The role of Climate Change Levy schemes in aviation decarbonization by 2050

Rosa M Arnaldo Valdés[1,2] and V Fernando Gómez Comendador[1]

[1] Universidad Politécnica de Madrid, Madrid, Spain

[2] Corresponding author: rosamaria.arnaldo@upm.es

Abstract. Aviation emissions between 2016 to 2050 could consume between the 12% and the 27% of the remaining carbon budget to keep global temperature rise below 1.5C above preindustrial levels. Consequently, aviation is being challenged to immediately start to reduce its in-sector emissions, then sharply reduce its CO2 emissions and fully decarbonize toward the second half of this century. Among the analyses carried out within the Horizon 2020 project PARE – Perspectives for Aeronautical Research in Europe, this paper tackles the potential role of Climate Change Levy Schemes in achieving the ambitious objective of aviation decarbonization by the year 2050. The authors develop a model to generate CCL marginal tax curves and study its effect on changing demand for air travel and CO2 emissions. The model uses a differentiated approach, taking into account the types of aircraft and types of flights, the distance they are operated (short, medium, long range), the nature of the flight - regular, charter, passenger, freight, passenger and express – and different types of air carriers (low cost, traditional, etc…). It also considers price elasticities of demand specific for different markets.

1. Introduction

According to ICAO, aviation is responsible for 2% of global CO2 emissions [1]. However, it is expected to occupy an increasingly large share, if it continues to grow as foreseen (5% annually), as other sectors are seeking to reduce their emissions in line with their carbon budgets [2]. Although international aviation community aspire to a 2% annual improvement in fuel efficiency and a carbon neutral industry growth from year 2020 onwards, the achievement of this goal is still at risk; and even if achieved, aviation will still produce by 2050 a significant amount of CO2, that might endanger the achievement of the goals of the Paris Agreement [3].

ICAO 2019 report [1] quantified emissions of the aviation sector over the period 2016-2050 between 56 GtCO2 in a business as usual scenario and 12 GtCO2 in an optimistic, but unlikely to meet, scenario with technological improvements and 100% of biofuels use. These figures would imply that aviation emissions, from 2016 to 2050, could consume between the 27% and the 12% of the remaining carbon budget to keep global temperature rise below 1.5C above preindustrial levels [4].

Up to now, the aviation industry base its approach on four pillars of climate action: new technology [5], [6] and substitute fuels [7]; optimised operations of current aircraft; and infrastructure improvements. Global market-based (GMB) measures could help to offset the residual emissions that cannot be reduced through these alternatives. [8]

At this state, much attention have been devoted to a market based instrument [9], the climate change levy schemes [10], [11], mostly at national and local level [12]. Recent reports [13], [14] claimed that the new technology and operations improvements will not be enough to mitigate the

predictable fuel demand and emissions growth from aviation; and further measures would be required. For those authors carbon pricing will play a vital role in conveying further reductions in CO2 emissions and fuel demand.
The core part of this analysis pretends to gather analytics and insights to answer how taxing CO2-emissions (Climate Change Levy schemes) will imply significant changes in aviation industry, including aviation demand, industry and markets structure and emission reduction.

2. Climate Change levy schemes.

The main rationale for taxing environmental is the argument of externalities. Carbon taxes are a type of Pigouvian tax [15], [15], this type of taxes seeks to correct a negative or positive externality, in this case, the decarbonization of aviation. By leaving a tax on the activity that generates pollution, the social costs of contamination can be 'internalised' (so the agent must pay the tax) and optimum level of contamination would be achieved for society.

Although this measure is generally recognised as positive, there is no yet a clear agreement on what could be the most convenient type of tax, what should be its value, and what would be the expected impacts.

CCL schemes are based on the consideration of the price elasticity of aviation. Assuming an elasticity close to 1, an increase of 1% in price would imply a 1% reduction on the demand.

Under different considerations of the price elasticity of aviation, certain authors have recently proposed different tax values. Some authors claim that a tax of € 150/ton CO2 could be an effective measure to reduce air transport demand and therefore aviation emissions [16].

Others consider a uniform, globally applied CO2 price of $25 per tonne [17]. This emissions price resembles to the medium scenario considered by AGF and results are equivalent to the US 2010 inter agency study of environmental harms per tonne. Authors claim that a price of $25 per tonne of emissions would imply the addition of US 6 cents per litre, (8 %), to the price of jet fuel [18], [19].

Latest study of Delf for the EU considers the effects of a fuel excise duty on kerosen, equivalent to 330 €/kilolitre, as an average 10% ticket price increase and a 11% passenger demand decline in at European level [20].

Aviation might be subject to different types of taxes, being the most common Ticket taxes, ii) distance-based ticket tax, iii) Frequent Flyer Levy (FFL) [21], iv) Value added tax, v) Taxation on aircraft fuel, vi) Environmental taxes and vii) 5. Taxes for air cargo. The study by CE Delft for the European Commission provides the more updated and comprehensive inventory of taxes applied in aviation [20].

Although in many countries aviation is exempted from all taxes, a significant amount of countries charge taxes on certain aviation activities. For example in the European Union, VAT and taxes on domestic operations are the most predominant and applied in at least 17 states [22]. Six EU states applied some kind of taxes on international aviation, normally in the form of passenger's ticket taxes for those departing from airports in the country. Outside the EU, 13 countries tax aviation, mainly as taxes on ticket or departure taxes, usually a fixed amount per passenger, subject to passenger class and/or destination of the flight. A small number of countries applies VAT or sales taxes. Additionally commercial air transport, both passengers and cargo operation, is subject to various charges and fees that are not seen as taxes, as these are levied to cover the costs of provided services.

However aviation is currently under-charged from an environmental perspective. This low charge regime is even more important for international aviation. When it comes to the taxation of aircraft fuel different schemes are applied. Fuel on domestic flights is sometimes subject to taxes (e.g. freight is charged with a tax of € 1.33 per ton of freight in France). However, international flights fuel is usually exempt from taxes due to international agreements.

ICAO recommends not to tax the intake of jet fuel based on reciprocity, a practice that is followed by most countries and generally mentioned in bilateral Transport Agreements [23], [24], [25]. In Europe, aircraft fuel for commercial air transport operations, is exempt from excise duty; though States may eliminate this exemption for domestic flights and intracommunity. The Energy Tax Directive stablish a minimum excise duty rate for kerosene of € 330/1,000 L, a value that is normally took as reference to calculate the scale of the jet fuel tax exemption.

ICAO (policy doc 8632)], and also IATA, recommends, that "international air transport is [to apply a] zero [VAT] rate", to guarantee an impartial handling of international aviation all over the many authorities into which international flights operates. However, domestic flights are frequently subject to VAT, or VAT is impose directly on fuel, or on air navigation, airport or service charges. At European level [26], States may exempt passenger transport from VAT or apply a zero VAT rate, and additionally some activities for commercial air traffic on international routes should be exempt from VAT (such as the supply of goods for the fuelling and provisioning of aircraft and other activities).

