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How Much Can Carbon Taxes Contribute to Aviation Decarbonization by 2050

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Abstract: Aviation emissions from 2016 to 2050 could consume between 12% and 27% of the remaining carbon budget to keep global temperature rise below 1.5 °C above preindustrial levels. Consequently, aviation is being challenged to immediately start to reduce its in-sector emissions, then sharply reduce its CO_2 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.

Keywords: aviation; decarbonization; climate; levy; taxes

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1. Introduction

According to International Civil Aviation Organization (ICAO), aviation is responsible for 2% of global CO_2 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 the international aviation community aspires 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. Even if achieved, aviation will still produce by 2050 a significant amount of CO_2, which might endanger the achievement of the goals of the Paris Agreement [3].

An ICAO report from 2019 [1] quantified emissions of the aviation sector over the period 2016–2050 as between 56 $GtCO_2$ in a business-as-usual scenario and 12 $GtCO_2$ in an optimistic, but unlikely-to-meet, scenario with technological improvements and 100% use of biofuels. These figures suggest that aviation emissions, from 2016 to 2050, could consume between 27% and 12% of the remaining carbon budget to keep global temperature rise below 1.5 °C above preindustrial levels [4].

Up until now, the aviation industry based its approach to decarbonization on four pillars of climate action: new technology; substitute fuels; optimized operations of current aircraft; and infrastructure improvements [5–7]. Global market-based (GMB) measures could help to offset the residual CO_2 emissions that cannot be reduced through these alternatives [8–10].

Much attention has been devoted to a market-based instrument [11], the climate change levy (CCL) schemes [12,13], mostly at national and local levels [14,15]. Recent reports [16,17] claimed that the new technology and operations improvements will not be enough to mitigate the predictable fuel demand and CO_2 emissions growth from aviation, and further measures would be required. Those authors believe carbon pricing will play a vital role in conveying further reductions in CO_2 emissions and fuel demand.

This analysis attempts to gather analytics and insights to answer the question of how taxing CO_2 emissions (climate change levy schemes) will lead to significant changes in the aviation industry, including aviation demand, industry and markets structure, and emission reduction. Although carbon dioxide is not the only way aviation affects the climate, this paper only deals with CO_2 and not with other climate-relevant species. Aircrafts emit other gases and aerosols that change the composition of the atmosphere, such as NOx and water vapor. They also produce "contrails", which affect the cloudiness of the sky and how much solar radiation reaches the surface of the Earth. The extent to which these extra factors amplify the CO_2 effect is still poorly understood and not captured in ICAO's estimates of aviation's impact on the climate.

2. Climate Change Levy Schemes

Carbon taxes are a type of Pigouvian tax [18]. This type of tax seeks to correct a negative or positive externality, in this case, the decarbonization of aviation. By levying a tax on an activity that generates pollution, the social costs of contamination can be "internalized" (so the agent must pay the tax) and an optimum level of contamination would be achieved for society. Although this measure is generally recognized as positive, there is not 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 [19].

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 lead to 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 €/tonne CO_2 could be an effective measure to reduce air transport demand and therefore aviation emissions [16]. Others consider a uniform, globally applied CO_2 price of USD 25 per tonne [20]. This emissions price resembles the medium scenario considered by the Advisory Group on Climate Change Financing (AGF) and results are equivalent to the US 2010 interagency study of environmental harms per tonne. Authors claim that a price of USD 25 per tonne of emissions would lead to the addition of US 6 cents per liter, (8%), to the price of jet fuel [21,22]. The latest study of Delf for the EU considers the effects of a fuel excise duty on kerosene, equivalent to 330 €/kiloliter, as an average 10% ticket price increase and a 11% passenger demand decline at the European level [23].

Although in many countries aviation is exempted from all taxes, a significant amount of countries charge taxes on certain aviation activities. 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 tonne of freight in France). However, international flights fuel is usually exempt from taxes due to international agreements

3. Modelling the Impacts of Aviation Climate Change Levy Schemes

As part of the study, a model to calculate CCL marginal curves was developed (Figure 1). This is an easy-to-use and generally applicable model that could be employed to assess the effects of the introduction, change, or abolition of aviation taxes or aviation-specific tax exemptions.

The basic rationality behind the model is that because the various CCL schemes (taxes) impact the price of flying, their direct impact is on aviation demand. The magnitude of the impact is given by the price elasticity of demand. A change in passenger demand translates into a change in the number of flights and the revenue passengers kilometer (RPK), which also impacts fuel consumption and CO emissions. The change in demand also causes a change in output of the aviation sector, which has an impact on the cost of flying, fiscal revenue, direct and indirect jobs, value added, and ultimately in Gross Domestic Product (GDP). These impacts 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 in fuel consumption.
- Change in CO_2 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's fuel consumption, aircraft's passenger 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 for the projection of the demand, traffic, and impacts up to 2050. Reference yearly growth rates are taken from Boeing and Airbus forecasts.

