Objective Skygreen 2022-2030

The economics of aviation decarbonisation towards the 2030 Green Deal milestone
EXECUTIVE SUMMARY

European aviation is determined to achieve carbon-neutrality by 2050, with the EU proposing an intermediate target of a 55% reduction by 2030 compared to 1990 levels. This Report assesses what this would mean for aviation in practical terms, looking at the various strategies – new technologies, implementation of the Single European Sky as well as other operational improvements, increased production and uptake of sustainable aviation fuel (SAF) – and their cost. We find that merely reducing flying is not the solution: reducing emissions by the required amount is possible, but will require investment, and that needs a buoyant aviation sector. We also outline a number of additional options that could further accelerate Europe’s aviation decarbonisation journey.

This report provides answers to the following questions:

1. With Sustainable Aviation Fuels (SAFs) currently costing up to six times that of kerosene, exactly how much extra will flying with 4%, 5% or 10% SAF add to airlines’ operating costs by 2030 – and how does that balance against rising taxes on kerosene by 2030?
2. How will the phasing out of aviation’s free emissions allowances from 2024 onwards impact airline balance sheets?
3. By how much can industry-driven responses (fleet renewal, new technology, operational improvements, increased SAF usage) contribute to achieving the 55% reduction target?
4. Which decarbonisation pathways have the greatest potential to drive emissions reduction as quickly and as cost-effectively as possible?
5. Could policymakers take additional measures that would further accelerate decarbonisation?

In our analysis, we apply the three traffic scenarios – High, Base and Low – developed in our recent EUROCONTROL Aviation Outlook 2050, and provide a first estimate of the extra costs and implications of the various regulatory and industry-driven decarbonisation proposals for each scenario.

KEY FINDINGS OF THIS REPORT

1. A 55% CO₂ emissions reduction target by 2030 is achievable in ALL scenarios, but this relies heavily on market-based measures.
2. The High scenario with the most traffic is counterintuitively the most efficient to reach net zero emissions by 2050 at lower cost, as higher revenues will drive increased investment in new technology.
3. Policy-driven decarbonisation measures will add €34.8-€62.0 billion in additional costs across the EUROCONTROL Network Manager area over the period 2022-2030 if all industry-led actions are excluded, such as ATM optimisation (including SES), fleet update/renewal, and increased SAF usage…
4. …but applying industry-driven measures can drastically reduce the cost of decarbonisation measures by €32.9 to €45.7 billion over the same period.
5. The most important industry-driven measure is increasing SAF usage; for this to become a reality, the ReFuelEU Aviation initiative is essential in enabling a swift ramp up of SAF production and usage.
6. For the period 2022-2030, the extra cost of a 5% SAF blending share compared to 100% kerosene is estimated to be €10 billion in the base scenario, reaching €21 billion in 2030.
7. Industry-led measures can deliver 13.4%-24.1% of the net emissions savings, depending on the pace of decarbonisation.
8. To reduce CO₂ emissions quicker, airlines should accelerate the pace of fleet renewal by 3-7 years to ensure they operate the most efficient new technology.
9. We need to accelerate aviation decarbonisation by prioritising actions, fostering the transition (e.g. by offering financial support and encouraging alliances), and balancing taxation with the need for aviation to recover.
METHODOLOGY

This report explores the cost of meeting the 55% emissions reduction target by 2030 on the basis of the three traffic scenarios developed in the EUROCONTROL Aviation Outlook 2050 report; it complements in more detail the EUROCONTROL Objective Skygreen Think Paper. The outcomes of this report are heavily based on the wealth of data that EUROCONTROL makes available to our stakeholders, partnerships with OEMs and SAF producers, as well as network, fuel burn/emissions and economic/cost models. The three EUROCONTROL Aviation Outlook 2050 Report scenarios also factor in the speed and scope of industry acceptance of policy measures, and can be summarised as follows:

- **Base scenario:** This assumes moderate traffic growth and uptake of SAFs, in line with ReFuelEU Aviation obligations. In this scenario, taxation of fossil-based fuel will be proportionally high, as a lower volume of SAFs is used.
- **High scenario:** This envisages that SAFs become available (at an economically attractive price), allowing blending of SAFs at percentages higher than current European regulatory requirements. It also assumes more investment in other emissions-reducing technologies before 2030. It shows that, counter-intuitively, increasing flying can lead to more emissions reductions. If the High scenario occurs, the kerosene taxation paid by the industry is likely to be greatly reduced.
- **Low scenario:** This assumes much less breaking of the nexus between flying and emissions. That will result in slower and much less emission reductions.

The report examines the impact on these three scenarios of a number of policy and industry-driven measures. It first considers the extra costs of SAF uptake across the EUROCONTROL Network Manager area, at levels below, in accordance with, and above the ReFuelEU Aviation proposal; increased ETS and CORSIA obligations; and taxation; before showing the positive impact of SES implementation, airspace design, operational changes and new aircraft technology. The policy measures are then re-enforced on the resulting reduced fuel and emissions, involving a recalculation of the differential costs for each scenario.

POLICY INITIATIVES

**SAF: Fundamental to meeting the 55% emissions reduction**

In July 2021 the European Commission published its “Fit for 55” package of legislative proposals to support its interim goal of reducing emissions by 55% by 2030, including the ReFuelEU Aviation initiative. ReFuelEU imposes on fuel suppliers a requirement to blend mandatory minimum volume percentages of SAF at EU airports. The blending obligation commences from 2025 at 2% SAF, gradually increasing to 63% in 2050. The proposal also includes a sub-obligation for synthetic aviation fuels starting in 2030 with 0.7%, and progressively getting to 28% of e-fuels in 2050. To avoid fuel tankering and carbon leakage, an obligation is also placed on aircraft operators to uplift at least 90% of the yearly fuel required at EU airports.