The ICAO Council is favour that environmental levies on aviation should be charges pretty than taxes, as charges straight relate to the costs of the subsequent environmental damage. Additionally IACO supports that moneys collected through those charges should be employed to diminish the damage of aircraft emissions

3. Methodology

The methodology followed in this pilot case study follows a qualitative and analytical approach with the following main steps (figure1):

- Overall assessment of possible solutions and alternatives for aviation decarbonisation.
- Assessment of lessons learned from the implementation of CCL in aviation or in other industries.
- Definition of the most probable CCL scheme for aviation.
- Development of a simple and generally applicable model to assess the impact of taxes in aviation.
- Generation of CCL marginal tax curves and its effect on changing demand for air travel. The model and CCL curves considers price elasticities of demand specific for different markets.
- Assessment of CCL impact on fuel efficiency technology improvement and the acceleration of its entry into service.
- Analysis of CCL impact on the evolution of the short, medium and long-range markets.
- Sensitivity analysis.

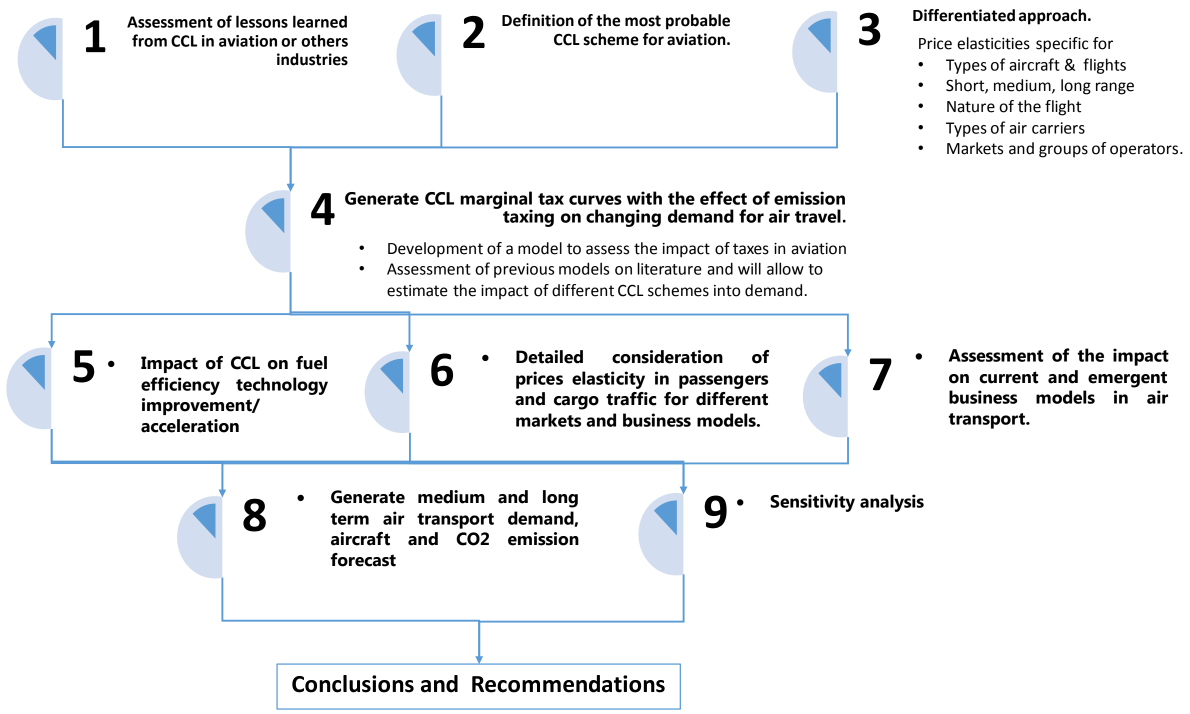


Figure 1. Methodology for the "pilot what if" study on the Aviation Decarbonisation case.

4. Modelling the impacts of Aviation Climate Change levy schemes.

As part of the study a model to calculate CCL marginal curves has been developed (figure2). This is an easily to use and generally applicable model that could employed to assess the effects of the introduction, change or abolition of aviation taxes or aviation-specific tax exemptions.

Basic rationally behind the model is that because the various CCL schemes (taxes) impact the price of flying, therefore aviation demand is its more direct impact. The magnitude of the impact is given by the price elasticity of demand. A change in passengers demand translates in a change in the number of flights and the Revenue Passengers Kilometre (RPK), what also impacts fuel consumption and CO2 emissions. The change in demand causes also a change in output of the aviation sector which has an impact on the cost of flying, fiscal revenue, direct and indirect jobs and value added, and ultimately in GDP. These impact are calculated by an input-output analysis. Hence, the following impacts can be modelled and projected up to 2050:

- CCL schemes and derived impact in the cost/price of flying.
- Passenger demand.
- Change in RPK and number of flights.
- Change un fuel consumption
- Change in C02 emissions.
- Increase in flight cost and Fiscal revenue from the aviation sector.

The granularity of the model goes down to flight modelling. Each flight is modelled considering its origin and destination, airline, aircraft model, aircraft model fuel consumption, aircraft passenger's capacity, occupation factor and average ticket price for each flight. The model applies the hypotheses and variations in parameters down to the level of the flight and allows further aggregation of results by route, country or region, so impacts of taxes can be studied at the level required by the user. Additionally the model allows to project the demand, traffic and impacts up to 2050. Reference yearly growth rates are taken Boeing and Airbus forecasts.

The model allows to define three different CCL schemes: taxes on fuel, on VAT and on ticket prices. It allows to model average airport charges departure and flight range, (e.g. different departure airport charges can be modelled at an airport for short, medium and long range flight). It also accounts for the specific VAT of any country in the world and allows to define specify VAT tax for each country. Any value of tax on fuel could be modelled. Exceptions to the taxes could be modelled also to certain extend. The model will allow to make different assumptions on fuel consumption and economic impact of the taxes for different companies if necessary.

With respect to the price elasticity of demand the model is based on Intervistas [27] study, where a number of elasticities are provided. These are applied to each flight.

Reference year for traffic, demand in RPKs and CO2 calculations of the model was 2018. CO2 calculation has been calibrated by comparing with the actual values of fuel consumption and CO2 emissions in Europe and worldwide for the year 2018. Additionally results have been found coherent in magnitude to previous studies by ICAO and other sources:

CO2 impacts are considered for each flight taken into account the distance of the route and the specific aircraft model fuel consumption. Improvements in fuel efficiency can be incorporated for each flight or for a set of flights, allowing to model improvements in fuel consumption technology, removal of a fleet or the introduction of a new and more efficient aircraft model.