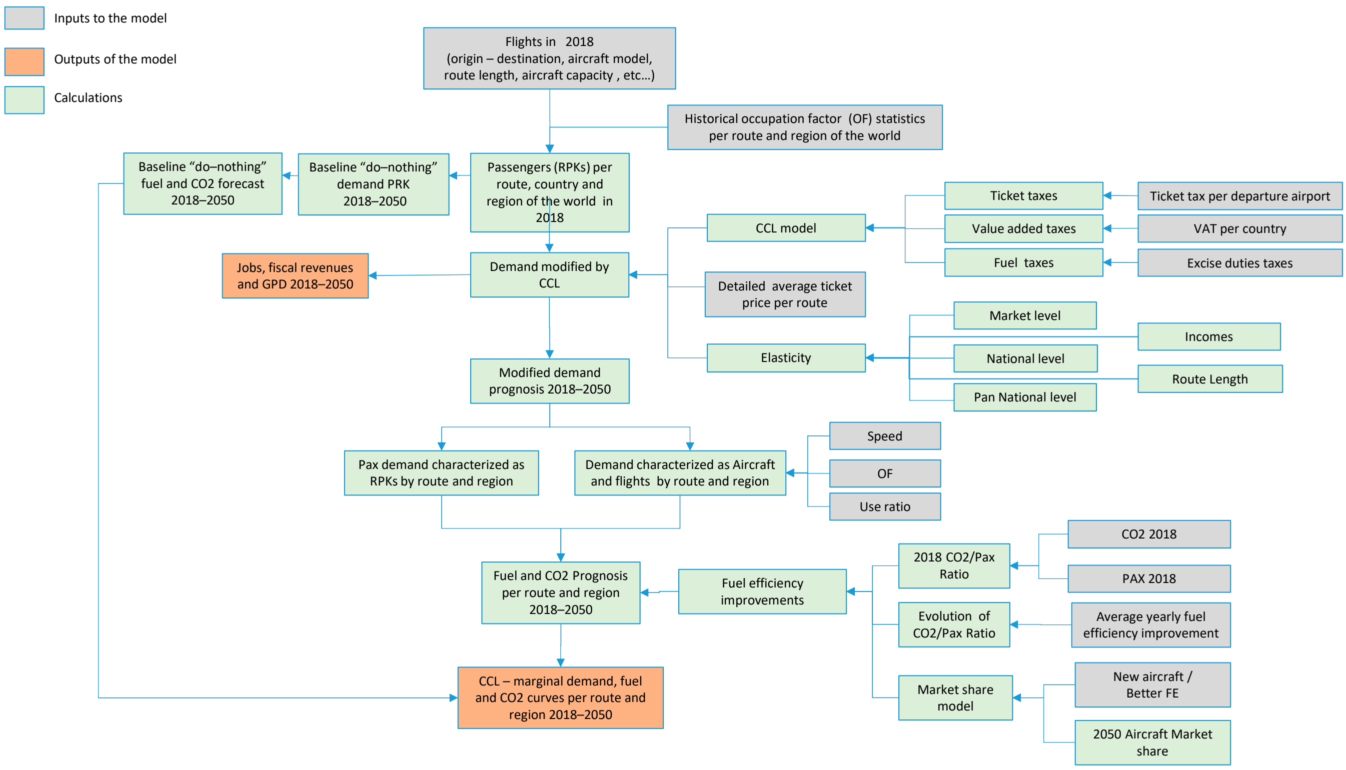


Figure 1. Building blocks for the climate change levy (CCL) impacts model.

The model allows us to define three different CCL schemes: taxes on fuel, on Value Added Tax (VAT), and on ticket prices. It allows us to model the average airport charges for departures based on flight range (e.g., different departure airport charges can be modelled at an airport for short-, medium-, and long-range flights). It also accounts for the specific VAT of any country in the world and allows us to define a VAT tax for each country. Any value of tax on fuel could be modelled. Exceptions to the taxes could also be modelled to a certain extent. The model allows us 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 the Intervistas [24] study, where a number of elasticities were provided. These are applied to each flight. Reference year for traffic, demand in RPKs, and CO_2 calculations of the model were from 2018. The CO_2 calculation was calibrated by comparing it with the actual values of fuel consumption and CO_2 emissions in Europe and worldwide for the year 2018. Additionally, results were coherent in magnitude to previous studies by ICAO and other sources. CO_2 impacts are considered for each flight, taking into account the distance of the route and the specific aircraft model's fuel consumption. Improvements in fuel efficiency can be incorporated for each flight or for a set of flights, allowing the model to incorporate improvements in fuel consumption technology, removal of a fleet, or the introduction of a new and more efficient aircraft model.

3.1. Dealing with Uncertainty

One issue to be discussed in this approach is the high level of uncertainty that comes with long term traffic forecast and with the implementation of institutional and regulatory policies in aviation.

Decision making for the environment and in aviation is usually associated with long periods of return and great uncertainties on adoption speed, which makes sustainable investment and policy decisions difficult. To specifically address the uncertainty impact for optimal business strategies, some authors have developed elaborate risk assessment approaches. The authors of [25] analyze the case study of the deployment of hydrogen fuel stations for hydrogen cars in a European country by incorporating a generalized Bass model for the adoption-diffusion process into an N-fold compound, real option framework.

The risk of suboptimal decisions regarding the optimal timing of fuel taxes is a matter of concern, and should be tackled in later phases of the definition process for the taxes. However, the proposed methodology implements some measures to account for uncertainty in the calculations.

On one side, the traffic growth prognosis used in the study relies on growth rates forecasted by relevant aviation stakeholders. Forecasting the number of airplanes demanded by airlines and passengers in the future is a complex problem affected by important uncertainties. Although a number of approaches and methodologies have been developed by the academia and the industry, the accuracy of any fleet demand forecast relies very much on a deep knowledge of the industry and on reliable data about the evolution of the various markets and segments.

A selected group of companies, including manufactures, consultancies, and governmental agencies, produce regular updates of short-, medium-, and long-term forecasts that are considered a reference for any market study in aviation. The aim of this study is not to build an additional forecast, but to integrate the best publicly available long-term forecasts and hypotheses about the trends, highlighted by reference reports about credible and expected evolution of airplane fleets' demand, production, retirement, and delivery. All these inputs about the expected long term evolution of the global world fleet market are used to estimate future CO_2 emissions. In this way, the current study benefits from the best knowledge in the market. This allows us to estimate a range of values for the expected long-term passengers and fleets.

