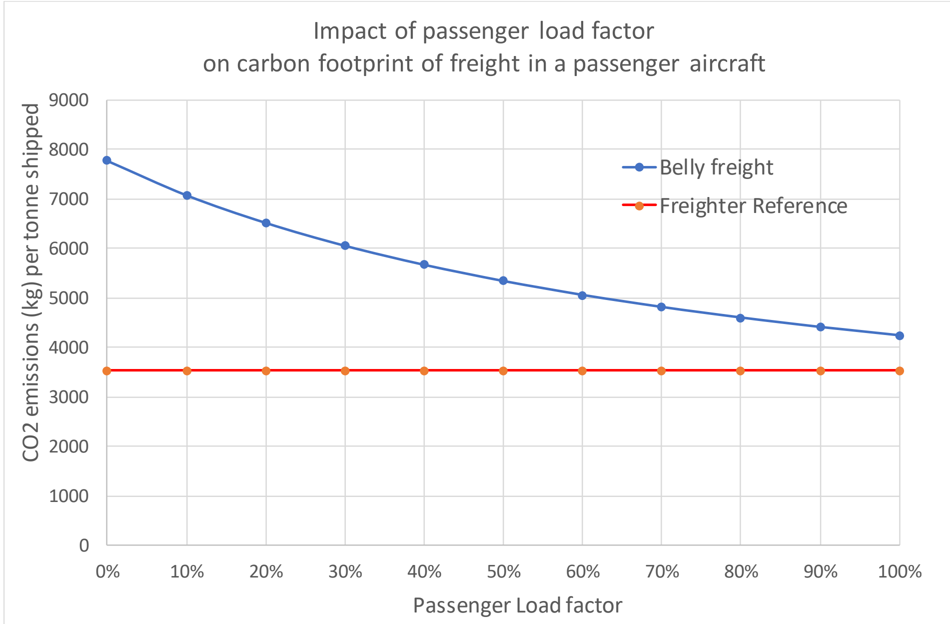


Figure 10: Sensitivity to the passenger load factor of CO_2 emissions allocated to freight emissions on the basis of IATA RP 1678 (assumed freight load factor 80%). The dashed red line indicates the carbon footprint per ton of freight on a comparable dedicated freight aircraft on the same route (example for the B777 on the Shanghai-Amsterdam route)

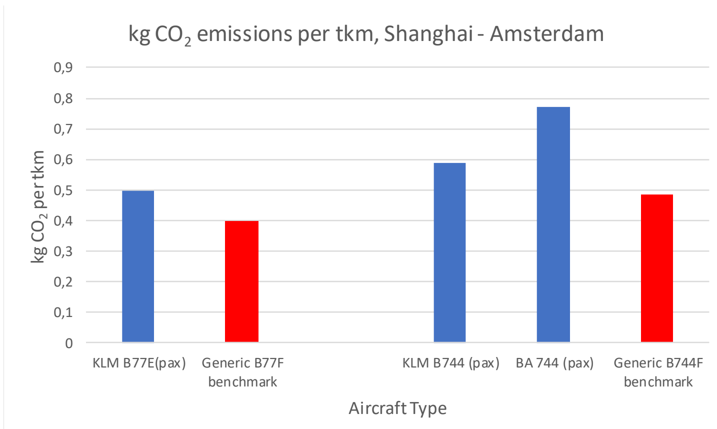
3.6 Analysis and discussion of the results w.r.t. carbon footprint