The three scenarios present different SAF blending shares, 5% in the base scenario in 2030, 10% for the High, and 4% in the Low scenario. As noted above, this will require significant technological investment and other developments from SAF suppliers. Depending on the SAF production technology pathways, the range of SAF production costs is from €1,000/tonne to more than €4,500/tonne. SAF is today typically two to six times more expensive than kerosene.

The figure on the next page shows how for the period 2022-2030, the extra costs of SAF compared to 100% kerosene are estimated to be:

- **Base scenario:** €10 billion by 2030, with €2.1 billion in 2030 alone, based on 5% uptake
- **High scenario:** €12.1 billion by 2030, based on 10% uptake
- **Low scenario:** €4.3 billion by 2030, based on 4% uptake

However, these extra costs need to be balanced against the extra costs of the new energy taxation obligations, and the revision of the ETS directive, which applies only to kerosene.

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3. At the point of publication of this report, the impact on traffic (flights and emissions) is currently high for some States adjacent to Belarus, Russia and Ukraine. However, the overall impact on the full European network remains relatively small.

4. The study considers 4 pathways: Hydroprocessed Esters and Fatty Acids (HEFA), Gasification/Fischer-Tropsch, Alcohol to Jet (ATJ) and Power to Liquid (PtL).
The higher the share of SAF, the greater the potential emissions reduction. In 2030, the net CO\(_2\) emissions reduction from SAF blend shares of 10%, 5% and 4% for all flights in the EUROCONTROL Network Manager (NM) area is modelled in the table below, which shows their contribution to achieving the -55% target:

<table>
<thead>
<tr>
<th>2030 EUROCONTROL NM Area</th>
<th>High 10% SAF uptake</th>
<th>Base 5% SAF uptake</th>
<th>Low 4% SAF uptake</th>
</tr>
</thead>
<tbody>
<tr>
<td>Savings from SAF</td>
<td>8.8% emission reduction</td>
<td>4.6% emission reduction</td>
<td>3.9% emission reduction</td>
</tr>
</tbody>
</table>

The extra costs for increasing the share of SAF are relatively low compared to EU-ETS and kerosene taxation costs. Therefore, the ReFuelEU Aviation initiative brings net emissions savings at an affordable cost. Finally, SAF is price-elastic, and the law of supply & demand implies that increasing demand will reduce production costs.

**Ramping up kerosene taxes**

The Revision of the Energy Tax Directive implements the new energy taxation principle that ramps up taxes on kerosene for intra-European flights over a 10-year transition period and applies a zero-minimum rate to SAF. This report assumes the start of the transition period on 1st January 2024\(^5\). The final minimum rate of 10.75€/GJ would be reached by the end of the transitional period, and is fixed at one-tenth per year.

<table>
<thead>
<tr>
<th>% of final minimum rate of taxation</th>
<th>2024</th>
<th>2025</th>
<th>2026</th>
<th>2027</th>
<th>2028</th>
<th>2029</th>
<th>2030</th>
<th>TOTAL 2024-2030</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>10%</td>
<td>20%</td>
<td>30%</td>
<td>40%</td>
<td>50%</td>
<td>60%</td>
<td>70%</td>
<td></td>
</tr>
<tr>
<td>High (€ billion)</td>
<td>€1.07</td>
<td>€2.17</td>
<td>€3.30</td>
<td>€4.42</td>
<td>€5.53</td>
<td>€6.62</td>
<td>€7.79</td>
<td>€30.90</td>
</tr>
<tr>
<td>Base (€ billion)</td>
<td>€1.00</td>
<td>€2.02</td>
<td>€3.07</td>
<td>€4.14</td>
<td>€5.16</td>
<td>€6.20</td>
<td>€7.26</td>
<td>€28.85</td>
</tr>
<tr>
<td>Low (€ billion)</td>
<td>€0.88</td>
<td>€1.88</td>
<td>€2.86</td>
<td>€3.87</td>
<td>€4.78</td>
<td>€5.70</td>
<td>€6.61</td>
<td>€26.58</td>
</tr>
</tbody>
</table>

We estimate that between 2024 and 2030, taxation on kerosene applied to intra-European flights significantly increases aircraft operators’ costs over the period 2022-2030 by an estimated €28.8 billion in the Base scenario, rising to as high as €30.9 billion in the High scenario.

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\(^5\) The revision of the Energy Taxation Directive (ETD), part of the ‘Fit for 5S’ package, is a consultation procedure. It requires unanimity in Council, after consulting the European Parliament. This report assumes 2024 as the first year the EU’s ETD would enter into force in light of the current discussions and approval by the European Parliament and the Council of the EU.
EU ETS Directive revision means no free allowances after 2027

CO₂ emissions from aviation have been included in the EU ETS since 2012. Under the EU ETS, all airlines operating in Europe, European and non-European alike, are required to monitor, report and verify their CO₂ emissions, and to surrender allowances against these emissions. They receive tradeable allowances covering a certain level of emissions from their flights per year (in 2012, 85% of allowances were allocated for free). In the Revision of the EU ETS Directive, the current level of free allowances will be cut by 25% annually starting in 2024, resulting in a complete phase-out by 2027. The evolution of free allowances under the EU ETS is shown below.
The phasing out of aviation’s free emissions allowances from 2024 onwards results in an increase of around 116 million allowances\(^6\) for auctioning in the period 2024-2030 even under the Base scenario (and over 98 million under the High scenario and 121 million under the Low scenario). Under the High Scenario, more efficient flights and lifecycle carbon savings with SAF lead to less CO\(_2\) emissions in scope of the EU ETS.

