

On behalf of:



Federal Ministry
for the Environment, Nature Conservation
and Nuclear Safety

of the Federal Republic of Germany

giz Deutsche Gesellschaft
für Internationale
Zusammenarbeit (GIZ) GmbH



PtX.Aviation Calculator Documentation

Version 2.0.0

International PtX Hub Berlin
May 27, 2022

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Imprint

This Calculator on PtX.Aviation is published by the PtX Hub. The PtX Hub is commissioned by the German Federal Government. It is mainly funded by the International Climate Initiative (IKI) and implemented by GIZ (Deutsche Gesellschaft für Internationale Zusammenarbeit GmbH). The opinions and recommendations expressed do not necessarily reflect the positions of the commissioning institutions or the implementing agency.

The paper builds on the expertise and input of many experts of the PtX Hub and GIZ. We would in particular like to recognise and Charlotte Hussy and Lukas Peiler. We are grateful for the valuable inputs and comments received from a multitude of experts and colleagues.

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1 Introduction

This text documents the methodology and technical details of the PtX.Aviation Calculator from the International PtX Hub Berlin. The calculator is available to users free of charge at [this link](#).

The chapter [Flow of data](#) describes the general structure and data flow of the calculator. The chapter [Assumptions, Calculations and Sources](#) describes the different assumptions, underlying calculations and sources.

If you have any further questions that cannot be answered in the documentation, please do not hesitate to [contact us](#).

1.1 Abbreviations & Units

- m —————→ million
- bn —————→ billion
- km —————→ Kilometre
- m² —————→ Squared metre
- km² —————→ Squared kilometre
- h —————→ hour
- kWh —————→ Kilowatt-hour
- MWh —————→ Megawatt-hour
- GWh —————→ Gigawatt-hour
- TWh —————→ Terawatt-hour
- kW —————→ Kilowatt
- MW —————→ Megawatt
- GW —————→ Gigawatt
- TW —————→ Terawatt

2 Flow of data

The aim of the calculator is to show in a transparent way the environmental impact of the use of synthetic kerosene in passenger aviation. For this purpose, the calculator is divided into two parts, *Input* and *Output*. In the segment *Input*, the amount of kerosene per time unit to be produced synthetically is determined. In the segment *Output*, various environmental influences of the determined quantity are displayed.

2.1 Input

In order to better visualise the magnitude of the kerosene demand of passenger aviation, own routes or example routes / predefined scenarios can be selected.

2.1.1 Custom routes

The option *Custom routes* offers the possibility to choose customized flight routes. To do so, start and destination can be selected using the search fields and the drop-down lists. The resulting distance appears underneath. If the option *Custom routes* is chosen, further parameters can be selected.

Passengers approximately: In the *Passengers approximately* field, a choice can be made between the demand of kerosene for a single person or an entire aircraft. This option is preset to *Single passenger*.

Quantity of flights: In the field *Quantity of flights* the frequency of the flight can be set. This option is preset to *Once per year*. This is particularly important for the necessary production capacities and the area required for renewable energies, as this calculation requires a temporal component.

Year of prognosis: In the field *Year of prognosis* the year of the prognosis can be selected. Accordingly, the demand for kerosene changes, as an improvement in the efficiency of the aircraft is assumed. In addition, the forecast costs change.

2.1.2 Example routes/scenarios

The option *Custom routes* offers the possibility to choose example routes or predefined scenarios from the drop-down list. Further explanation to the example routes or predefined scenarios can be found in the description of the different options within the list and under the source link given in the description. After the selection, the amount of kerosene consumed in the selected option is shown.

2.1.3 Blend

In the segment *Blend*, the percentage with which fossil kerosene is to be replaced by synthetic kerosene can be specified.

After all parameters have been determined, the necessary amount of synthetic kerosene per selected time unit is obtained. This value is the initial value for the further calculation.

2.2 Output

The output calculations are based on the amount of kerosene to be produced synthetically.

2.2.1 Energy

To compare the energy required to produce synthetic kerosene and ultimately bound up in the fuel, these different amounts of energy are listed here. Based on the amount of kerosene, the following results are calculated:

Energy content in PtL: The amount of energy contained in the synthetically produced kerosene is displayed.

Energy needed for production of PtL: The amount of energy used to produce the kerosene is displayed.

Capacities: The production capacities that have to be provided for the production of the kerosene within the given time unit are displayed. The capacities are calculated from the amount of kerosene and the full load hours of the renewable energy source.