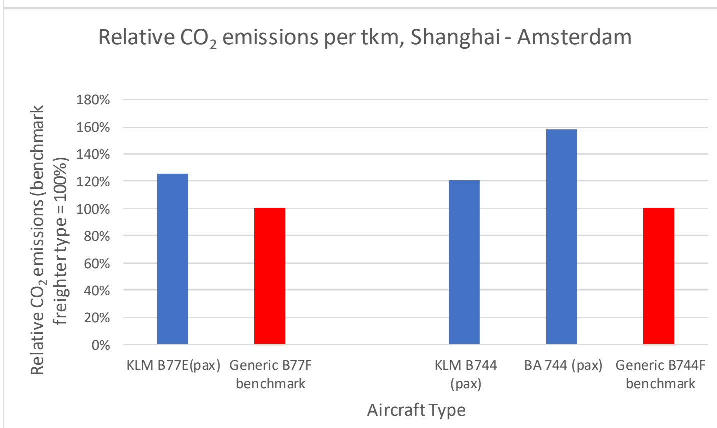
Sections 3.3 and 3.4 have analysed flight-level emissions and emission allocation on the Shanghai – Amsterdam and the New York – Amsterdam trade lanes respectively. Figure 11 summarizes the results graphically. The two upper graphs show the CO_2 emissions per tonne-kilometre for the five flights chosen in Table 1 and Table 3 for the trade lanes Shanghai – Amsterdam and New York – Amsterdam respectively. The two lower graphs show the relative CO_2 emissions for these five flights, where the dedicated freighter flights are chosen as benchmarks.

Figure 11 shows that the carbon footprint of freight carried by the B777 is significantly lower than for freight carried by the B747. The B777 is a newer and more efficient type compared to the B747. IATA RP 1678 properly reflects this difference for both passenger and full freight configurations.

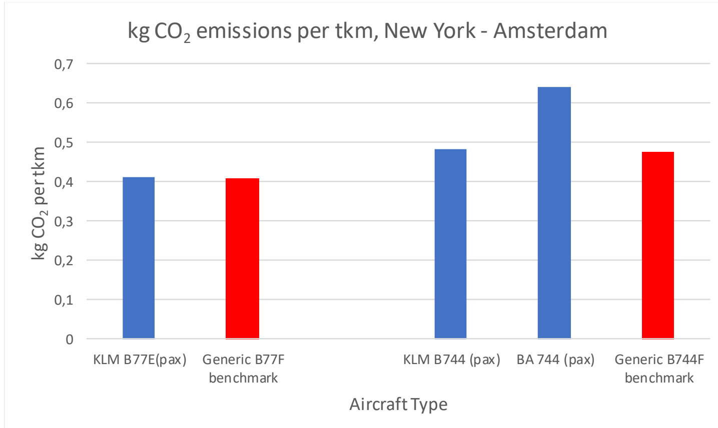
The calculation also reveals that the difference between emissions allocated by IATA RP 1678 to freight on passenger and cargo aircraft varies strongly between the Shanghai and New York routes. On the Shanghai – Amsterdam route, a tonne of freight on the passenger aircraft gets 21%-59% more emissions assigned than a tonne on a cargo aircraft. For the New York – Amsterdam route a tonne of freight on the passenger aircraft gets 1%-34% more emissions assigned than a tonne on a cargo aircraft. Although this might suggest a dependence on the length of the flight, the difference between these two routes can actually be largely explained by a lower applied cargo load factor on the New York – Amsterdam route.

For both routes and within each aircraft type, the IATA RP 1678 methodology assigns more emissions per unit of cargo to belly freight than to freight in the dedicated freighters. This is equally true for per ton and per tonne-kilometre emissions. This implies that if a choice is made on the basis of per shipment emissions, the use of dedicated freighters would be favoured over belly freight transport. In the predominant market conditions[33] this would mean that decisions based on footprints determined according to IATA RP 1678 would lead to less fully loaded bellies in passenger flights and additional movements of the dedicated freighters and additional CO_2 emissions associated with that change. For one of the examples discussed in this report, Section 3.7 presents a quantitative estimation of the expected real-world emission increase as a result of such shift.





[33] In real world conditions, empty bellies of passenger aircraft would trigger the management system of airline operators to reduce transport prices, thus making it more attractive to send goods by these flights. Nonetheless, the emission allocation scheme as implied by the IATA RP 1678 would still make belly freight a less attractive option than it should be, thus possibly tilting some shippers to choose the dedicated freighter and creating extra aircraft movements.