Given current political developments, the study assumes a high carbon price of €200 in the light of the current global energy crisis. With a carbon price of €200/tonne, the revision of the EU ETS Directive results in significant differential costs to airspace users from 2024 onwards (€23.2 billion for the Base scenario, €19.6 billion for the High scenario and €24.1 billion for the Low scenario for the cumulative period 2022 to 2030). The High scenario is expected to be less impacted by the reduction of free allowances than the Base and Low scenarios.

### Extra costs of policy measures over 2022-2030 without SES implementation, ATM optimisation and fleet upgrade

In summary, with a carbon price of €200/tonne, the extra cost of the policy measures (with 10%, 5% and 4% of SAF in 2030) without the implementation of the Single European Sky (SES), without air traffic management (ATM) optimisation measures and without new aircraft technology, for the period 2022-2030 compared to the reference scenario (a hypothetical ‘do nothing’ scenario assuming 100% kerosene use) is around €62.0 billion for both the Base and High scenarios, and €55 billion for the Low scenario. Of those figures, the additional costs in 2030 alone comprise of around €14 billion in the Base and High scenarios and over €12 billion in the Low scenario.

<table>
<thead>
<tr>
<th>Cumulative costs over 2022-2030 (€ billion)</th>
<th>High (with 10% SAF uptake in 2030)</th>
<th>Base (with 5% SAF uptake in 2030)</th>
<th>Low (with 4% SAF uptake in 2030)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Extra fuel mix costs (SAF/kerosene)</td>
<td>€12.1</td>
<td>€10.0</td>
<td>€4.3</td>
</tr>
<tr>
<td>Extra ETS costs*</td>
<td>€19.6</td>
<td>€23.2</td>
<td>€24.1</td>
</tr>
<tr>
<td>Reduced CORSIA costs**</td>
<td>€-0.6</td>
<td>€-0.3</td>
<td>€-0.2</td>
</tr>
<tr>
<td>Extra taxation costs</td>
<td>€30.9</td>
<td>€28.8</td>
<td>€26.6</td>
</tr>
<tr>
<td>Total extra costs</td>
<td>€62.0</td>
<td>€61.8</td>
<td>€54.8</td>
</tr>
</tbody>
</table>

* Lifecycle carbon savings with SAF leading to less CO\(_2\) emissions in scope of the ETS does not outweigh the costs associated with the phasing out of aviation free emissions allowances from 2024 onwards, leading to increased ETS costs compared to the reference scenario.

** Using 4%, 5% or 10% SAF actually reduces the cost of CORSIA compared with a 100% kerosene reference scenario, resulting in a reduction in each of the scenarios.

To put these extra costs into perspective, this would translate as per the table below into the following extra costs per flight in the EUROCONTROL Network Manager (NM) area, and for intra-EEA flights (which carry a higher per-flight cost as all of these flights would be subject to all of these policy measures). The calculations are based on an estimated 13.8 million flights a year in the NM area (High), 12.1 million (Base) and 11.0 million (Low) with the corresponding figures for intra-EEA area flights 6.4 million, 5.7 million and 5.1 million respectively:

<table>
<thead>
<tr>
<th>Extra cost per flight in 2030 (€)</th>
<th>High</th>
<th>Base</th>
<th>Low</th>
</tr>
</thead>
<tbody>
<tr>
<td>Extra cost per flight in 2030, NM Area</td>
<td>€1,003</td>
<td>€1,160</td>
<td>€1,127</td>
</tr>
<tr>
<td>Extra cost per flight in 2030, intra-EEA</td>
<td>€1,809</td>
<td>€2,087</td>
<td>€2,139</td>
</tr>
</tbody>
</table>

Using the average total operating cost per flight\(^7\) for the Boeing 737 Next Generation (NG) and Airbus A320 family, the increase in operating costs from policy measures considering intra-EEA flights is shown in the table below:

\(^6\) The study has also considered the routes covered by the UK ETS and Swiss ETS.

INDUSTRY-DRIVEN RESPONSES

This section looks at how aviation-specific and industry-driven measures can help achieve the 55% emissions reduction by 2030, and offset the costs identified above were no actions to be taken.

Modernising airline fleets will cut fuel consumption

Emissions can be reduced at source by reducing fuel consumption during flight. One option is to invest in more efficient aircraft. Until 2030, progress in airline fleet efficiency will essentially be driven by evolutionary technologies related to aerodynamics (winglets, blended wing, etc.), materials (additive manufacturing, composite, nanomaterials), aircraft equipment systems, and propulsion (higher bypass ratio, open rotor, higher turbine temperature, etc.).

In the 3 scenarios, operational fleet efficiencies are mainly achieved through fleet renewal, assuming developments in 2022–2030 will be mainly powered by conventional gas turbines. We hypothesise that by 2030, six new types of aircraft will be rolled out from 2025 to 2030. These assumptions are further developed in the figure on the next page:
We consider both the new projects in the figure above, and aircraft and engine technology improvements on the fleet aircraft programmes currently available on the market. Assuming that by 2030, about 1/3 of the total fleet has been replaced, the CO₂ percentage reduction on the reference scenario is 1.9% for the Base scenario, 2.8% for the High scenario and 1.1% for the Low scenario. Between 2022 and 2030, this removes 19 million tonnes of CO₂ in the Base scenario, 30 and 9 million tonnes of CO₂ in the High and Low scenario respectively.