Yearly growth rates used as a reference in our model were taken from Boeing and Airbus forecasts, but we also included five worldwide studies covering a forecast period of 20 years and global passenger fleet. All of them take uncertainty into account in their prognoses:

- Boeing Commercial Market Outlook 2019–2038,
- Airbus Global Market Forecast 2019–2038,
- Japan Aircraft Development Corporation (JADC) Worldwide Market Forecast 2019–2018,
- United Aircraft Corporation (UAC) Market Outlook 2019–2038, and
- The Airline Monitor Commercial Aircraft Market Forecast 2019–2044.

The developed model can be run for different growth scenarios and generate a confidence interval for the CO_2 predictions.

Additionally, the model is also used to evaluate the overall impact of implementation delays. This might help to better estimate the implementation strategy in further steps of the process.

3.2. Considerations about COVID-19

The year 2020 was unprecedented in terms of its disruption to the air transport industry. Global airlines have only started to timidly recover from a more than 90% decline in passenger traffic and revenue in early 2020, but a full recovery will take years [26].

In this situation, main stakeholders agree to forecast a challenging short-term market with long-term resilience. They expect air transport will overcome its short-term challenges, regain stability, and emerge strongly.

It is still soon to get reliable figures of such possible recovery, but big manufacturers are updating their forecasting. The latest Boeing Market Outlook (BMO) forecasts demand for aerospace products and services at a total value of USD8.5 trillion over the next decade. This figure is lower than the $8.7 trillion a year ago due to the impact of the COVID-19 pandemic.

The 2020 Boeing Market Outlook includes projected demand for 18,350 commercial airplanes in the next decade, 11% lower than the comparable 2019 forecast. In the long term, key industry drivers are expected to remain stable. Commercial fleet is expected to return to its growth trend, generating demand for more than 43,000 new airplanes in the 20-year forecast time period.

The recovery period after COVID-19 might cause a shift of a few years in the figures calculated in this study.

4. Application of the Model

The new model was used to answer some questions about CCL implementation not broadly tackled in the previous works 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 liter of fuel (equivalent to €0.4 per Kg of fuel), that will apply in 2021. This value of tax has been selected for easy comparison with the most recent and relevant studies. Note that for the sake of the calculations the effects of the COVID-19 pandemic are not considered, and traffic in 2021 is calculated as a projection of industrial figures in 2018.

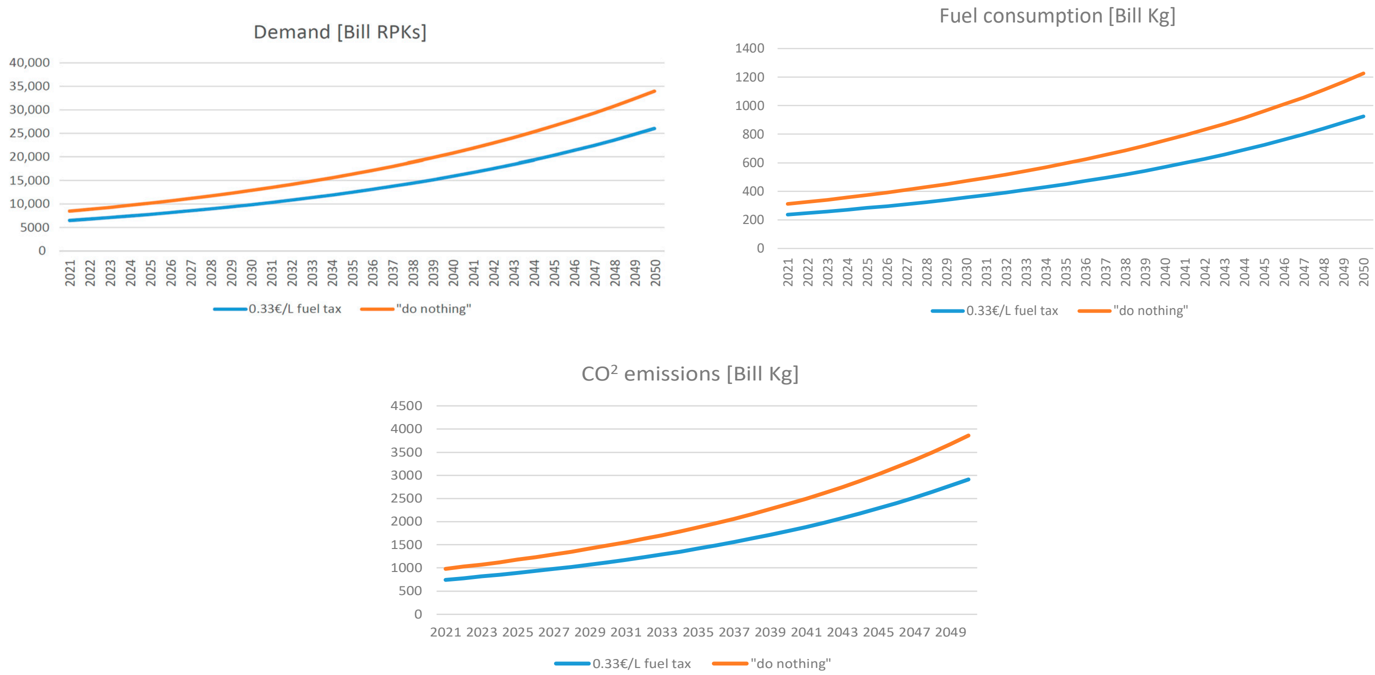
4.1. Overall Results: Demand, Fuel, CO_2, and Fiscal Revenue

As a starting point, Figure 2 presents the overall results of applying the mentioned fuel tax in terms of demand, fuel consumed, and CO_2. These results correspond to a worldwide application projected up to 2050.