2.2.2 Costs

The composition of the fuel costs for the flight / scenario depends on the selected blend in the *Input* segment. In addition, the specific fuel costs vary due to a change in the year of prognosis.

Total costs for fuels: A breakdown of the composition of fuel costs is shown and differences are calculated. Depending on the location of start and destination of the chosen route / scenario, costs for taxes and costs for certificates might apply. The field *Additional Costs through PtL* calculates the difference between the current costs and the costs for a 100% supply of fossil kerosene.

Graphs: In order to provide a better overview of the differences, a graphical presentation of the specific prices is available.

Calculation: Furthermore, the calculator offers the possibility to view the calculations of the costs. These change dynamically with changes in the parameters.

2.2.3 Resources

Based on the amount of kerosene required and the amount of energy needed to produce the kerosene, the resource consumption can be calculated.

Land Usage: Based on the amount of energy required to produce kerosene and the power characteristics of the renewable energy source, the land consumption is calculated. It is possible to change the power characteristics of the renewable energy source in the segment *Location of Renewable Energy*.

Direct water usage: Based on the amount of kerosene required, the direct water consumption for the production of kerosene can be calculated.

Total CO₂ consumption: The total CO₂ consumption is the difference between local CO₂ emissions and captured CO₂ for production of PtL.

Comparison: In order to better visualise the land consumption, the required area is projected onto a map. The location of the map changes dynamically with the location of the renewable energy source.

3 Assumptions, Calculations and Sources

In the following chapter, all calculations and its assumptions used in the Calculator are shown and explained.

3.1 Input

3.1.1 Distance for Custom Routes

The distance between two given airports is calculated with the formula of the [great-circle distance](#)¹. To capture normal deviations from the ideal route, 2% is added to the great-circle-distance. In addition, a flat rate of 50 kilometres per flight is added to account for take-off and landing loops. The values are taken from a comparison of the calculated distances with distances actually flown from example flights with data from [FlightAware](#)².

- GCD = Great-circle-distance
- D = Overall distance
- R = Mean earth radius ≈ 6371 km
- φ_1 = Latitude start
- λ_1 = Longitude start
- φ_2 = Latitude destination
- λ_2 = Longitude destination

$$GCD = 2R \arcsin \sqrt{\sin^2 \frac{\varphi_1 - \varphi_2}{2} + \cos \varphi_1 \cos \varphi_2 \sin^2 \frac{\lambda_1 - \lambda_2}{2}}$$

$$D = GCD * 1.02 + 50 \text{ km}$$

The maximum distance is 12,000 km. For longer flights, there was not enough information about kerosene consumption. The minimum distance is 100 km. For shorter flights, no accurate average values for kerosene consumption could be found.

¹<https://undergroundmathematics.org/trigonometry-compound-angles/the-great-circle-distance>

²<https://de.flightaware.com/>

3.1.2 Settings for Custom Routes

Passengers approximately: A distinction can be made between a single passenger or an entire aircraft. The following values are used:

- Distance of flights \leq 3500 km:
 - Single passenger: 1
 - Airplane: 150
- Distance of flights $>$ 3500 km:
 - Single passenger: 1
 - Airplane: 250

These values are taken from an analysis of different aircraft models, their capacities and their typical operational routes with data from [FlightAware](#)³. The number of passengers can be changed as desired under [Changing assumptions](#).

Quantity of flights: The following frequencies of flights are possible:

- Once per day
- Once per week
- Once per month
- Once per year

Year of prognosis: The following years can be selected for the prognosis:

- 2021
- 2022
- 2023
- 2025
- 2030
- 2035
- 2040
- 2045
- 2050

Starting in 2021, a [1.5% improvement](#)⁴ in fuel efficiency is assumed.

In addition to specific kerosene consumption, costs, taxes and certificate prices also change with the year of prognosis.