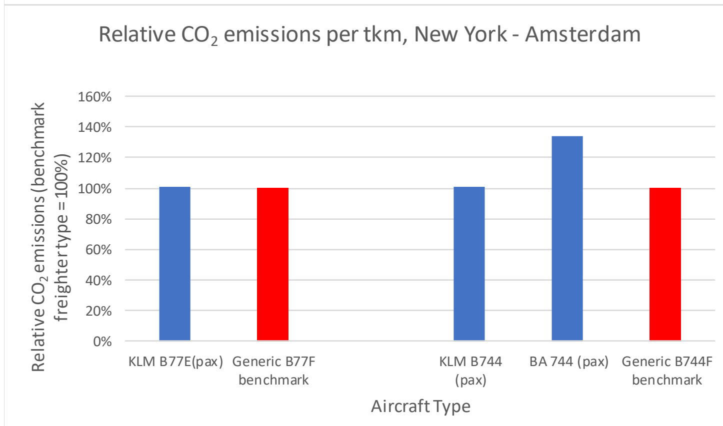


Figure 11: Overview of results for emissions allocated to freight on the Shanghai – Amsterdam and the New York – Amsterdam routes (section 3.3 and 3.4).

Impact of the passenger cabin configuration
The computations further show that emission allocation by IATA RP 1678 to freight on passenger aircraft depends on the number of seats. For the same aircraft type (B744) with identical cargo loads on the Shanghai – Amsterdam route, freight in a BA-configuration passenger aircraft (275 seats) will get 0.771 kg CO_2 assigned per tkm, while the assigned footprint is 0.587 kg CO_2 per tkm for a KLM-configuration aircraft (408 seats) on the same route, while cargo loads are identical, and fuel burn of the BA aircraft is smaller. Also on the New York – Amsterdam route the footprint for freight on the aircraft with the BA-configuration is about 30% higher than for the KLM-configuration. If a shipper would have the choice between both aircraft types for a given shipment, this significant difference in footprint would be a strong motivation to send the shipment with the KLM-flight. Based on the outcome of emission allocation according to IATA RP 1678 the aircraft with the largest number of seats (KLM) would be preferred by shippers, while aircraft with higher shares of business class seats (and hence a smaller total number of seats) will be avoided.

From the perspective of carrying passengers it is obvious that using aircraft with higher numbers of seats is environmentally beneficial, as also reflected in the lower footprints per passenger listed for the KLM-configurations in Table 2 and Table 4. That this benefit is also attributed to the belly freight, however, is questionable.

If one looks at the marginal emissions resulting from an additional tonne of freight on the 10 flights assessed in Table 2 and Table 4, it is clear that for the combined CO_2 emissions of the two flights (the KLM and BA flight) on the same route it does not matter on which flight the shipment is sent: the marginal emission are equal for both configurations. This means that also with respect to the choice between passenger aircraft with different seat configurations the IATA RP 1678 method gives results that are not directionally correct. A preference of shippers to use passenger aircraft with high seat numbers would only lead to reduced CO_2 emissions if it would affect the share of passenger aircraft with high seat numbers on a given route. This, however, is unlikely as passenger flights are mainly motivated by demand for passenger transport.

3.7 Implications of preferring dedicated freight aircraft

The examples cases assessed above show that IATA RP 1678 incentivizes the use of dedicated freighters and disincentivizes the use of belly freight capacity on passenger aircraft. As long as shifting freight from passenger to freight aircraft does not generate addition freighter flights, the impact on CO_2 emission is negligible. The marginal emissions resulting from an additional tonne of freight on the flights assessed in Table 2 and Table 4 show that the increase in CO_2 emissions resulting from the additional freight load on the freighter aircraft is compensated by an equal reduction of the CO_2 emissions of the passenger aircraft from which that load is removed.