Bringing fleet renewal forward by 3-7 years is an even more efficient path to more rapid aviation decarbonisation, providing additional annual fuel and CO₂ emissions savings ranging from 1.7% to 5.3% over 2028-2030. Airlines’ strategy for aircraft replacement programmes could make a significant contribution in order to attain the -55% target with a reduced reliance on market-based measures.

The identified assumptions of fuel savings and associated emission reductions come from a number of different sources, namely ICAO, SESAR, the industry and the EUROCONTROL NM. An analysis performed with our R-NEST simulation tool reveals that the fuel and CO₂ saving benefits, as a result of the implementation of the airspace changes as planned by NM from 2019 to 2030, are expected to be 2.48% in 2030. By 2030, we also estimate that 6.46% additional fuel burn/CO₂ savings could be achieved for the Base scenario, based on the planned implementation of ATM changes (e.g. SESAR) and other operational measures (an 8.4% fuel efficiency improvement for the High scenario, and 4.53% for the Low scenario).

### Industry-driven emissions reductions can make a significant contribution

In 2030, these industry-driven measures including increased use of SAFs would deliver the following savings in exhaust CO₂ emissions, and proportional contribution to achieving the -55% target:

#### Operational improvements will optimise flight efficiency

Reducing emissions also requires operational improvements, optimising flight efficiency by enabling the flying of more fuel-efficient trajectories, introducing specific operational measures that reduce fuel consumption (such as measures that reduce holding/sequencing times), and minimising fuel burn in aircraft operations in all phases of flight (for example through better aircraft weight management, or optimising fuel management practices).

The Single European Sky (SES) provides the necessary policy and regulatory framework to enable the industry to deliver the necessary airspace modernisation.

<table>
<thead>
<tr>
<th>New type of aircraft</th>
<th>Size</th>
<th>Technology</th>
<th>Range</th>
<th>Aircraft segment</th>
<th>2025</th>
<th>2026</th>
<th>2027</th>
<th>2028</th>
<th>2029</th>
<th>2030</th>
</tr>
</thead>
<tbody>
<tr>
<td>Electric aircraft (2 versions)</td>
<td>9</td>
<td>Revolutionary</td>
<td>&quot;Very short Short&quot;</td>
<td>Turboprop</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>19</td>
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<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Turboprop with regional jet specificities / capabilities</td>
<td>70</td>
<td>Evolutionary</td>
<td>Short &amp; Medium</td>
<td>Turboprop</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Turboprop with regional jet specificities / capabilities</td>
<td>90</td>
<td>Evolutionary</td>
<td>Short &amp; Medium</td>
<td>Turboprop</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Hybrid electric</td>
<td>30-40</td>
<td>Revolutionary</td>
<td>&quot;Very short &amp; Short&quot;</td>
<td>Turboprop</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Conventional aircraft (re-engined and upgraded)</td>
<td>170</td>
<td>Evolutionary</td>
<td>Medium &amp; long</td>
<td>Single aisle</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Wide body aircraft (re-engined and upgraded)</td>
<td>300</td>
<td>Evolutionary</td>
<td>Long</td>
<td>Wide body</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

The new type of aircraft column highlights the main characteristics of the aircraft.
The aircraft segment column presents the segment corresponding to the aircraft type previously defined.

| High scenario | Base scenario | Low scenario |
In other words, industry-driven measures (including higher than mandated SAF uplift) could represent from 13.4% to 24.1% of the net emissions savings, depending on the pace of decarbonisation. The vast majority of the remainder would thus need to rely on market-based measures such as ETS and CORSIA.

### Significant overall decarbonisation costs can be achieved by industry-driven measures

If the emissions reductions from operational improvements and fleet upgrades could be achieved by 2030, fuel consumption could also be reduced by 17.2% in the Base scenario, 24.1% and 13.4% in the High and Low scenarios respectively. These improvements in terms of fuel efficiency would reduce costs in terms of smaller volume of fuel used, decrease the cost of taxation on kerosene, lower the costs related to the number of allowances to be bought for ETS/CORSIA, and reduce extra costs related to SAF, as less SAF is required. Figure below compares the costs “before” (i.e. the extra cost of policy measures without industry-driven measures) and “after” those industry-driven measures have been applied.
The following figure, by subtracting the extra costs including industry-driven measures (“after industry measures”) from the policy measure-only costs (“before industry measures”), reveals the degree to which implementing industry-driven measures can drastically reduce the cost of the decarbonisation measures, resulting in a **€32.9 billion** cost reduction in the Base scenario, and by **€45.7 billion** in the High scenario.