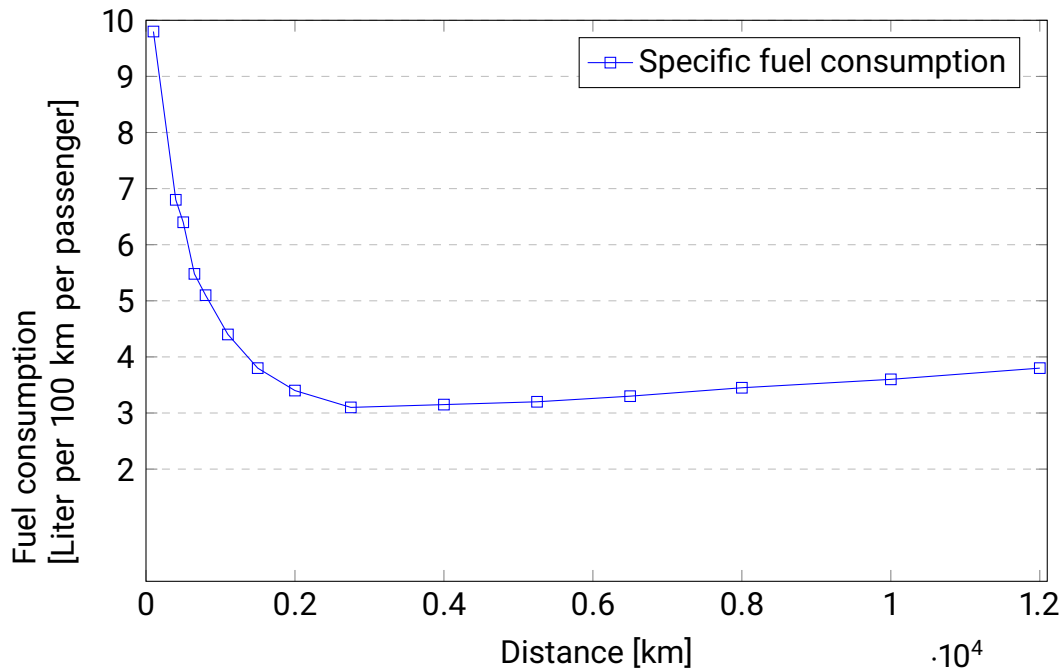
³<https://de.flightaware.com/>

⁴<https://www.iata.org/en/programs/ops-infra/fuel/fuel-efficiency/>

3.1.3 Fuel consumption for Custom Routes

Based on the distance between the start and destination of the custom route, the specific kerosene consumption per person can be calculated.

Specific fuel consumption per passenger over distance of flight



The graph "Specific fuel consumption per passenger over the flight route" shows the specific consumption on a scale from 100 km to 12000 km. The data is sourced from the world's largest airlines, such as [Lufthansa](#)⁵. By interpolation between the given data points the fuel consumption per 100 km per passenger for the given flight route can be obtained.

The resulting fuel consumption per 100 km per passenger can be changed under [Changing assumptions](#).

3.1.4 Fuel consumption for Example Routes / Scenarios

In most cases, the CO₂ emissions of the present scenarios were taken as the source and calculated back to kerosene consumption using a [stoichiometric reaction equation](#)⁶. Sources are given within the entry of the list and can be opened by clicking the link.

- FC = Fuel consumption

⁵<https://www.lufthansagroup.com/media/downloads/de/verantwortung/LH-Factsheet-Nachhaltigkeit-2020.pdf>

⁶<https://www.klimaschutz-portal.aero/glossar/kohlenstoffdioxid/>

- E = CO₂ emissions
- SC = Stoichiometric coefficient = $2,5 \frac{l(\text{Kerosene})}{kg(\text{Emissions})}$

$$FC = \frac{E}{SC}$$

3.1.5 Settings for Example Routes / Scenarios

Passengers approximately: The function is disabled because the amount of kerosene is already determined.

Quantity of flights: The function is disabled because the time unit (year) is already determined.

Year of prognosis: The following years can be selected for the prognosis:

- | | |
|--------|--------|
| • 2022 | • 2035 |
| • 2023 | • 2040 |
| • 2025 | • 2045 |
| • 2030 | • 2050 |

Costs, taxes and certificate prices change with the year of prognosis.

3.1.6 Blend

The fuel consumption can be determined by calculating the data of the Custom Route or by the data of the Example Route / Scenario. The "Blend" slider can be used to determine what percentage of this fuel consumption should be replaced by synthetic kerosene. The following values have a significant meaning:

- 2% : Proposal of the [ReFuelEU Aviation](#) from 2025 onwards.
- 5% : Proposal of the [ReFuelEU Aviation](#) from 2030 onwards.
- 20% : Proposal of the [ReFuelEU Aviation](#) from 2035 onwards.
- 32% : Proposal of the [ReFuelEU Aviation](#) from 2040 onwards.
- 38% : Proposal of the [ReFuelEU Aviation](#) from 2045 onwards.
- 50% : At this moment, there are no air crafts certified to fly with a higher blend than 50%.
- 63% : Proposal of the [ReFuelEU Aviation](#) from 2050 onward.