However, additional CO_2 emissions are expected when shifting freight from passenger to freight aircraft generates additional flights of freight aircraft. This case is assessed in this section by comparing two scenarios:

Original scenario: Consider 8 passenger flights on the route Shanghai-Amsterdam carried out by B777-200 ER passenger aircraft. On this route the real-world average passenger load factor is 89% and the average freight load factor is 80%. It means that each flight carries some 285 passengers and 10.4 tonnes of freight.

New situation scenario: All freight is shifted from the 8 passenger flights to a dedicated freighter. The passenger flights still have a 89% passenger load factor, but the freight load factor now is 0% and thus no freight is carried on the passenger aircraft. Instead there is one additional dedicated freighter flight carrying 10.4*8 = 83.2 tonnes, which is roughly 80% of the carrying capacity. We do not consider the logistic feasibility of this scenario, associated e.g. with the implied low frequency of freighter flights (which in reality may not be a problem as there many daily freight flights from China to Europe).

Results
Table 5 and Table 6 show the modelling results for the two scenarios. As expected, in the new situation the emissions of the 8 passenger flights go down as the aircraft become lighter due to the absence of belly freight. However, there is one extra dedicated freighter flight in the new situation. The additional emissions associated with that freighter flight exceed the savings on the passenger flights. Per 8 flights in the original situation CO_2 emissions are 1942 ton. In the new situation for the same amount of passengers and freight there are 2092 tonnes of CO_2 emitted, an increase of 7.7% in CO_2 emissions.

This example shows that, when shifting freight from passenger flights to dedicated freighters leads to creation of extra flights, this leads to extra CO_2 emissions. This proves that the results of the IATA RP 1678 carbon footprint method with respect to the comparison of freight on passenger and freight aircraft are directionally incorrect.

Table 5: Fuel burn and CO_2 emissions per flight for the original and new situation scenarios.

Scenario	Fuel burn per flight, tonne	CO_2 emissions per flight, tonne	CO_2 emissions per passenger, kg	CO_2 emissions per tonne of freight, kg
Original situation, combined passenger -- freight	77.060	242.7	663.2	4422
New situation, passenger only flight	71.487	225.2	812.0	n/a
New situation freight only flight	92.080	290.1	n/a	3486

Table 6: Fuel burn and CO_2 emissions per flight for the original and new situation scenarios.

Scenario	Total burn of all flights, tonne	Total CO_2 emission of all flights, tonne
Original situation: 8 passenger flights with belly freight	616.5	1941.9
New situation: 8 passenger flights for passengers only + 1 dedicated freighter flight	664.0	2091.5

3.8 Conclusions on freight emission computation and allocation

The following statements summarize our evaluation of freight emissions computations done on the basis of per ton or per tonne-kilometre flown and computed according to the IATA RP 1678 methodology:

1. Freight emissions depend on the aircraft type. The lower footprints for freight on a B777 aircraft are a logical consequence of the fact that the B777 is a newer and more efficient type compared to the B747. IATA RP 1678 properly captures this difference for both passenger and full freight configurations.
2. Following IATA RP 1678 emission allocation rules, emissions allocated to cargo flown on passenger aircraft are generally higher than emissions allocated to cargo flown on a dedicated freighter, under realistic load factor conditions. If decisions on how to fly cargo (belly freight versus dedicated freighter) are based on these computed emissions, this would lead to a preference for using dedicated freighters. This leads to lower cargo load factors on passenger aircraft and, if sufficient freight is shifted, to more freighter movements. The latter is found to result in higher real-world emissions. Results of the IATA RP 1678 carbon footprint method with respect to the comparison of freight on passenger and freight aircraft are directionally incorrect: it promotes choices that result in increased rather than decreased CO_2 emissions.