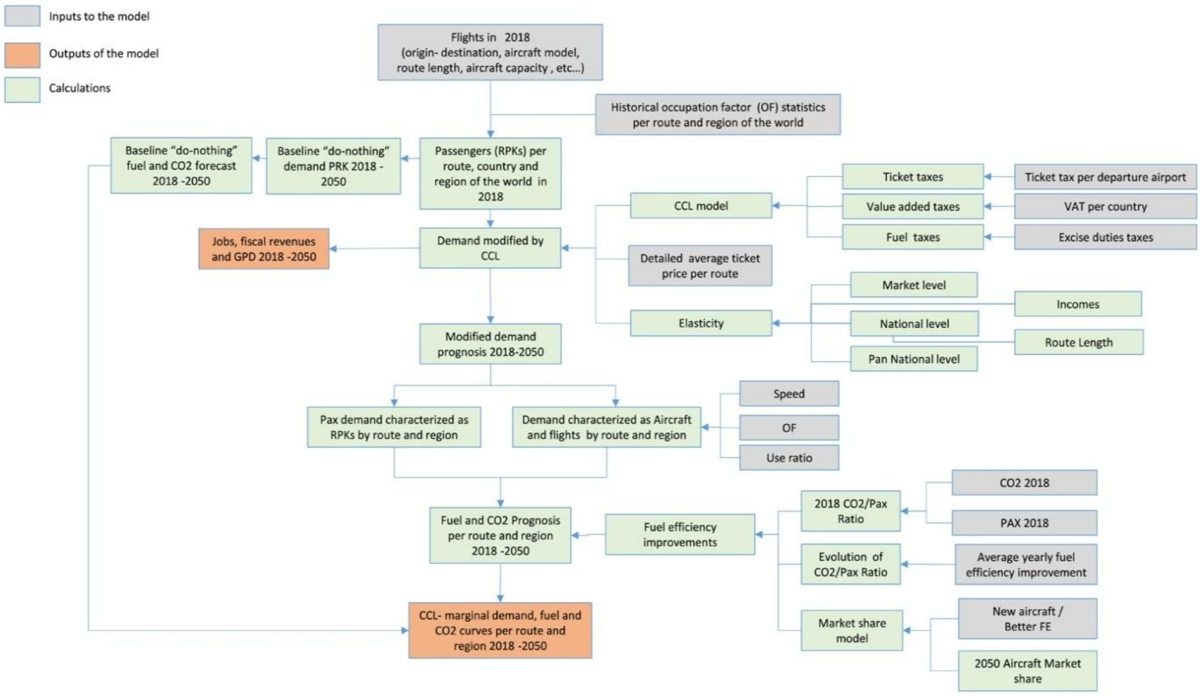


Figure2. CCL impacts model building blocks.

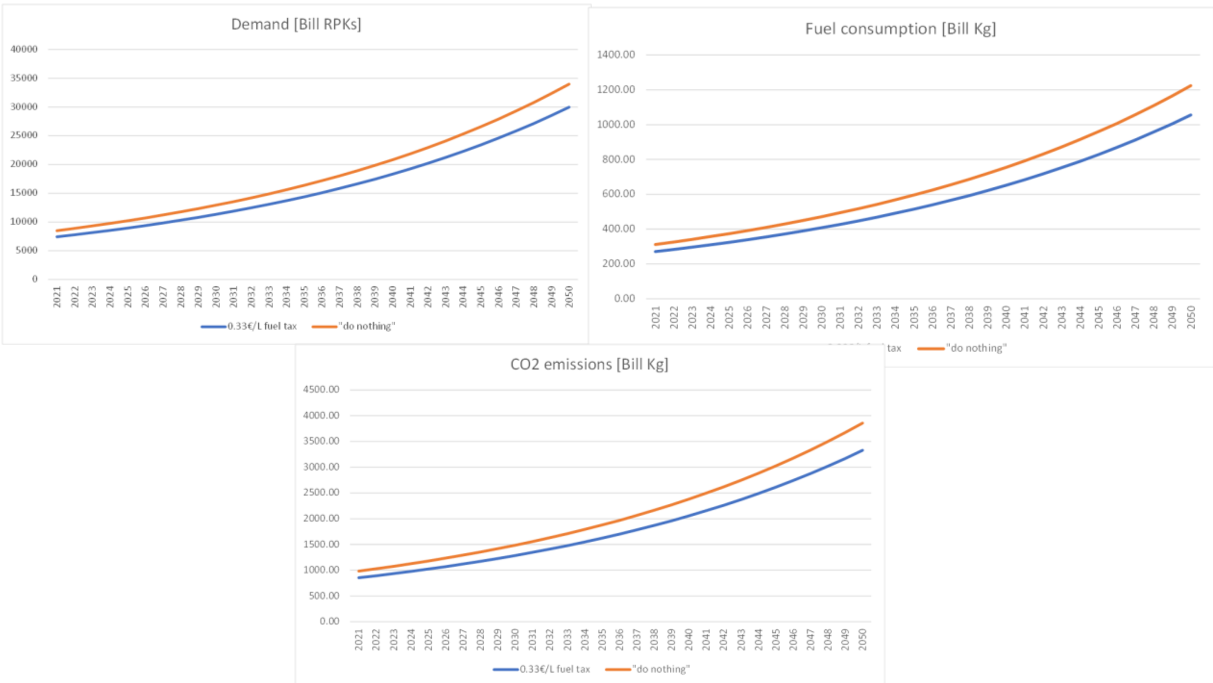
5. Application of the model.

Although the possible applications of the model are broader, in this study it has been used to answer some questions about CCL implementation not broadly tackled in the previous work available in the literature. All the following cases are illustrated for a tax on fuel CCL scheme equivalent to the current fuel excise duty of 0.33 € per litre of fuel (equivalent to 0.4€ per Kg of fuel[1]), that will apply in 2021. This value of tax has been selected to easy comparison with the most recent and relevant studies. Note that for the sake of the calculations COVID effect is not considered and traffic in 2021 is calculated as a projection of industrial figures in 2018.

5.1. Overall results: demand, fuel, CO2 and fiscal revenue.

As starting point, figure 3 presents the overall results of applying the mentioned fuel tax in terms of demand, fuel consumed and CO2. This results correspond to a worldwide application projected up to 2050. For the whole period 2021-2050 the application of the tax implies a global 12% reduction of demand, as well as a reduction on 13% tone of fuel and CO2 produced with respect to the do nothing scenario. Additionally the overall fiscal revenue obtained from the tax application is estimated to be 108 Bill € in 2021 and increases progressively up to 422 Bill€ in 2050. Detailed figures for each year are provided in the table below. This figures and values obtained are coherent with other previous studies. Delft study considers a fuel tax of 0.333€/l but applied only to European International flights, with a 10% increase in the average ticket price, 11% decline in passenger demand and 27 Billion € for the year of application.