For the period 2021–2050, the application of the tax implies a global 12% reduction of demand, as well as a reduction of 13% of fuel and CO_2 produced with respect to the do-nothing scenario. Additionally, the overall fiscal revenue obtained from the tax application is estimated to be 108 billion Euros in 2021 and increases progressively up to 422 billion Euros in 2050. Detailed figures for each year are provided in Figure 2. These figures and values are coherent with other previous studies. The Delft study considers a fuel tax of 0.333 €/L but it was applied only to European international flights, with a 10% increase in the average ticket price, 11% decline in passenger demand, and 27 billion Euros for the year of application.

4.2. Impact on Operational Costs and the Activity of the Air Transport Industry

A tax of fuel of €0.33 per liter (€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 lead to a 72% increase in the price of fuel with respect to the prices in 2019. Global fuel consumption by commercial airlines reached an all-time high of 161.5 billion Euros of fuel cost in 2019 (96 billion gallons at a 0.55 €/kg means). Since fuel is 23.5% of airlines' total expenditure, operational costs of airlines for the same year are estimated at 687.5 billion of euros [27]. The application of the proposed tax might cause an increase of the percentage of fuel in the total expenditure of the airlines, higher than the levels in 2012 (rough calculation led to 40%). That could mean a decline in air transport activity to levels much worse than those of 2012/2013. Although 0.33 €/L has been proposed at the European level as a 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 detrimental for European aviation and cause a significant loss of competitiveness against other regions of the world.



	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030
Demand [Bill PRKS] "do nothing"	8490.8822	8890.7092	9310.6286	9751.6997	10215.039	10701.826	11213.3	11,750.774	12,315.628	12,909.319
Demand [Bill PRKS] 0.33€/L Fuel Tax	7426.9718	7779.1012	8149.0265	8537.6899	8946.085	9375.2597	9826.3195	10,300.43	10,798.822	11,322.792
Fuel consumption [Bill KG] "do nothing"	311.69485	326.1879	341.39867	357.36448	374.12463	391.72057	410.19596	429.59684	449.97171	471.37174
Fuel consumption [Bill KG] 0.33€/L Fuel Tax	270.7549	283.19005	296.24366	309.94799	324.33704	339.44667	355.31465	371.98081	389.48715	407.87793
CO2 emissions [Bill KG] "do nothing"	981.83879	1027.4919	1075.4058	1125.6981	1178.4926	1233.9198	1292.1173	1353.23	1417.4109	1484.821
CO2 emissions [Bill KG] 0.33€/L	852.87793	892.04866	933.16752	976.33616	1021.6617	1069.257	1119.2411	1171.7396	1226.8845	1284.8155

	2031	2032	2033	2034	2035	2036	2037	2038	2039	2040
Demand [Bill PRKS] "do nothing"	13,533.386	14,189.451	14,879.223	15,604.507	16,367.21	17,169.339	18,013.015	18,900.475	19,834.081	20,816.323
Demand [Bill PRKS] 0.33€/L Fuel Tax	11,873.709	12,453.018	13,062.242	13,702.989	14,376.955	15,085.931	15,831.806	16,616.574	17,442.339	18,311.323
Fuel consumption [Bill KG] "do nothing"	493.85083	517.46584	542.27668	568.34657	595.74212	624.53362	654.79515	686.60486	720.04517	755.20302
Fuel consumption [Bill KG] 0.33€/L Fuel Tax	427.19983	447.50207	468.83653	491.25795	514.82404	539.59566	565.63702	593.01582	621.80349	652.07537
CO2 emissions [Bill KG] "do nothing"	1555.6301	1630.0174	1708.1716	1790.2917	1876.5877	1967.2809	2062.6047	2162.8053	2268.1423	2378.8895
CO2 emissions [Bill KG] 0.33€/L	1345.6795	1409.6315	1476.8351	1547.4625	1621.6957	1699.7263	1781.7566	1867.9998	1958.681	2054.0374

	2041	2042	2043	2044	2045	2046	2047	2048	2049	2050
Demand [Bill PRKS] "do nothing"	21,849.831	22,937.381	24,081.902	25,286.485	26,554.395	27,889.075	29,294.163	30,773.498	32,331.133	33,971.347
Demand [Bill PRKS] 0.33€/L Fuel Tax	19,225.868	20,188.451	21,201.682	22,268.319	23,391.273	24,573.617	25,818.594	27,129.631	28,510.343	29,964.55
Fuel consumption [Bill KG] "do nothing"	792.17009	831.04311	871.92411	914.92072	960.1465	1007.7212	1057.7714	1110.4303	1165.8386	1224.145
Fuel consumption [Bill KG] 0.33€/L Fuel Tax	683.91093	717.39402	752.61311	789.66152	828.63772	869.64562	912.79487	958.20117	1005.9866	1056.2801
CO2 emissions [Bill KG] "do nothing"	2495.3358	2617.7858	2746.5609	2882.0003	3024.4615	3174.3219	3331.9798	3497.8553	3672.3917	3856.0567
CO2 emissions [Bill KG] 0.33€/L	2154.3194	2259.7912	2370.7313	2487.4338	2610.2088	2739.3837	2875.3039	3018.3337	3168.8578	3327.2822

Figure 2. Overall results of a 0.33 €/L fuel tax.

4.3. 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 that this tax could be applied globally. Figure 3 illustrates how 70% of the reduction in CO_2 emissions will be produced by aviation with origins in just four 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 to the implementation of the tax in order to obtain a significant CO_2 savings. A worldwide agreement less than that could lead to an insignificant CO_2 savings and at the same time produce negative counter effects in the economy, air transport, and tourism for those regions.