### Cumulative costs over 2022-2030 (€ billion)

<table>
<thead>
<tr>
<th></th>
<th>High (with 10% SAF uptake in 2030)</th>
<th>Base (with 5% SAF uptake in 2030)</th>
<th>Low (with 4% SAF uptake in 2030)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Before industry measures</td>
<td>After industry measures</td>
<td>Before industry measures</td>
</tr>
<tr>
<td>Extra fuel mix costs (SAF/kerosene)</td>
<td>€12.1</td>
<td>€-18.5</td>
<td>€10.0</td>
</tr>
<tr>
<td>Extra ETS costs</td>
<td>€19.6</td>
<td>€8.7</td>
<td>€23.2</td>
</tr>
<tr>
<td>Reduced CORSIA costs</td>
<td>€-0.6</td>
<td>€-1.4</td>
<td>€-0.3</td>
</tr>
<tr>
<td>Extra taxation costs</td>
<td>€30.9</td>
<td>€27.4</td>
<td>€28.8</td>
</tr>
<tr>
<td>TOTAL cumulative costs</td>
<td>€62.0</td>
<td>€16.4</td>
<td>€61.8</td>
</tr>
</tbody>
</table>

### Cost savings from industry-driven measures 2022-2030 (€ billion)

<table>
<thead>
<tr>
<th></th>
<th>High (with 10% SAF uptake in 2030)</th>
<th>Base (with 5% SAF uptake in 2030)</th>
<th>Low (with 4% SAF uptake in 2030)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fuel cost mix savings (SAF/kerosene)</td>
<td>€-30.6</td>
<td>€-21.4</td>
<td>€-26.7</td>
</tr>
<tr>
<td>ETS cost savings</td>
<td>€-10.9</td>
<td>€-8.3</td>
<td>€-5.9</td>
</tr>
<tr>
<td>CORSIA cost savings</td>
<td>€-0.7</td>
<td>€-0.5</td>
<td>€-0.4</td>
</tr>
<tr>
<td>Taxation cost savings</td>
<td>€-3.5</td>
<td>€-2.6</td>
<td>€-1.9</td>
</tr>
<tr>
<td>Cumulative cost savings</td>
<td>€-45.7</td>
<td>€-32.9</td>
<td>€-34.8</td>
</tr>
</tbody>
</table>

However, even if the cost of decarbonisation measures can be reduced, airlines face additional costs. The impact of the COVID-19 outbreak on airline revenues and losses suggests that higher prices are likely to lead to an increase in ticket prices. Based on the EUROCONTROL airline operating cost model developed for this study, and a carbon price of €200/tonne, these extra costs are converted to average extra costs per flight as per the table below:

### Area

<table>
<thead>
<tr>
<th>Area</th>
<th>High</th>
<th>Base</th>
<th>Low</th>
</tr>
</thead>
<tbody>
<tr>
<td>Intra-EEA flights</td>
<td>€894/flight</td>
<td>€1325/flight</td>
<td>€1345/flight</td>
</tr>
<tr>
<td>EUROCONTROL NM (all flights)</td>
<td>€215/flight</td>
<td>€521/flight</td>
<td>€411/flight</td>
</tr>
</tbody>
</table>

Using the average total operating cost per flight for the A320 family and B737NG, the table below estimates the cumulative operating cost increase from all decarbonisation measures for intra-EEA flights in 2030:

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8 Rather than allocating the same amount, the charge per ticket should be prorated based on distance, on ASKs, on passenger numbers, or on some combination of these.
CONCLUSIONS

This report has provided a quantitative assessment as well as some guidance on the potential effectiveness and associated costs of decarbonisation measures that would enable the industry to achieve a 55% CO₂ emissions reduction by 2030. It is based on the European Commission’s proposed policy measures, while considering variability in blending shares.

The figure below shows the yearly differential net costs for airspace users over 2022-2030. Clearly the Base scenario is the most expensive. Starting in 2027, the High scenario shows a downward trend that is likely to continue beyond 2030. The curve for the differential costs for the High scenario intersects the Low scenario curve in 2025-2026. Hence, from that point onwards, the extra costs of decarbonisation are passed on to passengers at lower prices than in other scenarios.

This clearly shows that the High scenario, boosted by a higher level of revenues, results in an increased investment in measures to reduce emissions from aviation. The most promising decarbonisation potential arises from SAFs, improved operational measures and new aircraft technology. This is the preferred trajectory, offering the most promising decarbonisation capability by 2050 at a lower cost.

The Low scenario negatively affects the revenues, profitability and investment capabilities of airspace users. It is highly reliant on market-based measures, obliging airlines to significantly rely on carbon trading and offsetting measures. With fewer allowances available in the future, such a heavy reliance on market-based measures is clearly a risk factor to consider. In addition, this scenario exposes the weakest resilience in any future economic downturn.

The middle Base scenario, despite slower traffic growth, still enables positive investment decisions in more efficient technologies, but not to a degree that would deliver lower costs than the Low scenario. These results demonstrate that without financial support and extra incentives, the costs of decarbonisation measures can slow down the potential of the aviation industry to decarbonise.
POTENTIAL OPTIONS TO ACCELERATE AVIATION DECARBONISATION

PRIORITISE ACTIONS WHICH RESULT IN THE HIGHEST REDUCTIONS IN NET CO₂

1. Accelerate the development of CO₂ efficient and disruptive technologies while improving current fleet technology. This could be enabled by alliances and partnership at EU or pan-European level (Horizon Europe, ETS Innovation Fund, Modernisation Fund, NextGenerationEU).
2. Encourage accelerated fleet renewal to significantly reduce CO₂ emissions, while maintaining connectivity.
3. Building on the EU legally-binding blending shares, encourage the industry to uptake higher levels of SAF on a voluntary basis where the market allows.
4. In particular, push for a larger share of e-SAF to motivate higher investment in green hydrogen production facilities.
5. Facilitate access to feedstock of the SAF pathways and availability of renewable energy for producing e-SAF, which will require a massive volume of renewable electricity and green hydrogen.
6. Drive a thriving European SAF market through proportionate financial incentives to promote higher SAF uptake along with the regulatory measures. Proportionality in financial support should be driven by the efficiency and relative extra cost of the SAF as well as its potential to support the trajectory to net zero emissions.