[1] Density of aviation fuel considered as 0.825 Kg/L. Density is normally in the range of 0,775 – 0,840 kg/l **Fuente especificada no válida.**



	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030	2031	2032	2033	2034	2035	2036
Demand [Bill PRKS] "do nothing"	8490.88225	8890.70919	9310.62861	9751.69971	10215.0394	10701.8256	11213.3004	11750.7738	12315.6277	12909.3194	13533.3864	14189.4505	14879.2225	15604.5075	16367.2098	17169.3389
Demand [Bill PRKS] 0.33€/L Fuel Tax	7426.93597	7779.0633	8148.98646	8537.64759	8946.04027	9375.21249	9826.26957	10300.3775	10798.7661	11322.733	11873.6469	12452.9521	13062.1723	13702.9152	14376.8774	15085.8491
Fuel consumption [Bill KG] "do nothing"	311.69	326.19	341.40	357.36	374.12	391.72	410.20	429.60	449.97	471.37	493.85	517.47	542.28	568.35	595.74	624.53
Fuel consumption [Bill KG] 0.33€/L Fuel Tax	270.75	283.19	296.24	309.95	324.34	339.45	355.31	371.98	389.49	407.88	427.20	447.50	468.84	491.26	514.82	539.59
CO2 emissions [Bill KG] "do nothing"	981.84	1027.49	1075.41	1125.70	1178.49	1233.92	1292.12	1353.23	1417.41	1484.82	1555.63	1630.02	1708.17	1790.29	1876.59	1967.28
CO2 emissions [Bill KG] 0.33€/L	852.88	892.05	933.17	976.33	1021.66	1069.26	1119.24	1171.74	1226.88	1284.81	1345.68	1409.63	1476.83	1547.46	1621.69	1699.72

	2037	2038	2039	2040	2041	2042	2043	2044	2045	2046	2047	2048	2049	2050
Demand [Bill PRKS] "do nothing"	18013.0149	18900.4752	19834.0806	20816.3229	21849.8314	22937.3814	24081.9022	25286.4853	26554.3945	27889.0747	29294.1626	30773.4975	32331.1326	33971.3472
Demand [Bill PRKS] 0.33€/L Fuel Tax	15831.7196	16616.4828	17442.2428	18311.2206	19225.7606	20188.3369	21201.5616	22268.1919	23391.1386	24573.4744	25818.4437	27129.4718	28510.1752	29964.3724
Fuel consumption [Bill KG] "do nothing"	654.80	686.60	720.05	755.20	792.17	831.04	871.92	914.92	960.15	1007.72	1057.77	1110.43	1165.84	1224.14
Fuel consumption [Bill KG] 0.33€/L Fuel Tax	565.64	593.01	621.80	652.07	683.91	717.39	752.61	789.66	828.64	869.64	912.79	958.20	1005.99	1056.28
CO2 emissions [Bill KG] "do nothing"	2062.60	2162.81	2268.14	2378.89	2495.34	2617.79	2746.56	2882.00	3024.46	3174.32	3331.98	3497.86	3672.39	3856.06
CO2 emissions [Bill KG] 0.33€/L	1781.75	1868.00	1958.68	2054.03	2154.32	2259.79	2370.73	2487.43	2610.21	2739.38	2875.30	3018.33	3168.85	3327.28

Figure 3. Overall results of a 0.33€/L fuel tax.

5.2. Impact in operational cost and in the air transport industry activity.

It is possible to extract some conclusions about the impacts of a 0.33€/L tax fuel policy in the operational cost of the airlines by observing what has been the effect of effective fuel cost increase for the air transport in past periods. A tax of fuel of 0.33 per litre (0.4€ per kg) is indeed a big increase in the price of fuel. As of January 2020, the price of Jet A1 was approximately €0.55 per kg. The 0.4€ per kg fuel tax will imply a high 72% increase in the price of fuel respect to the prices in 2019. Global fuel consumption by commercial airlines reached an all-time high of 161.5 Billion € of fuel cost in 2019 (96 billion gallons at a 0.55€/kg means). Being fuel the 23.5% of the airline total expenditure, operational cost of airlines for the same year are estimated in 687.5 billion of euros. [28]

The application of the proposed tax might imply an increase of the percentage of fuel in the total expenditure of the airlines higher than the levels in 2012 (rough calculation lead to 40%). That could mean a decline in air transport activity to levels much worse than those of 2012/2013. This calculation, although approximate, illustrates that although 0.33€/L has been proposed at European level as fuel tax for European aviation (and used in this study for comparative purposes), this tax will not be sustainable worldwide. Additionally if implemented only in Europe it could be to detrimental for European aviation and imply a significant loss of competitiveness against others regions of the world.

5.3. Regional contribution and cooperation.

As stated by most authors the effectiveness of a tax on fuel will depend very much on the homogeneity of its application. It is expected then that this tax could be applied globally worldwide. Figure 4 illustrates how 70% of the reduction in CO_2 emissions will be produced by aviation with origin in just 4 regions: Europe, North America, Middle East and Southeast Asia.

By applying the 80/20 Pareto's law, (which states that for many phenomena 80% of the result comes from 20% of the effort), it would be necessary that at least these regions would agree on the implementation of the tax in order to obtain a significant CO2 saving. A worldwide agreement less than that could lead to an insignificant CO2 saving and at the same time produce negative counter effect of the economy, air transport t and tourism for those regions.

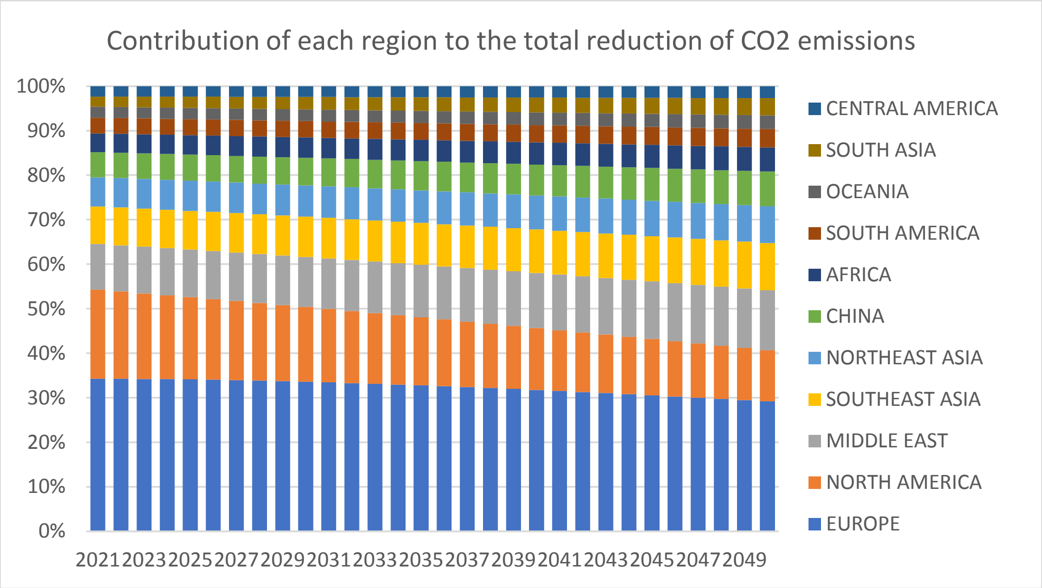


Figure 4. Contribution (in %) of Regions to the reduction in CO2.