3.2 Energy

In the following, all energy-related data are listed and their assumptions are mentioned and clarified:

Energy content of replaced kerosene: The amount of energy contained in the substituted kerosene is displayed. This figure refers to the LHV, which according to [Xu et al.](#)⁷ is given as 9.6 kWh / litre.

Energy needed for production of PtL: The amount of energy used to produce the kerosene is displayed. This value includes the following production steps according to [Beccatini et al.](#)⁸. The energy consumption of the individual production steps was projected in each case to the quantity required for the production of 1 litre of PtL:

Electrolysis for the production of H₂: 12 kWh/liter PtL

This includes only the H₂ that is bound up in the fuel according to [Sunfire](#)⁹.

Capture of CO₂: 6 kWh/liter PtL

This value refers to [direct air capture](#)¹⁰.

Reduction of CO₂: 8.8 kWh/liter PtL

The method for the CO₂-reduction is the Reverse Water Gas Shift Reaction with an energy consumption according to [Vidal et al.](#)¹¹

Further production processes: 1 kWh/liter PtL

This includes the energy needed for supporting steps such as pumping.

3.2.1 Capacities

Required capacities are calculated according to the following formula:

- RC = Required capacity in Power
- QF = Quantity of flights in Quantity/Hours

⁷https://web.stanford.edu/group/haiwanglab/HyChem/approach/Report_Jet_Fuel_Thermochemical_Properties_v6.pdf

⁸<https://pubs.acs.org/doi/10.1021/acs.iecr.0c05392>

⁹<https://www.sunfire.de/de/news/detail/erfolgreiche-inbetriebnahme-des-weltweit-groesst>

¹⁰https://www.dena.de/fileadmin/dena/Dokumente/Pdf/9219_E-FUELS-STUDY_The_potential_of_electricity_based_fuels_for_low_emission_transport_in_the_EU.pdf

¹¹<https://www.sciencedirect.com/science/article/abs/pii/S2212982018305213?via%3Dihub>

- *FLH* = Full-load hours of source of renewable energy per year
- *RP* = Required product e.g. work of electrolysis

$$RC = RP * QF * FLH / 8760h$$

Please refer to [3.4.1](#) for details on the full-load hours.

3.2.2 Comparison

The comparison shows the distance that an electric vehicle can cover when powered with the same energy used for the production of PtL. To enable a fair comparison, a 100% blend of PtL for the flight / scenario was assumed for the calculation. It is assumed that the electric vehicle consumes [15 kWh per 100 km¹²](#). The energy consumption of electric vehicle can be changed under [Changing assumptions](#).

To match the number of passengers that are used in the calculation for the kerosene usage the number of cars are adjusted. When choosing an *Example Tour/Scenario* the number of cars is set to 1 million.

¹²https://theicct.org/sites/default/files/publications/ICCT_LitRvw_EV-tech-costs_201607.pdf

3.3 Costs

The costs are calculated on the basis of the composition of the kerosene. It is important to note that prices are quoted per flight and not per time unit. The price for synthetic kerosene is based on [this study](#)¹³ and [this study](#)¹⁴. The price for fossil kerosene is based on [this study](#)¹⁵.

All flights that start and land on european airports are considered for taxes and certificates. Taxes are assumed according to the [ReFuelEU Aviation](#). The prices for certificates are based on an own estimate. Scenarios that include worldwide flights and thus include Intra-EEU-flights as well are excluded of taxes and certificates.

All prices can be changed in [Changing assumptions](#). The following overview shows the prices assumed for the selectable years:

Year	Production		Levies on fossil Kerosene	
	fossil Kerosene	synthetic Kerosene	Taxes	CO ₂ -Certificates
2021	0.50 € / liter	2.33 € / liter	0.00 € / liter	0.01 € / liter
2022	0.87 € / liter	2.3 € / liter	0.00 € / liter	0.11 € / liter
2023	0.89 € / liter	2.27 € / liter	0.00 € / liter	0.13 € / liter
2025	0.92 € / liter	2.20 € / liter	0.074 € / liter	0.16 € / liter
2030	1.01 € / liter	2.04 € / liter	0.26 € / liter	0.23 € / liter
2035	1.09 € / liter	1.84 € / liter	0.371 € / liter	0.23 € / liter
2040	1.14 € / liter	1.64 € / liter	0.371 € / liter	0.23 € / liter
2045	1.19 € / liter	1.52 € / liter	0.371 € / liter	0.23 € / liter
2050	1.24 € / liter	1.42 € / liter	0.371 € / liter	0.23 € / liter

The following calculations are given:

Total costs for fuels: Total costs of fuel including production and levies for the given blend.