3. A further indication of the directional incorrectness of IATA RP 1678, when used for selecting the carrier for a shipment, is provided by a comparison of footprints assigned to freight in passenger aircraft with different seat configurations. Specifically the number of seats, influenced by the ratio between business class and economy class seats, is found to affect the emission allocation. If decisions on how to fly cargo are based on carbon footprints obtained through application of the IATA RP 1678 method, the aircraft with the largest number of seats will be preferred by shippers, while aircraft with higher shares of business class seats will be avoided. Such preference is not supported by the marginal emissions of an additional tonne of freight for both aircraft types, which differ negligibly. This potentially creates an illogical preference for routing of freight. This is especially the case when the cargo weight payload capacity of aircraft with fewer passengers / seats is potentially larger[34]. Air freight routing decisions based on IATA RP 1678 carbon footprint calculations could thus lead to further underutilisation of this larger available cargo weight capacity.

The origin of the observed directional incorrectness of footprint results derived from IATA RP 1678 lies in the fact that the method uses weight as the basis to assign CO_2 to passengers. Even though the weight of luggage, seats, personnel and on-board service equipment are included in the weight assigned to passengers, passengers are basically treated as freight. As flying passenger aircraft is decided predominantly on the basis of passenger demand rather than freight demand, it would be justified to assign a higher “weight” to passengers than to freight in the attribution of CO_2 emissions.

[34] This depends on the specifics of business class seats, which are generally much heavier than economy class seats, however, occupy much larger space in the cabin. We estimated that on average, a larger number of business class seats create additional weight capacity for the freight.

4 Carbon footprinting for decision support in aviation networks

This chapter shows how carbon footprinting can be included in air freight routing decisions, thus underscoring the need for a proper emission allocation method for air freight.

4.1 Carbon footprint based transport decisions

This section explains the basic principles of incorporation of carbon footprint methods into transport decisions using the calculation examples from section 3.3 and 3.4.

Suppose a shipper needs to transport a shipment of *S* units[35] between two fixed locations. Suppose further that there are two transport options, A and B[36], with the following attributes:

A^e and B^e	– CO_2 emission associated with a unit of freight for options A and B
A^c and B^c	– direct costs of transport per option per unit of freight
A^t and B^t	– transit time per option
C^T	– cost valuation of time per unit of freight
C^E	– cost of a unit of CO_2 emission
Q^A and Q^B	– quality per option, expressed in monetary terms[37]

The generalized costs C^A and C^B for both options can be computed as follows:

$$C^A = S * (A^e * C^E + A^c + C^T * A^t + Q^A)$$
$$C^B = S * (B^e * C^E + B^c + C^T * B^t + Q^B)$$

A shipper chooses option A if $C^A < C^B$ and option B otherwise. In case $C^A = C^B$ either option can be chosen.

While making the choice with respect to transport options, shippers have to determine the importance of the different factors. If the choice is to be based largely on emissions, the cost per tonne of CO_2 emissions C^E can be made substantially high such that other cost components become less important. Otherwise, if the speed and cost of transport are more important than emissions, the costs of a tonne of CO_2 emissions can be set to a smaller value.

To illustrate this choice principle, Table 6 shows an example of a shipment of one tonne of freight from Shanghai to Amsterdam. The direct transport cost per tonne is set to €2000 for both belly freight and dedicated freighter options. The emission data is taken from the calculation example of section 2.4. For simplicity, the time-related cost and the quality component are set to 0.

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[35] A unit can be one tonne, m^3 or any other relevant unit. The exact formulation of the unit is not important in this discussion.

[36] The number of options may be (significantly) larger than two, a set of two options is used for simplicity in this illustration.

[37] The term Q^i is introduced for completeness, as other, not expressed, factors can play a role in the choice. If there are no such factors, Q^i can be neglected and set to be 0.

Table 6 shows two calculation examples for the total generalized cost for a price of CO_2 of €100 per tonne CO_2 and €500 Euro per tonne of CO_2.

Table 6: Example of inclusion of CO_2 cost into the total generalized cost of shipment for the shipment of one tonne of cargo from Shanghai to Amsterdam.