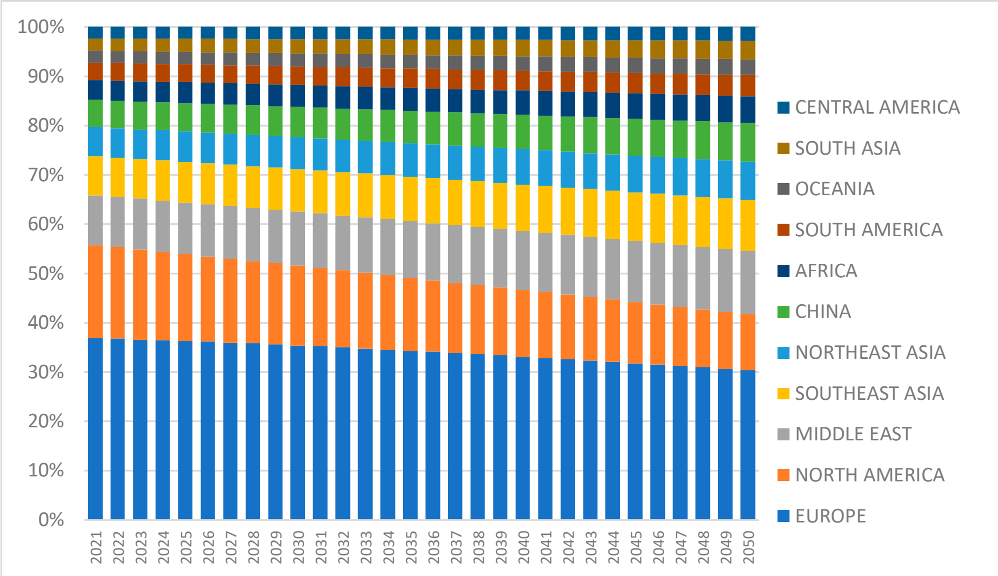


Figure 3. Contribution (in %) of regions to the reduction in CO_2.

Additionally, there is an underlying prevention of one-sided tax policies that would damage local tourism, trade, and domestic carriers, increase import prices, and decrease the demand for exports. If states apply CCL unilaterally, or do not subscribe to an overall agreement, they will be pressured to establish lower rates to defend their economic interests [13,28].

4.4. Impact on Different Markets

The fuel tax may affect the short-, medium-, and long-range markets in different ways. In this regard, two key questions need to be evaluated: Which market is more affected in terms of demand and which market might contribute the most to the CO_2 emissions reduction? Figure 4 illustrates how the demand is reduced in each of the markets in terms of RPKs (revenues passengers per kilometer). It can be appreciated how the biggest reduction takes place in the medium-haul market with an initial reduction of around 634 billion RPKs in 2021 and a final reduction of 2340 billion RPKs by 2050. For the short-haul market, the initial reduction by 2021 is around 260 billion RPKs and by 2050 is around 1007 billion RPKs. For the long-haul market, the reduction is of 316 billion RPKs by 2021 and of 1225 billion RPKs by 2050. On average it means an 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 5 shows how each market contributes to the global reduction of CO_2. It can be observed that the biggest reduction of CO_2 is expected in the medium-haul market, which will account for 49.5% of the total reduction with 68 billion Kg CO_2 by 2021 and 252 billion Kg CO_2 by 2050. The short-haul market accounts for 20.5% of the global reduction with 28 billion Kg CO_2 by 2021 and 109 billion Kg CO_2 by 2050. The medium-haul markets accounts for 30% of the global reduction with 41 billion Kg CO_2 by 2021 and 161 billion Kg CO_2 by 2050.

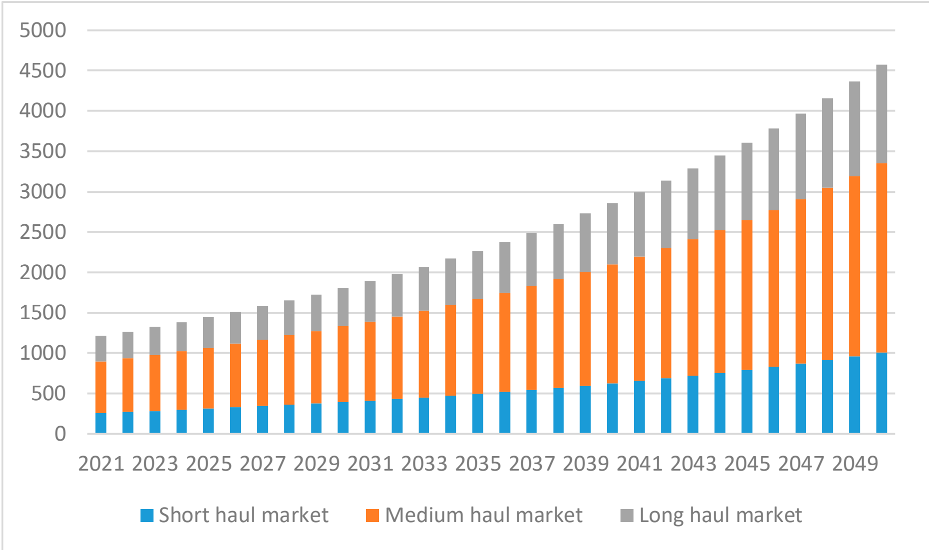


Figure 4. Reduction in demand for short-, medium-, and long-haul markets.