Additionally, there is an underlying prevention of one-sided tax policy would damage local tourism, trade and domestic carriers, increase import prices, decrease the demand for exports. If states apply CCL unilaterally, or do not subscribe an overall agreement, they will be pressured to establish lower rates to defend their economic interests. Because of all those reason international coordination is needed. [29], [11]

5.4. Compensating developing countries.

One of the concerns of implementing carbon charges for aviation is that developing countries are made no worse off by the global adaption of such charges, and up to what extent this could be avoided through reasonably practicable compensation rules. Compensation of developing countries for the monetary damage of environmental is extensively accepted as a critical factor to their implementation.

The IMF (Internationally Monetary Fund) [17] found that the combination of a global charge with targeted compensation would be the more effective way to colliding objectives of efficiency and equity, however, it will withdraw a significant part of the potential CO2 savings. Such compensation has been quantified at 40 percent of global revenues. With a gross estimation by 2020, a globally implemented carbon charge of $25 per tonne of CO2 on international aviation fuel could have raised in 2020, with no COVID 19 incidence, around $12 billion. 40% of this amount would leave about $7 billion for compensating developing economies, and will therefore withdraw from climate finance. Developing countries might use this compensations funds to subside local aviation, jeopardizing the CO2 reductions provided by the tax itself.

5.5. Fuel efficiency improvement.

It is also claimed that emissions pricing would induce other mitigation options beyond this reduction in demand. These include more efficient operations and improved efficiency of new planes.

Based upon historical data some authors have quantified jet aircraft fuel efficiency historical improvement at a rate of 1.2-2.2% per year on a seat/km basis. International aviation community aspire to a 2% annual fuel efficiency improvement and a carbon neutral growth from 2020.

To comparatively assess the effect of CCL against this effect a simulation has been run under different hypothesis from 2% up to 4% of fuel efficiency improvement, in addition to de do nothing and 0.33€/L fuel tax scenarios. Data shown that a 2-4% yearly fuel efficiency improvement does not provide a significant CO_2 emissions improvement when compared to a 0.33€/L fuel tax (figure5).

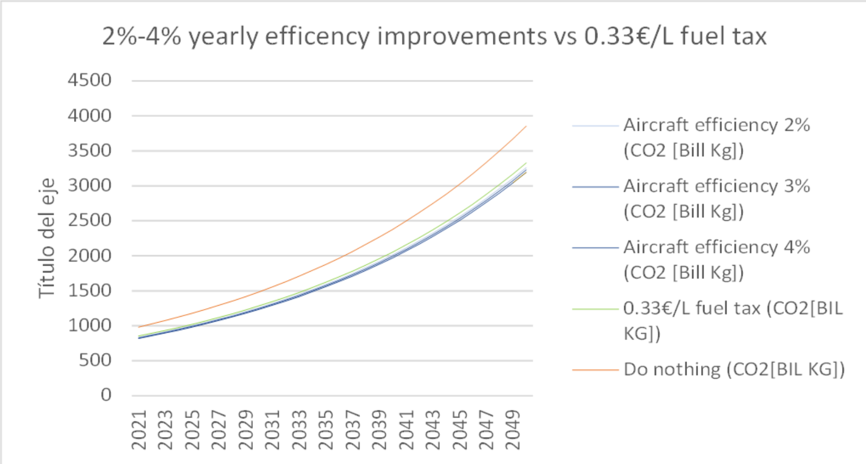


Figure 5. Fuel efficiency improvement

5.6. Impact on different markets.

The fuel tax may affect in a different way the short, medium and long range markets. In this regards two key questions need to be evaluated: which market results more affected in terms of demand and which market might contribute the most to the CO_2 emissions reduction.

Figure 6 illustrates how the demand is reduced in each of the markets in terms of RPKs. It can be appreciated how the biggest reduction takes place in the medium haul market with an initial reduction of around 634 Bill RPKS in 2021 and a final of 2340 Bill RPKs by 20250. For the short haul market the initial reduction by 2021 is around 260 Bill RPKS and by 2050 is around 1007 Bill RPKs. For the long haul market the reduction is of 316 Bill RPKs by 2021 and of 1225 Bill RPKs by 2050. In average it means a 11% yearly reduction for the short haul market, a 16% yearly reduction for the medium haul market and a 14% yearly reduction for the long haul market.

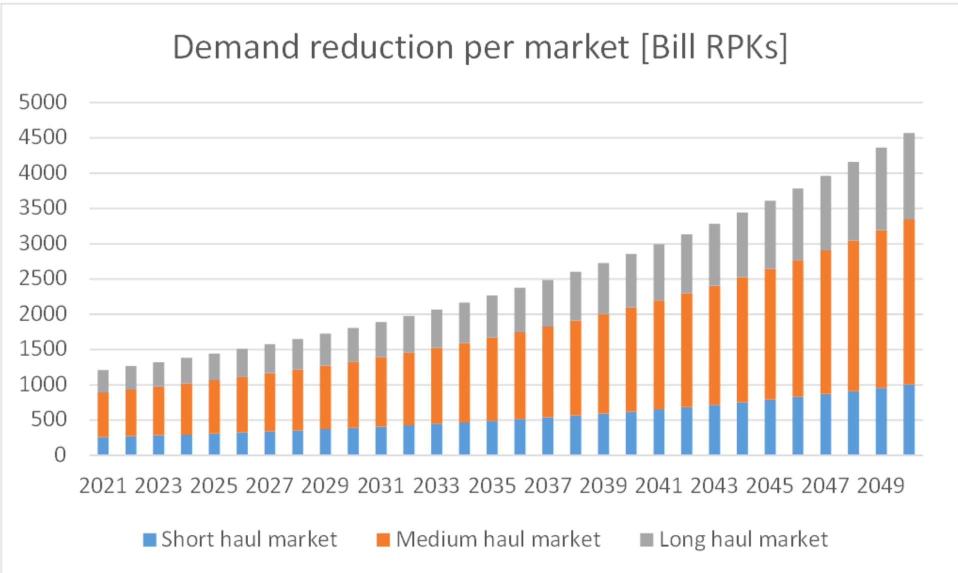


Figure 6. Reduction in demand for short, medium and long haul market

Figure 7 show how each market contributes to the global reduction of CO2. It can be observed that the biggest reduction of CO2 is expected in the medium haul market, which will account for 49.5% of the total reduction with 68 Bill Kg CO2 by 2021 and 252 Bill Kg CO2 by 2050. The short haul market accounts for 20.5% of the global reduction with 28 Bill Kg CO2 by 2021 and 109 Bill Kg CO2 by 2050. The short haul markets accounts for 30% of the global reduction with 41 Bill Kg CO2 by 2021 and 161 Bill Kg CO2 by 2050.