Aircraft type		**KL B777-200 ER passenger**			**B777-200F freighter**	
C^E **- Cost of** CO_2 **(€ per tonne** CO_2**)**		**100**	**500**		**100**	**500**
A^e and B^e - Emissions (tonnes) per tonne freight transported		4418	4418		3528	3528
A^c and B^c - Transport cost (€ per tonne)		2000	2000		2000	2000
Emission cost A^e * C^E and B^e * C^E (€)		442	2209		352	1764
C^A **and** C^B **- Generalized cost (€)**		**2442**	**4209**		**2353**	**3764**

As can be seen in Table 6, the CO_2 costs attributed to the emission values based on IATA RP 1678 allocation makes the choice of the belly freight shipment option more expensive than the shipment by a dedicated freighter (under the condition of equal transport costs and a positive CO_2 price per tonne). The incentive increases with increasing CO_2 price used in the calculation. Choosing a dedicated freighter over the belly of a passenger flight will add aircraft movements and leave belly capacity unused on the passenger flights. The outcome of the comparison in Table 6 can be influenced in favour of belly freight only if the belly freight transport is provided at a discount by the carrier, namely of €89 (= 2442 – 2353) per tonne of freight at a CO_2 price of €100 per tonne of CO_2 and a discount per tonne of freight of €445 (= 4209 – 3764) at a CO_2 price of €500 per tonne of CO_2.

The sensitivity of a cost comparison, that includes a CO_2 price, to the level of this CO_2 is assessed for the example of the Shanghai – Amsterdam B777 flights. In the example shown in Figure 12, we make a comparison of the total price per tonne shipped, starting with a small price advantage of belly freight in the absence of a CO_2 price, namely transport costs of belly freight of €1900 per tonne and dedicated freighter transport costs of €2000 per tonne. Once CO_2 emissions are priced, belly freight loses its cost advantage and becomes more expensive at a CO_2 price of around €110 per tonne. This shows that a higher CO_2 price may lead to an increased total price advantage of dedicated freighters and hence additional freighter flights and more real life CO_2 emissions.

Figure 12: Sensitivity of the total freight price with respect to an included CO_2 price

4.2 Generalization for the transport market

Under the condition that CO_2 emissions from transport operations are included in the transport choice decisions, a properly designed and implemented carbon footprinting methodology will have a reducing effect on the real-world emissions from the airfreight networks. A balanced[38] allocation of emissions between passengers and freight should disincentivise[39] the use of dedicated freighters for the freight that can be flown in the bellies of the passenger aircraft. If a large number of shippers include emissions into their decision making process, the effect of these decisions will be measurable at the macro level. At the level of the overall freight market, with large volumes of transport and emissions, the climatic impacts will be noticeable.

Real-world emission reduction will come from a shift of cargo from the dedicated freighters to the available belly freight capacity, thus reducing the number of flights carried out by the freighters. The dedicated freighters will then be more oriented towards those segments of the market where passenger belly capacity is insufficient or where the attributes of the cargo are such that the cargo cannot be carried in the passenger bellies, and on the origin – destination pairs where there are no suitable passenger network connections. Of course, increasing the amount of freight carried in the bellies of passenger aircraft will increase their weight and thus their emissions. These extra emissions, however, will be less than the emissions saved by the decrease in the number of freighter flights, as the results from Section 3.7 imply.

[38] By balanced allocation we mean that emissions are allocated to the activities that cause them – in this context it means that there a balance should be found between emission allocation to the freight and emission allocation to the passengers

[39] The level of incentives for the use of belly freight capacity will depend on the specific methodological elaboration and the weight that is given to GHG emissions during the transport choice process. Section 4.1 showed that the assignment of a certain price to a tonne of CO_2 emissions can quantitatively include GHG emissions into the selection of transport options.

A cargo shift from dedicated freighters to the bellies of the passenger aircraft can potentially reduce the size of the market for dedicated freighters, thus increasing the unit costs for the main deck freight[40] on the dedicated freighters. This may increase transport costs of specialized main deck cargo such as machinery, horses and other freight that is not suitable for the bellies. This is a second order cost impact that may be taken into account into the evaluation of GHG abatement costs associated with the measure to shift freight from dedicated freighters to bellies of passenger aircraft. This cost impact in itself also has knock-on consequences. From the sustainability point of view, these can even be positive in the sense that - at the macro level - it may reduce (the growth in) air freight volumes. This reduction of the dedicated freighter market may also have effects on the development of passenger networks, potentially increasing margins and allowing for investments in more efficient equipment.