FOSTER THE TRANSITION THROUGH FINANCIAL SUPPORT AND ALLIANCES

1. Motivate public and private investors to fund sustainable solutions for the aviation sector via green funds, grants, state-backed loans, contracts for difference, etc. (incl. by the EU Taxonomy).
2. Ensure a coordinated approach between the aviation industry, electricity producers, the (e)-SAF industry and other actors in the supply chain to synchronise development and deployment of the different sustainable solutions (by joining alliances, such as the European Clean Hydrogen Alliance or the Alliance for Renewable and Low Carbon Fuels Value Chain and the Alliance for Zero-Emission Aviation).
3. Engage the aviation sector as a strategic partner to contribute to defining the European energy decarbonisation strategy.

BALANCE TAXATION WITH THE NEED FOR AVIATION TO RECOVER

1. Monitor closely the impact of taxation on aviation to ensure fair tax treatment with other transport modes, avoid double taxation and carbon leakage, and preserve connectivity.
2. Monitor the variations of the carbon market to assess inter alia the effects of potential energy crises and to mitigate the risks of carbon market volatility on the competitiveness and economic sustainability of European aviation.
3. Earmark if possible revenues collected from aviation-related taxes to foster aviation innovation and increase its funding capabilities.
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INTRODUCTION

Few industries have been harder hit by the COVID-19 pandemic than air travel, but still, this is not the greatest strategic long-term challenge that global aviation faces. Clearly, decarbonising this sector and ultimately achieving climate-neutrality by 2050 pose significant technical challenges to the aviation industry, and the future of aviation cannot be guaranteed if the industry fails to become sustainable. Sustainability in aviation in a much sharper focus was also a key condition attached to the multi-billion euro aid packages that the European Commission approved for many European carriers.

Our business has been under long-term pressure to reduce its contribution to climate change, and the drive to cut fuel burn and reduce associated emissions has been underway for many years. European aviation has risen to the challenge across the whole value chain with large-scale investments in innovative technologies enabling modern aircraft to enter into airline fleets, airspace restructuring and a range of operational efficiency gains to be achieved. As an illustration, fuel consumption per passenger has declined significantly, dropping by 25% from 2005 to 2019 for European airlines from 4.49 to 3.38 litres per passenger. However, these improvements have only been partially able to counterbalance the impact of the steady growth in traffic observed until 2019.

As traffic is expected to recover to 2019 levels potentially earlier than anticipated, the need to drive emissions further downwards in the most cost-effective way is pressing; this also brings an opportunity to build back better and more sustainably from the pandemic.

While the EU’s objective of an economy with net-zero greenhouse gas emissions by 2050 is at the heart of the European Green Deal, and in line with the EU’s commitment to global climate action under the Paris Agreement, it is crucial to define how this ambitious target could work out in practice, and address the public desire to see it happen in a more incremental way over time. As a result, rather than considering 2050 with the inherent uncertainty of projected emissions and technical readiness levels of more disruptive technologies, this report addresses the 2030 emission reduction objective (55% cuts in greenhouse gas emissions from 1990 levels) as a crucial milestone to be met on the path towards decarbonisation, setting a decarbonisation pathway to achieve the necessary goals.

This report assesses what this would mean for aviation in practical terms, looking at the various strategies – a number of policy measures (‘Fit for 55 legislative proposals’), new technologies, implementation of the Single European Sky (SES) as well as other operational improvements, increased production and uptake of sustainable aviation fuel (SAF) – and their cost. It also outlines a number of additional options that could further accelerate Europe’s aviation decarbonisation journey.

The outcomes of this study, aligned to the most recent EUROCONTROL traffic forecast, are heavily based on the wealth of data that EUROCONTROL makes available to our stakeholders, partnerships with original equipment manufacturers (OEMs) and SAF producers, as well as network, fuel burn/emissions and economic/cost models.

1.1 Purpose of the document

This report explores the cost of meeting the 55% emissions reduction target by 2030 on the basis of the three traffic scenarios developed in the EUROCONTROL Aviation Outlook 2050 report; it complements the EUROCONTROL Objective Skygreen Think Paper.

This report provides answers to the following questions:

- With SAFs currently costing up to six times that of kerosene, exactly how much extra will flying with 4%, 5% or 10% SAF add to airlines’ operating costs by 2030 – and how does that balance against rising taxes on kerosene by 2030?
- How will the phasing out of aviation’s free emissions allowances from 2024 onwards impact airline balance sheets?
- By how much can industry-driven responses (fleet renewal, new technology, operational improvements, increased SAF usage) contribute to achieving the 55% reduction target?
- Which decarbonisation pathways have the greatest potential to drive emissions reduction as quickly and as cost-effectively as possible?
- Could policymakers take additional measures that would further accelerate decarbonisation?