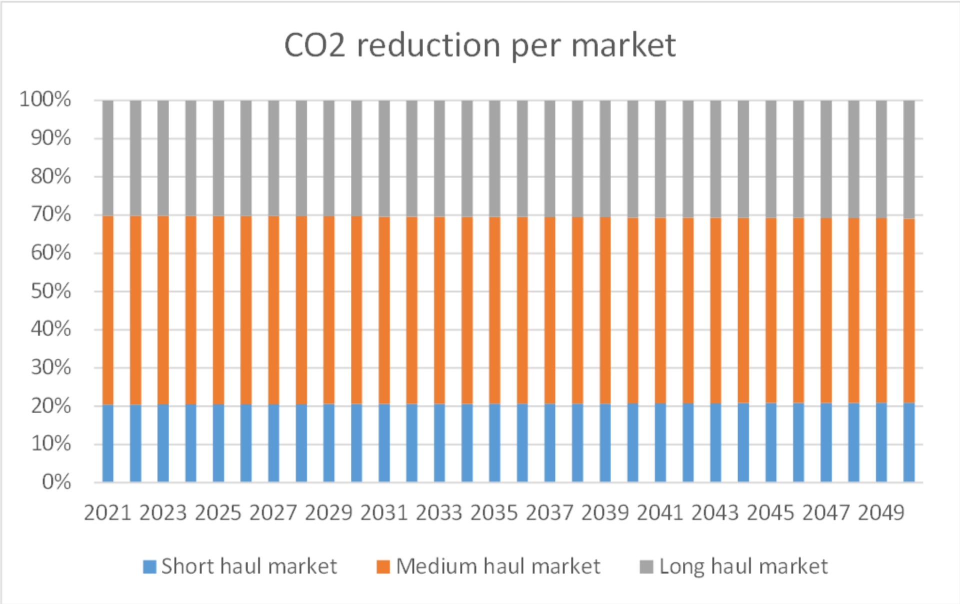


Figure 7. Contribution of each market in % to the global CO2 reduction

5.7. Implementation year.

The next analysis show the effect of implementing the tax in 2021 or delaying its application up to 2025 or even 2030. Figure 8 presents the accumulated CO2 emissions between 2021 and 2050 in Bill Kg for the three different implementation dates in contrast with the accumulated CO2 emission for the do nothing scenario. Implementation of the fuel tax in 2030 instead of 2021 would imply the emission of 3304 Bill Kg more of CO2, whereas implementing the tax in 2025 instead of 2021 would imply the emission of 950 Bill Kg more of CO2.

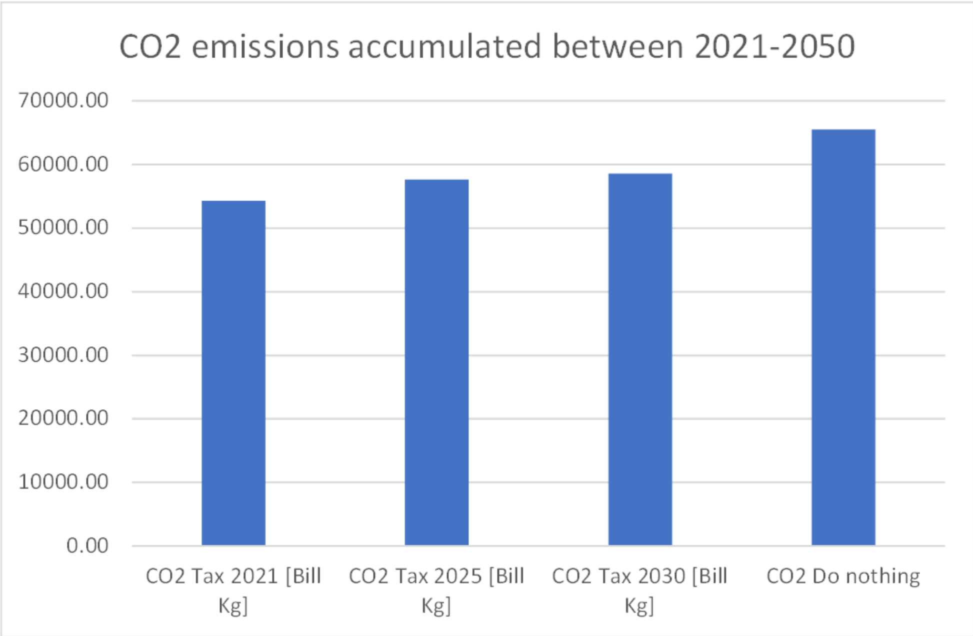


Figure 8. CO2 emissions by 2050.

5.8. Generation of the marginal CCL curves.

As discussed in the previous sections a fuel tax of 0.33€/L applied worldwide will imply a very high increase in the price of fuel. At the same time there is no yet an agreement among the different sources and studies of what might be the optimum value for such a tax, this figures varying depending on the study consulted. Those studies are not always easy to compare as they do not reproduce the same scenarios or considerer a local/ regional application of the tax.

To help to solve this problems we construct in this analysis marginal curves that represents the effect in demand and CO2 for different values of a global fuel tax, ranging from 0 to 500€/Ton of fuel in intervals of 25€/Ton. Being the value of 400€ /Ton (333€/KL) the tax equivalent to the excise of duty study that has serve for comparison in the previous analysis (figure 9 and 11).

By expressing these information in accumulative percentages we obtain the marginal CCL curves in figure 10, which give straightforward the % of reduction for the worldwide demand in the period 2021 to 2050 for any given tax. This marginal curve can be used as criteria for design. Similar abacus can be constructed for each region in the world o for each market segment (Short, medium, long haul). Similar abacus are provided for fuel consumption and CO2 emissions (figure 12).

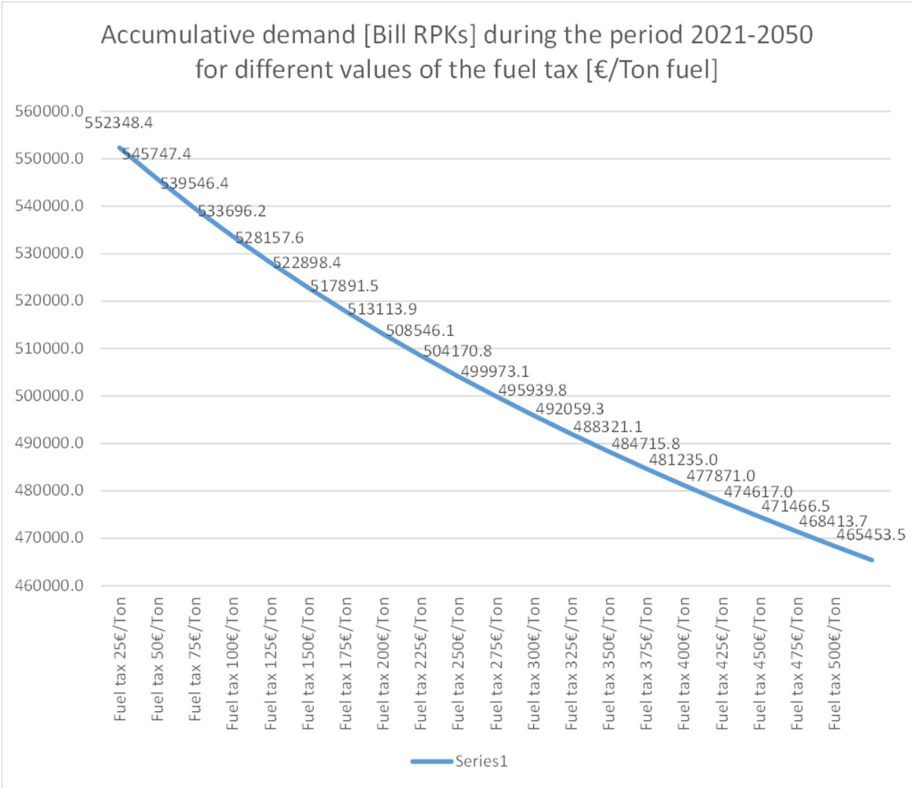


Figure 9. Accumulative demand during the period 2021-2050 in Billions of RPKs for different values of the fuel tax.