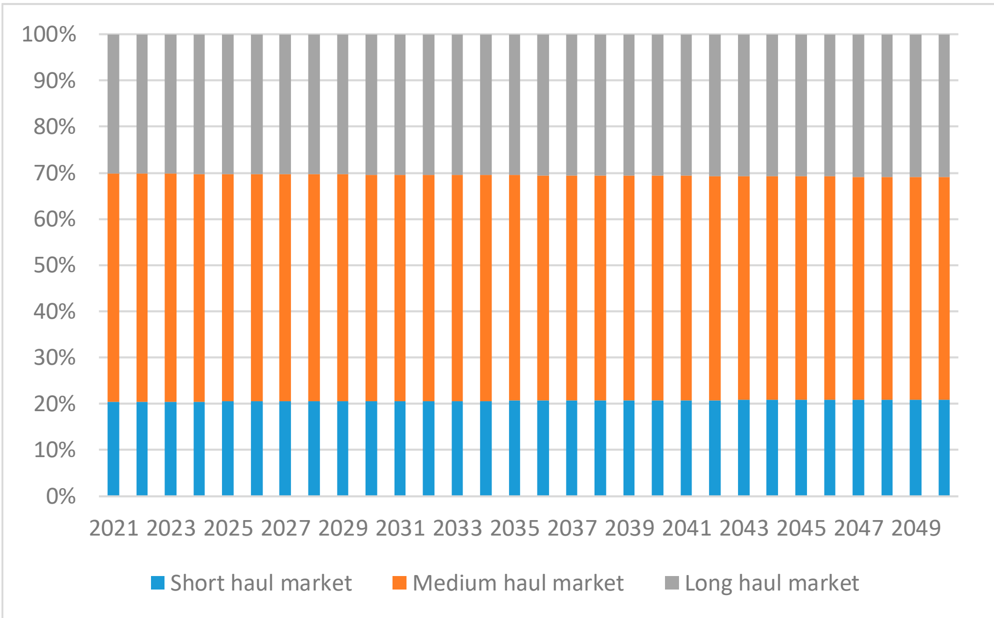


Figure 5. Contribution of each market, in percent, to the global CO_2 reduction.

4.5. Generation of the Marginal CCL Curves

As discussed in the previous sections, a fuel tax of 0.33 €/L applied worldwide will cause a very high increase in the price of fuel. At the same time there is no agreement among the different sources and studies of what might be the optimum value for such a tax; this figure varies 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 solve this problem, we constructed marginal curves that represent the effects on demand and CO_2 for different values of a global fuel tax, ranging from 0 to 500 €/tonne of fuel in intervals of 25 €/tonne. The value of 400 €/tonne (333 €/KL) is the tax equivalent to the excise of duty study that served for comparison in the previous analysis (Figures 6 and 7).

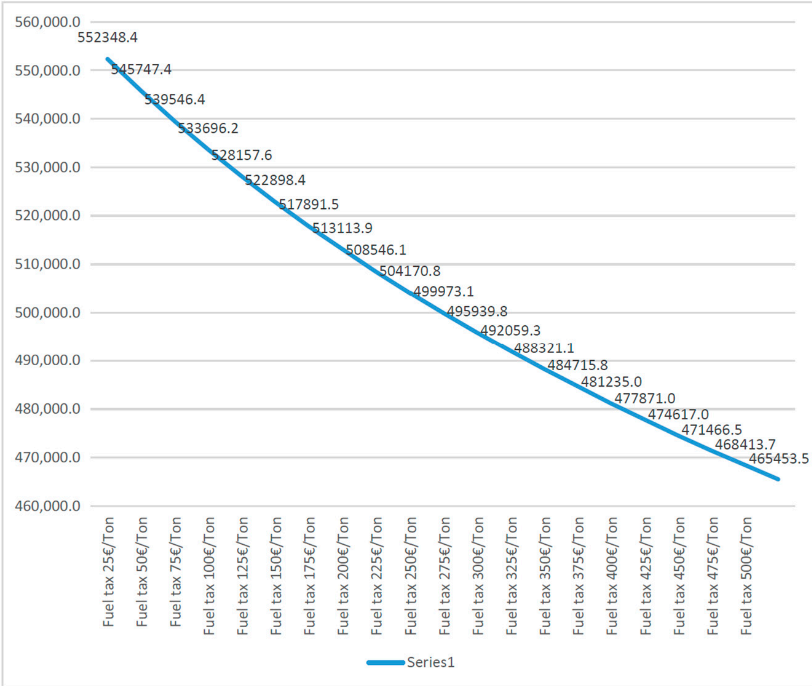


Figure 6. Accumulative demand during the period 2021–2050 in billions of revenue passengers kilometers (RPKs) for different values of the fuel tax.

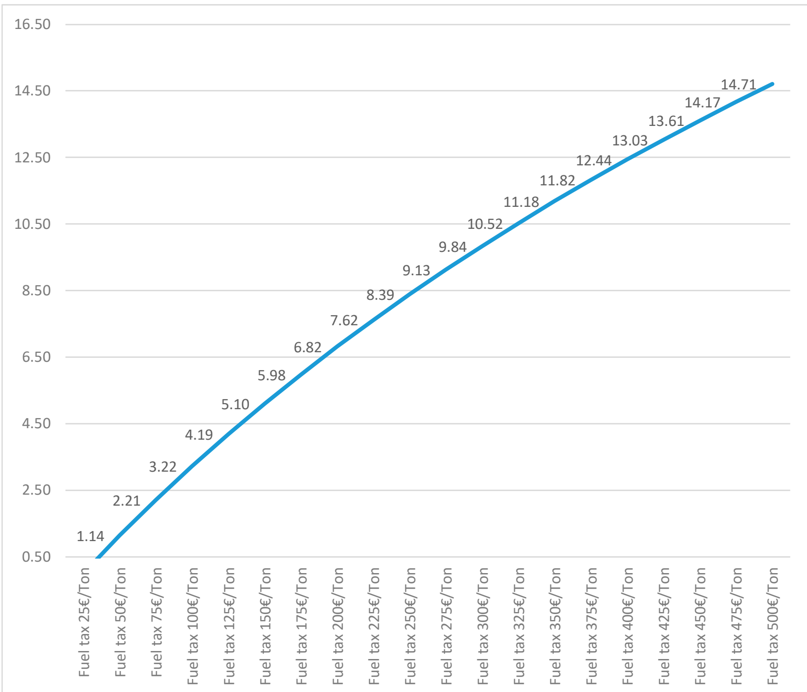


Figure 7. Fuel tax marginal curve: accumulative percent reduction in demand for the period 2021–2050 expressed in billions of RPKs for increments of 25 €/tonne in the fuel tax.