[40] There is a potential for the “death spiral” effect for this market – increased unit transport costs make transportation more expensive and reducing demand, which in turn further increases unit costs, thus closing the loop.

5 Directions for improvement of the air freight carbon footprint method (and standardization)

The previous sections of the report show that the current emission allocation principles of the IATA RP 1678 methodology generally assign more emissions to freight travelling in the bellies of passenger aircraft than to freight travelling in dedicated freighters. Inclusion of emissions into decisions on the route and aircraft choice for shipments will in that case favour dedicated freighters over the belly capacity. This, in turn, leads to underutilization of belly capacity and extra freighter movements and thus more real-world CO_2-emissions. This section provides a brief discussion on the requirements of an improved allocation method that, once implemented, would lead to decisions that cause real-world reduction of emissions from airfreight networks.

The development of improved emission allocation for air freight networks should consider at least two alternative options of emission allocation, namely 1) capacity-driven, when emissions are allocated proportionally to the use of the aircraft's capacity and 2) revenue-driven, when emissions are allocated proportionally to the amount paid for the services. Below these options are briefly described and discussed.

5.1 Capacity-driven emission allocation

In a capacity-driven emission allocation, emissions are allocated proportionally to the capacity consumed by a shipment. IATA RP 1678 is an example of capacity-driven emission allocation, where emissions are allocated proportionally to the shipment weight. However, for the elaboration of a directionally correct carbon footprint methodology, some other ways than IATA RP 1678 for capacity-driven emission allocation should be considered.

A very promising approach is to consider an allocation principle that is neutral with respect to whether a shipment travels on the passenger or dedicated freighter aircraft. For example, for the KLM Boeing 777-200 type, the passenger aircraft has 13 tonnes of belly freight capacity. It can be seen as a combi aircraft, where the freighter share is 12.7% (= 13/102) of a dedicated freighter version of the same aircraft type and the passenger part takes the remainder of the capacity of the aircraft. This way all passengers get 87.3% of the emissions, and freight gets 12.7% of the emissions. Subsequently, the emissions can be further allocated to the shipments proportionally to their weight. Still, the details of this allocation principle should be further elaborated, specifically, generalisation of the method across different aircraft types, cabin configurations and the freighter references.

The allocation method outlined above makes emission allocation neutral with respect to whether a shipment is travelling on a freighter or in the belly on a passenger flight. However, due to the fact that aircraft fuel burn is dependent on the aircraft weight, there will be second order effects (e.g. higher fuel burn of aircraft with a fully consumed freight capacity), that need to be carefully modelled, analysed and understood.

5.2 Revenue-driven emission allocation

Emission allocation can also be done proportionally to the revenue stream that passengers and freight generate[41]. The logic of this type of allocation is that carriers conduct transport activities to generate revenue and maximize profit, in other words, the flights are carried out because someone pays for them. The level of responsibility for CO_2 emissions and thus the quantity of allocated emissions could be thought to be proportional to the share of payment for a specific activity in the total revenue stream. The industry-wide assessment is that passengers generate 8 Eurocents per passenger-kilometre and one tonne-kilometre of freight generates 25 Eurocents of revenue for the carriers. Using the capacity of the KLM 777-200 aircraft, the passenger part (capacity of 320 seats) can potentially generate 0.08 * 320 = Euro 25.60 per kilometre flown, and the freight part (capacity of 13 tonnes) can potentially generate 13 * 0.25 = Euro 3.25 per kilometre flown, resulting in the total revenue generating capacity of Euro 28.85 per kilometre flown. This implies that the freight will get 11.3% of the total aircraft emissions. Subsequently, allocation of emission within the passenger part and within the freight part can be done either based on revenue generation, or based on capacity consumption.