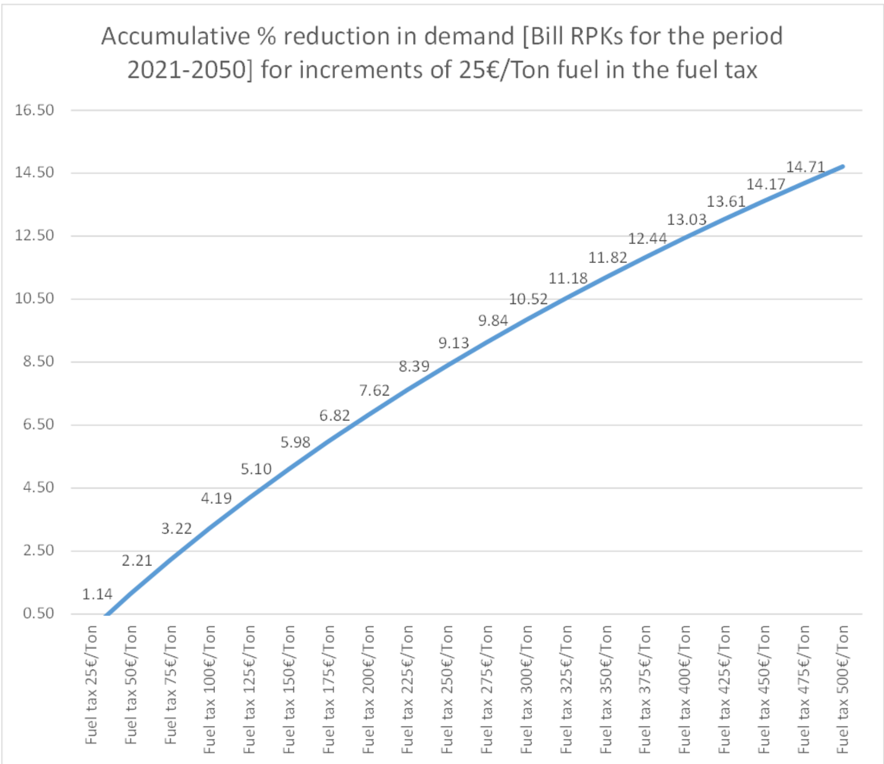


Figure 10. Fuel tax marginal curve: accumulative % reduction in demand for the period 2021-2050 expressed in Billions of RPKs for increments of 25€/Ton in the fuel tax.

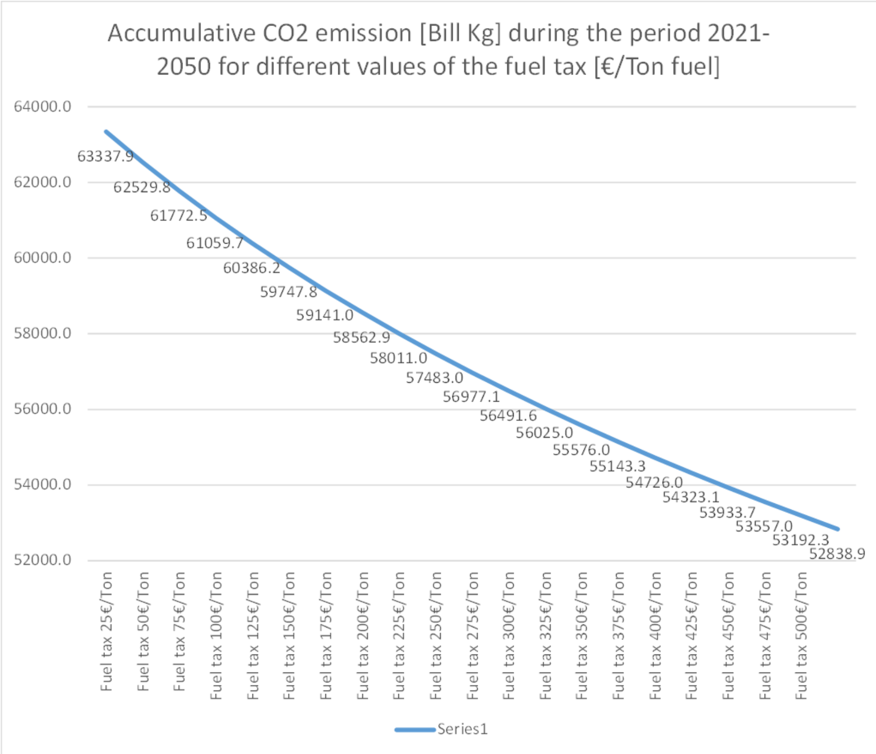


Figure 11. Accumulative fuel consumption during the period 2021-2050 in Billions of Kg for different values of the fuel tax.

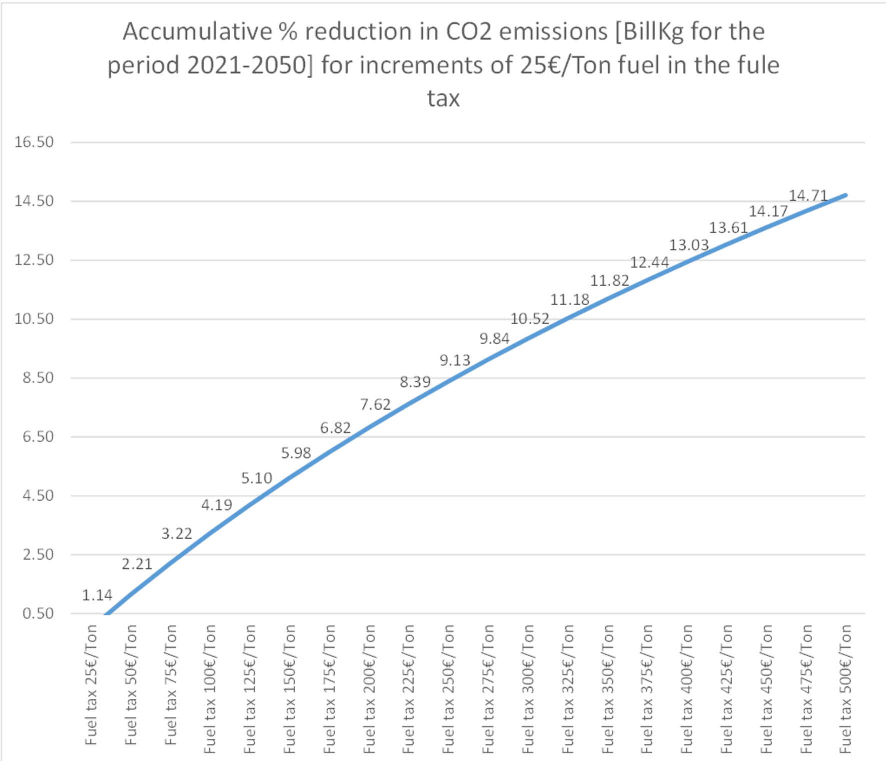


Figure 12. Fuel tax marginal curve: accumulative % reduction in fuel consumption for the period 2021-2050 expressed in Billions of Kg for increments of 25€/Ton in the fuel