By expressing this information in accumulative percentages we obtain the marginal CCL curves in Figure 8, which give straightforward percentage reductions for the world-wide demand in the period 2021–2050 for any given tax. This marginal curve can be used as the criteria for design. Similar tools can be constructed for each region in the world or for each market segment (short-, medium-, or long-haul). Similar tools are provided for fuel consumption and CO^2 emissions (Figure 9).

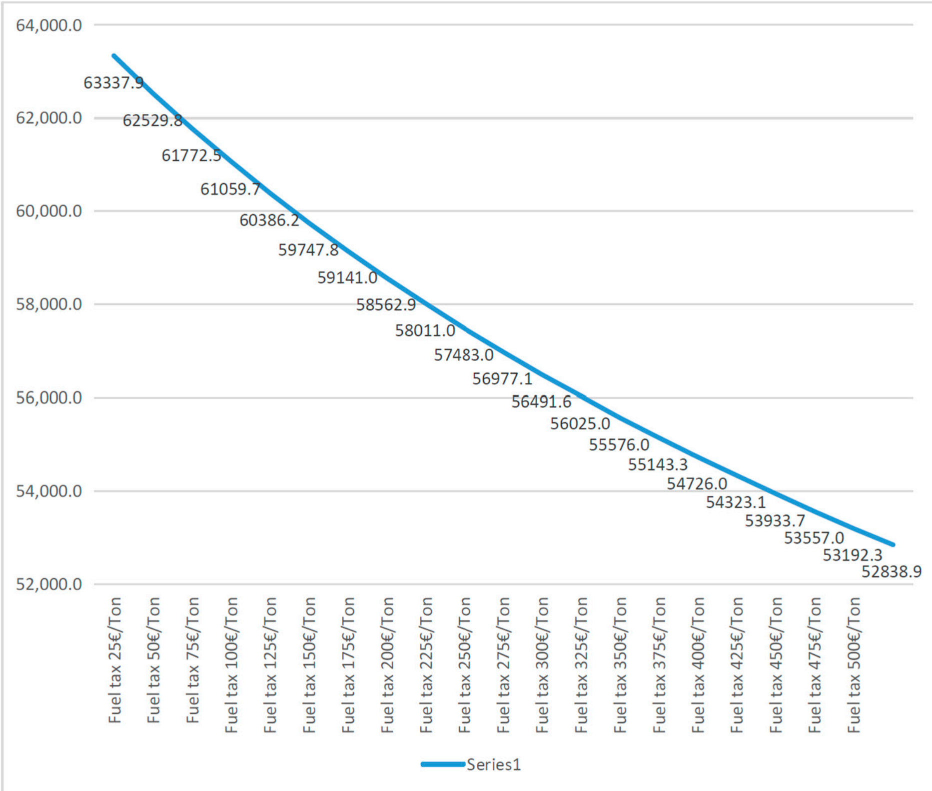


Figure 8. Accumulative fuel consumption during the period 2021–2050 in billions of Kg for different values of the fuel tax.

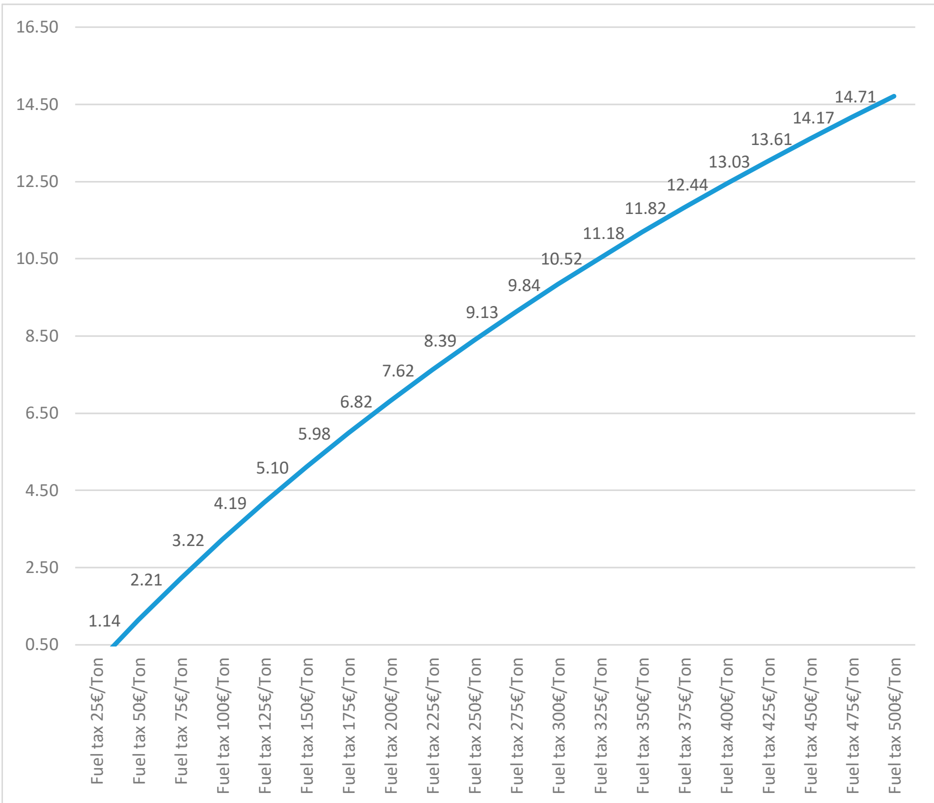


Figure 9. Fuel tax marginal curve: accumulative percent reduction in fuel consumption for the period 2021–2050 expressed in billions of Kg for increments of 25 €/tonne in the fuel.