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8 EUROCONTROL Think Paper # 10, 20th April 2021, ‘Flying the ‘perfect green flight’: How can we make every journey as environmentally friendly as possible?’ [Ref1.]
9 EUROCONTROL 2021-2027 forecast, 15th October 2021 [Ref2.]
10 Objective to keep the global temperature increase to well below 2°C and pursue efforts to keep it to 1.5°C
11 While covering all sectors of the economy, the aviation sector needs to play its part. Reduction of net emissions by 55% compared to 1990 levels is considered to be an aspirational target for aviation in this report.
12 Adopted by the Commission and communicated on 14 July 2021 including in particular an initiative to increase the production and the uptake of sustainable alternative fuels, a revision of the EU Emissions Trading System (ETS) and a revision of the Energy Tax Directive [Ref3.]
13 EUROCONTROL Aviation Outlook 2050 Main Report, April 2022 [Ref4.]
1.2 Intended audience

The intended audience of this document includes:

- Policymakers, by identifying the decarbonisation pathway that would maximise the benefits (in terms of emissions reduction) while minimising the costs (both direct financial costs and indirect costs) and the need for measures incentivising, for example, aircraft replacement;
- Airspace users, in particular with respect to the impact of decarbonisation measures on their costs;
- The ATM community, including air navigation service providers (ANSPs), since ‘greening’ trajectories is certainly a lower-hanging fruit due to the current absence of alternative fuels available at scale;
- European airports, since the optimisation of surface operations, reduction of energy and fuel consumption through the design of new energy-efficient infrastructure (e.g. use of GPUs (Ground Power Units)) are fundamental components of emissions reduction efforts;
- OEMs, as the report addresses the commercial availability of new aircraft designs and aircraft acquisition;
- SAF producers, since there is clear need to crack the “chicken & egg” problem to scale SAF up; and finally
- Non-governmental organisations (NGOs) and the general public campaigning for cleaner aviation, as this report puts forward clear and achievable measures to cut aviation emissions as part of the Paris Agreement obligations.

2 METHODOLOGY

The three scenarios are:

- **High scenario**: This scenario in flight terms is characterised by strong economic growth in a globalised world, with intensive investment in technology supporting sustainable aviation growth. This envisages that SAFs become available (at an economically attractive price), allowing blending of SAFs at percentages higher than current European regulatory requirements.
- **Base scenario**: This ‘most-likely’ scenario is characterised by moderate economic growth, with regulation reflecting environmental, social and economic concerns to address aviation sustainability. It follows both the current trends, and what are seen as the most likely trends in the future. The uptake of SAFs is in line with ReFuelEU Aviation obligations. In this scenario, taxation of fossil-based fuel will be proportionally high, as a lower volume of SAFs is used.
- **Low scenario**: This low-growth scenario in flight terms is characterised by slower economic growth; higher fuel, SAF and carbon prices; and more limited investment in new technology (or later than in the other scenarios). Aviation actors have to adapt to environmental and potential trade constraints, taking a more “inward” perspective. European travellers are likely to travel and consume more locally. This scenario encompasses assumptions where energy prices would be particularly high and a severe economic downturn might happen over a 30-year period. Hence, this scenario assumes much less breaking of the nexus between flying and emissions. That will result in slower and much less emissions reductions.

FIGURE 1 – FLIGHT FORECAST FOR EUROPE, WITH TOTAL GROWTH BETWEEN 2019 AND 2050
The report examines the impact on these three scenarios of a number of policy and industry-driven measures. It first considers the extra costs of SAF uptake across the EUROCONTROL Network Manager (NM) area, at levels below, in accordance with, and above the ReFuelEU Aviation proposal; increased ETS and CORSIA obligations; and taxation (Chapter 3); before showing the positive impact of SES implementation, airspace design, operational changes and new aircraft technology (Chapters 4 and 5). The policy measures are then re-enforced on the resulting reduced fuel and emissions, involving a recalculation of the differential costs for each scenario (Chapter 6).

A hypothetical ‘do nothing’ scenario serves as a reference against which the potential impacts of anticipated policy and industry-driven measures are assessed under the High scenario, Base scenario, and Low scenario. Extra flights are added as per the High scenario, Base scenario, and Low scenario without any specific action to improve the carbon efficiency of flights. More specifically, this reference scenario assumes:

- 100% kerosene use;
- EU ETS remains as it is, hence requiring aircraft operators to surrender allowances from all flights between two EEA airports and implementing a 2.2% year-on-year reduction in the allowances;
- no taxation on kerosene;
- that the 2021 in-service fleet is progressively replaced with aircraft available for purchase in 2021;
- no implementation of the airspace projects aimed over the period autumn 2021 until end of 2030; and
- although the Common Project 1 (CP1) regulation is binding in its entirety and directly applicable in all Member States, it is hypothetically not considered in the reference scenario in order to fully consider its contribution to the reduction of CO\textsubscript{2} emissions.

Finally, this report conducts two ‘what-if’ analyses (Chapter 7):

- a speed optimisation study that simulates the effect of (lower) speeds on fuel consumption and emissions; and
- an earlier aircraft acquisition/leasing assessment, looking at the emission savings and projected earnings/anticipated costs generated by bringing acquisition/leasing of more efficient aircraft forward by 3 and 7 years.

3 POLICY INITIATIVES

3.1 SAF: on the critical path to meet the -55% emissions reduction

As well as generating much lower end-to-end carbon emissions, SAF can also reduce direct emissions. Compared to kerosene, SAF has 90% reduced particulates, and 100% reduced sulphur - improving air quality in plane flight paths. Using a 50/50 SAF blend can also result in 50-70% fewer ice crystal contrails at cruising altitude\textsuperscript{16}. SAF is therefore on the critical path to cut emissions by 55% by 2030 and eventually achieve net zero emissions. The main challenge is twofold: (1) to ensure that there is sufficient sustainable feedstock to produce SAF in a ‘green’ way; (2) the cost of SAF compared to traditional jet fuel. As decarbonising the whole industrial/transportation sector is a critical step toward achieving a liveable climate future, (1) is not specific to aviation and as a result, may incur competition for limited resources such as feedstock and green energy.