Costs of production:

Prize for fossil Kerosene: Costs of production for the share of the fossil kerosene

¹³https://www.transportenvironment.org/wp-content/uploads/2021/08/2021_08_TE_study_efuels_DACCS.pdf

¹⁴<https://de.statista.com/statistik/daten/studie/253739/umfrage/prognostizierte-entwicklung-des-heizoelpreises-in-deutschland/>

¹⁵<https://www.eia.gov/analysis/projection-data.php#annualproj>

Taxes for fossil Kerosene: Costs of taxes for the share of the fossil kerosene

Certificates for fossil Kerosene: Costs of certificates for the share of the fossil kerosene

Costs for PtL: Costs of production for the share of the synthetic kerosene

Additional Costs through PtL: Difference between the current total costs and the total costs for 100% fossil kerosene.

3.3.1 Graphs

The graph *Prices in the year 20.. per liter:* shows a comparison of the prices for PtL and fossil kerosene for the chosen year. The graph *Development of prices per liter:* shows an overview of the prices for PtL and fossil kerosene until 2050.

3.3.2 Calculation

The calculations are shown as a formula and as a calculation with the actual values used. The values change dynamically with changes in the input parameters.

3.4 Resources

The following formulas are used for the calculations in the *Resources* section:

Land Usage

- LU = Land Usage
- RE = Required Energy for production of PtL
- TU = Time Unit
- LD = Density of location of renewable energy
- FLH = Full-load hours of source of renewable energy per year

$$LU = \frac{RE * year / TU}{LD * FLH}$$

Direct Water Usage

The water consumption was taken from [this source](#)¹⁶.

- OWC = Overall water consumption
- PtL = PtL Consumption per flight
- WC = Water consumption in production of PtL = 3.85 l Water / l PtL

$$OWC = PtL * WC$$

CO₂ Consumption

The CO₂ consumption was calculated stoichiometrically using the [stoichiometric reaction equation](#).

- PtL = PtL Consumption per flight
- CC = CO₂ consumption in production
- SC = Stoichiometric coefficient = $2,5 \frac{l(Kerosene)}{kg(Emissions)}$

$$CC = PtL * SC$$

¹⁶https://www.umweltbundesamt.de/sites/default/files/medien/376/publikationen/background_paper_power-to-liquids_aviation_2022.pdf

3.4.1 Location of Renewable Energy

The location and type of source of renewable energy influences the required capacities through the full load hours and the consumption of space through the power density. The following locations with corresponding values are available for selection:

Photovoltaics, Global Average:

Density: ca. 40 MW / km²

Full-load-hours: ca. 2,000 h / year

[Source¹⁷](#)

Wind Offshore, Germany (Hohe See):

Density: ca. 11,8 MW / km²

Full-load-hours: ca. 4,100 h / year

[Source¹⁸](#)

Photovoltaics, Egypt (Benban Solar Park):

Density: ca. 44,6 MW / km²

Full-load-hours: ca. 2,300 h / year

[Source¹⁹](#)

Wind Onshore, Argentina (Santa Cruz):

Density: ca. 15 MW / km²

Full-load-hours: ca. 5,500 h / year

[Source](#)

Photovoltaics, South Africa (Northern Cape):

Density: ca. 40 MW / km²

Full-load-hours: ca. 1,700 h / year

[Source](#)

¹⁷<https://maps.iee.fraunhofer.de/ptx-atlas/>

¹⁸<https://www.enbw.com/erneuerbare-energien/windenergie/unsere-windparks-auf-see/hohe-see/>

¹⁹<https://www.cleanthinking.de/benban-solarpark-drei-millionen-solarmodule-fur-eine-mill>

3.4.2 Comparison

The map shows the land usage of production projected onto the city corresponding to the chosen airport or the source of the renewable energy.

4 Changing assumptions

In the section *Assumptions*, a variety of assumptions can be changed. By clicking the arrow *Assumptions* in the section *Output*, the corresponding page can be opened. By clicking on *Change*, all marked values can be changed. Click on *Reset* to reset all values to the default settings.