5. Conclusions

Market-based measures, including climate change levy (CCL) schemes, are instruments designed to address the climate impact of aviation, beyond what operational and technological measures or sustainable aviation fuels can achieve. They are part of the comprehensive approach needed to reduce aviation's CO_2 emissions, as technological and operational measures alone are currently not sufficient to tackle the growing impact of the aviation sector on climate change. These indirect regulatory instruments influence actors' behavior by changing their economic incentive structure. Costs from environmental externalities, such as CO_2 emissions, are usually not reflected in consumption or investment decisions, but are nonetheless imposed on third parties. Putting a price on CO_2 emissions is important to harness market forces and achieve cost-effective emission reductions. Therefore, these types of policies work by reflecting the environmental impact of a certain action by attaching a cost to it, to signal and provide an incentive to the polluter to reduce this impact.

Although CCL is generally recognized as positive, there is no clear agreement on what is the most convenient type of tax, what should be its value, and what would be the expected impacts. Under different considerations of the price elasticity of aviation, certain authors have recently proposed different tax values between 25 and 150 €/tonne CO_2.

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 analyzed by developing a model to generate CCL marginal tax curves and study the effect of CCLs on changing demand for air travel and CO_2 emissions. In this study, we complement the available information by gathering analytics and insights to answer the question of how taxing CO_2 emissions (climate change levy schemes) will lead to significant changes in the aviation industry, including aviation demand, industry and markets structure, and emissions reduction.

We have produced CCL marginal curves that help to understand how taxing will affect aviation demand, markets structure, and emission reduction. We have illustrated the applications of the model to answer some questions about CCL implementation not broadly tackled in the previous works available in the literature, using a fuel excise duty on kerosene (0.33 €/L) as an example for comparative reasons.

Carbon taxes are a type of Pigouvian tax, this type of tax seeks to correct a negative or positive externality, in this case, the decarbonization of aviation. Therefore, the imposition of carbon taxes would increase the price of a flight, which could lead to a reduction in demand. In order to be environmentally effective, air traffic taxes should provide incentives for:

- Reducing fuel consumption and therefore pollution using more reliable aircraft.
- Shift the fuel mix to less emission-intensive sources.
- Optimize aircraft loads and thus decrease fuel consumption and emissions per passenger as well as reduce the number of flights.
- Avoid very short and very long distances.

Environmental effectiveness also depends on the susceptibility of the tax to fiscal competition and the possibilities of passengers and carriers avoiding it by flying from or by tanking in low or no-tax countries. The various aviation tax choices vary in their ability to set certain incentives. Introducing a carbon tax in the purchase of airline tickets will differently impact passenger demand in developing countries and those in non-developed countries, which means that countries would have to establish a tax at an appropriate level according to their economic circumstances.

In this context, a carbon fuel tax would reduce flight demand and supply and it can also be expected to contribute to aircraft load optimization. For the period 2021–2050, the application of the a fuel tax of 0.333 €/L will lead to a global 12% reduction of demand, as well as a reduction of 13% of fuel and CO_2 produced with respect to the do-nothing scenario. Additionally, the overall fiscal revenue obtained from the tax application is estimated to be €108 billion in 2021 and increase progressively up to €422 billion in 2050.

However, a tax of fuel of €0.33 per liter (€0.4 per kg) will cause a considerable increase in the price of fuel. As of January 2020, the price of Jet A1 was approximately $650 per metric tonne. This equates to about $0.65 per Kg or €0.55 per Kg. The €0.4 per Kg will lead to a 72% increase in the price of fuel with respect to the prices in 2019. The application of the proposed tax might lead to an increase of the percentage of fuel in the total expenditure of the airlines, higher than the levels in 2012 (rough calculation led to 40%). That could mean a decline in air transport activity to levels much worse than those of 2012/2013.

An aviation CO_2 tax would only be effective in reducing demand if it is common and equal among countries, as airlines could change their operational behavior to remain competitive. Seventy percent of the reduction in CO_2 emissions will be produced by aviation with origins in just four regions: Europe, North America, Middle East, and Southeast Asia. By 80/20 Pareto's law, the 20% of the regions that generates 80% of the traffic, should agree to the implementation of the tax for a significant CO_2 saving. Extensive cooperation is therefore required in designing and implementing international transportation fuel charges to avoid revenue erosion and distortions.

The main drawback to the use of taxes as a global climate policy instrument is the need for consensus between States regarding their introduction, as well as the detailed policy design, e.g., tax rates and tax bases. There are systematic differences between countries/regions in terms of economic development and how they address environmental concerns. More developed countries share a strong awareness of the risks derived from climate change, and they implement stringent environmental regulations. In comparison, developing countries have laxer environmental regulations, especially in terms of carbon emissions. These differences risk the generation of an internationalization of the value chains of pollution-intensive industrial production, known as the "pollution haven hypothesis" (PHH) or "carbon leakage". Pollution haven conjecture has been assessed in recent studies as a key issue in the effectiveness of global climate change measurements [29,30]. Global implementation of the tax is expected to also consider the possible negative effects for developing countries. Compensating developing countries for the economic harm they might suffer from such charges—ensuring that they bear "no net incidence"—is widely recognized as critical to their acceptability. However, compensation might also exacerbate carbon leakage problems.

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