Conclusions

Through this paper the potential role of Climate Change Levy Schemes in achieving the ambitious objective of aviation decarbonization by the year 2050 has been analysed by developing a model to generate CCL marginal tax curves and study its effect on changing demand for air travel and CO2 emissions.

To inform final decision we have produced CCL marginal curves that help to understand how taxing will impact aviation demand, markets structure and emission reduction, and we have illustrated the applications of the model to answer some questions about CCL implementation not broadly tackled in the previous work available in the literature, using a fuel excise duty on kerosene (0,33€/L) example for comparative reasons.

References

[1] ICAO "2019 Environmental Report - Aviation and Environment, ICAO, 2019"

[2] IATA, Airbus, Boeing, ATAG, Intergovernmental Panel on Climate Change (IPCC), "Aviation: Benefits Beyond Borders. ATAG Beginner's Guide to Aviation Efficiency, Intergovernmental Panel on Climate Change (IPCC), BBC News, Qantas.," ATAG org, January 2020

[3] EASA 2019 European Aviation Environmental Report 2019

[4] CAN & ICSA 2018 Contribution of the Global Aviation Sector to Achieving Paris Agreement Climate Objectives [Online] Available: https://icsa-aviation.org/wp-content/uploads/2018/04/CAN-ICSA-Aviation-TD-submission.pdf

[5] "IATA Technology Roadmap 2013. 2013 Available online: http://www.iata.org/whatwedo/environment/Documents/ technology-roadmap-2013.pdf (accessed on November 8, 2019)

[6] Bezos-O'Connor G, Mangelsdorf M, Nickol C, Maliska H, Washburn A and Wahls R. Fuel Efficiencies through Airframe Improvements. In Proceedings of the 3rd AIAA Atmospheric Space Environments Conference, Honolulu, HI, USA, 2730 June 2

[7] E. B. F. 2016 2 million tons per year: A performing biofuels supply chain for EU aviation. [Online]. Available: https://ec.europa.eu/energy/sites/ener/files/20130911_a_performing_biofuels_supply_chain.pdf.

[8] ATAG 2016 Brief: Global Offsetting Scheme Cost, Retrieved from: https://www.verifavia.com/bases/ressource_pdf/370/FACT-SHEET-GMBMcosts-Sept2016-1-.pdf

[9] ICAO 2019 10. COMMITTEE ON AVIATION ENVIRONMENTAL PROTECTION (CAEP) STEERING GROUP MEETING Montréal, Canada, 11 to 15 September 2017. Agenda Item 3: Global Market Based Measure Technical (GMTF) ICAO/ CORSIA PACKAGE (Presented by GMTF co-Rapporteurs), ICAO, 2019

[10] P Forsyth 2019Aviation Taxes – Impacts, Costs and Benefits" (online: http://greenfiscalpolicy.org/wp-content/uploads/2019/06/1560238770_AviationTaxesImpactsCostsandBenefits.pdf)

[11] A Krenek and M Schratzenstaller 2016 Sustainability-oriented EU Taxes: The Example of a European Carbon-based Flight Ticket Tax (online: https://ec.europa.eu/budget/mff/Library/hlgor/selected-readings/41-Carbon-basedFlightTicketTax-Schratzenstalle

[12] Conefrey Thomas, Gerald John and Valeri Laura 2008 The Impact of a Carbon Tax on Economic Growth and Carbon Dioxide Emissions in Ireland. *Journal of Environmental Planning and Management*

[13] 1astudybyTransport & Environment 2018 Roadmap to decarbonising uropeaEn aviation

[14] Air Transport Department, Cranfield University European Commission contract

TREN/05/MD/S07.52077 Fuel and air transport

[15] UNITED NATIONS HIGH COMISSIONER FOR REFUGEES. , “¿Cuál es el objetivo de los impuestos pigovianos? (online: https://eacnur.org/blog/objetivo-los-impuestos-pigouvianos/),” 2017

[16] Transport & Environment 2018 Roadmap to decarbonising European aviation, Retrieved from: https://www.transportenvironment.org/publications/roadmap-decarbonising-european-aviation.

[17] INTERNATIONAL MONETARY FUND 2011 Market-Based Instruments for International Aviation and Shipping as a Source of Climate Finance

[18] AGF 2010 Report of the Secretary-General‘s High-level Advisory Group on Climate Change Financing. New York: United Nations

[19] UBA, [Online]. Available: https://www.umweltbundesamt.de/en/press/pressinformation/high-costs-when-environmental-protection-is

[20] CE Delft 2019 “Taxes in the Field of Aviation and their impact. Final Report.” European Commission

[21] S B Stephen 2015 Devlinand, Managing aviation passenger demand with a frequent flyer levy., managing aviation passenger demand with a frequent flyer levy. stephen devlinand sandra bernick New Economics Foundation © 2015 The New Economics Foundation

[22] C. f. E. a. S. Research 2014 Study on the economic effects of the current VAT rules for passenger transport. Final Report TAXUD/2012/DE/334

[23] European Commission 2003 European Commission (2003), Council Directive 2003/96/EC of 27 October 2003 restructuring the Community framework for the taxation of energy products and electricity.

[24] E. M. &. A. M. Y. Kelly de Bruin 2019 The Impacts of Removing Fossil Fuel Subsidies and Increasing Carbon Tax in Ireland, The Economic and Social Research Institute, RS98, DOI: https://doi.org/10.26504/rs98

[25] European Commission 2003 Energy Tax Directive 2003/96/EC (Article 14(1)(b))26

[26] European Commission 2006 EC directive on the common system of Value Added Tax (2006/112/EC)23”

[27] I. C. Inc 2007 Estimating Air Travel Demand Elasticities. Final report

[28] IATA, jet fuel price monitor, [Online]. Available: https://www.iata.org/en/publications/economics/fuel-monitor/

[29] R. G. &. E. B. Hosoda 2016 Environmental impact of aircraft emissions and aviation fuel tax in Japan

[30] A. 2016 “ASTM D7566-16, Standard Specification for Aviation Turbine Fuel Containing Synthesized Hydrocarbons”. [Online]. Available: http://www.astm.org/Standards/D7566.htm