Another way of revenue-driven allocation is not to split the aircraft into a freight and a passenger part, but to allocate emissions proportionally to the revenue generated, independently from which part of the aircraft generates it. This modification would make it aircraft and cabin agnostic, as the number of seats per aircraft varies significantly (e.g. KLM 747 and BA 747 with 408 and 275 seats respectively – the aircraft with fewer seats generate more revenue per seat due to a higher number of expensive business class seats). Further analysis is necessary to assess if such modification would result in a better methodology.

5.3 Discussion on the follow-up steps

This report outlines the need for a better allocation method for emissions in combined air freight and passenger transport operations. It also briefly outlines two potential alternative approaches, capacity-based and revenue-based emission allocation, but does not further elaborate on them. The authors of this report deem it necessary to conduct further work on improved emission allocation for air freight. This work should consist of two pillars: technical specifications of an improved emission allocation method for air freight and close consultations with the industry representatives. Consultations with the industry representatives are a very important part of the work aimed at the following:

1) Ensuring industry involvement and broad support by all relevant parties;
2) Testing the new carbon footprinting method on the industry data and fine-tuning it;
3) Ensuring feasibility and ease of implementation of the new carbon footprinting method;
4) Ensuring industry-wide implementation and roll-out of the method in practice.

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[41] Note that this approach is probably the only viable one in case of combined waterborne transport, where the weight of human passengers is insignificant compared to the weight of freight.

Other aspects that need to be considered are consensus among the parties involved, elaboration on ways to include interests of all stakeholders and to overcome technical and organizational difficulties.

Furthermore, the COVID-19 crisis has shown a huge impact of the grounding of passenger aircraft on the air freight operations, when a substantial part of the freight transport capacity of passenger aircraft became unavailable. The fleet of dedicated freighters could not provide sufficient capacity to satisfy demand, especially in peak demand periods. It is, therefore, important to look at the problem in a more holistic way when optimising air transport for low CO_2 emissions, taking account also of other aspects such as system resilience with respect to a possible set of negative scenarios.

6 Conclusions and recommendations

Aviation cannot escape the need to reduce CO_2 emissions from transport operations. Airborne transport is different from almost all other modes because the same vehicle often transports passengers and freight at the same time. Widebody aircraft have a large belly freight capacity, much bigger than the space needed to transport the bags of passengers. As passenger airline networks are mostly driven by the passenger transport demand, it can be considered low hanging fruit for emission reduction to first utilize the available belly freight capacity on the passenger aircraft. Only in case belly capacity is consumed, or when it is insufficient or unsuitable for cargo or non-existing on the route, a freighter aircraft should be used to transport freight on that route.

The utilisation of belly capacity can be increased if CO_2 emissions are taken into account when decisions on routing and aircraft use are made. Additionally to the shipment costs, fictive or real CO_2 costs can be included into the decision making process. Therefore, it is important that CO_2 emissions of shipments are computed or estimated correctly (i.e. following the general principles of carbon footprinting) through a use of a proper carbon footprinting methodology.

This report shows that for the combined passenger-freight air networks operations, application of the IATA RP 1678 methodology generally allocates more CO_2 emissions to a shipment of freight transported on a passenger aircraft compared to when the same shipment is transported on a dedicated freighter aircraft. Based on this outcome, and amplified once emission data calculated in this way is included into the air freight routing decisions, freight shippers would favour dedicated freighter aircraft even if passenger belly capacity is available on the route. This in turn will result in a smaller freight load factor on the passenger aircraft and more dedicated freighter flights, the combination of which is found to increase real-world CO_2 emissions.

We recommend that amendments are developed to the IATA RP 1678 allocation principles that result in an emission allocation method that favours decisions that lead to real world emission reductions. This report outlines two potential approaches for such a methodology, one based on capacity and another one based on revenue, which could be further explored. We suggest industry involvement in the methodology elaboration from the start to ensure correctness of the method, operational feasibility and target user group acceptance.

7 Signature

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TNO

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