3.1.1 SETTING FUNDAMENTALS

3.1.1.1 BLENDING MANDATE TO INCREASE THE SUPPLY OF SAF

As part of the European Commission’s ‘Fit for 55’ climate package [Ref6.], the ReFuelEU Aviation proposal imposes a blending mandate on fuel suppliers to include SAF in aviation fuel supplied at EU airports. The blending obligation would commence from 2025 at 2% SAF, gradually increasing to 63% in 2050. The proposal also includes a sub-obligation for synthetic aviation fuels starting in 2030 with 0.7% and progressively getting to 28% of e-fuels in 2050. To avoid fuel tankering and carbon leakage, an obligation is also placed on aircraft operators to uplift at least 90% of the yearly fuel required at EU airports.

\textsuperscript{16} Source: in-flight research by NASA and the German Aerospace Centre (DLR)

"Fit for 55" refers to the at least 55% emission reduction target which the EU has set for 2030 compared to 1990 levels. The proposed package aims to bring the EU’s climate and energy legislation in line with the 2030 goal.
3.1.1.2 SCENARIOS FOR SAF BLENDING

Although the obligation is placed on the fuel suppliers rather than the airlines, so that consequently, all flights departing from EU airports will be covered, the report assumes that the minimum shares of SAF, including the minimum shares of synthetic aviation fuel, equally applies to all airports within the EUROCONTROL NM area.

This report assumes that the minimum share of SAF for the Base scenario is in accordance with the values and dates of application set out in Annex I of the ReFuelEU Aviation proposal, while the High scenario reflects a more proactive and positive approach with 2.8% 2025, and 10% blending in 2030. The Low scenario presents a lower 4% SAF uptake in 2030 commencing from 1.6% in 2025.

Over the timespan 2021-2025, scaling up of production to the minimum share of SAF set for 2025 is assumed, starting with the current percentage of total jet fuel consumption. This is based on linear interpolation. Similarly, a straight line is assumed between 2025 and 2030 known values.

FIGURE 2 – SAF BLENDING SHARES

As of today, at only 0.05% of total jet fuel consumption, the use of SAF is still very low in Europe (FIGURE 3^{17}).

^{17} https://www.eurocontrol.int/shared/sustainability/map-saf.html
SAF PRODUCTION PATHWAYS

The study considers 4 pathways: Hydroprocessed Esters and Fatty Acids (HEFA), Gasification/Fischer-Tropsch, Alcohol to Jet (AtJ) and Power to Liquids (PtL) as shown in FIGURE 4 below.

Current production is focused on HEFA (Hydro processed Esters and Fatty Acid) and, in neat form, HEFA reduces approximately 80% of carbon emissions compared to fossil fuels over the lifecycle. Stage 2 options have lower technology readiness (municipal solid waste (MSW) based gasification/Fischer-Tropsch\textsuperscript{18} and Alcohol to Jet) and still need to prove their potential for higher emissions reduction vs fossil jet fuel. The Power to Liquid (PtL)/eSAF\textsuperscript{19} pathway is lower technology readiness level and higher cost, with carbon reduction performance still to be clarified. Despite project announcements about PtL coming on stream in around 2025, realistically eSAF is currently unlikely to be available in substantial quantities before 2030.

\textsuperscript{18} Fischer-Tropsch jet fuel (a synthetic hydrocarbon or mixture of synthetic hydrocarbons produced from biomass, to be used to replace jet fuel)

\textsuperscript{19} PtL fuels are considered to be renewable fuels of non-biological origin (RFNBO), if electricity from renewable sources is used in the process.
The resulting aviation fuels are all ASTM-approved for blending of up to 50% today with conventional fossil jet fuel. Incorporation of aromatics (primarily benzene) into fuel allows for higher blend percentages up to 100%, as it provides the full range of molecules found in current jet fuels, as opposed to just paraffin, thereby allowing better compatibility with current jet engines. All relevant players in the aviation ecosystem recognise and fully support the need for 100% approval, in particular aircraft and engine OEMs (i.e. civil aircraft manufacturers Airbus/Boeing, military aircraft producers, & engine makers RR/P&W etc.) plus fuel producers. There are multiple trials with 100% SAF underway to collect performance and emission data. Realistically, however, this approval process is probably going to take 10 years.

3.1.1.4 SAF PRODUCTION STRUCTURE OUTLOOK

This report assumes that through to 2030, SAF capacity is almost all HEFA. However, MSW gasification plus synthesis and Alcohol-to-jet SAF technologies should mature in the mid-2020s. Based on the WEF CST forecast global production through to 2025 of FIGURE 5 below, the report assumes the production structure outlooks in FIGURE 6 for the High scenario, and FIGURE 7 for the Base and Low scenarios.

**FIGURE 5 – SAF PRODUCTION CAPACITY OUTLOOK (source: NESTE)**
3.1.1.5 SAF: ONE OF THE MAIN CHALLENGES IS COST

SAF costs considerably more to produce than fossil jet fuel. Due to high price pressure, currently low SAF demand and policy uncertainty, and although the proposed blending mandate guarantees that there should be a market, there is a great deal of uncertainty about SAF costs. Uncertainty is quantified by the use of ranges of cost. Assumptions used in preparing all range estimates for the various SAF pathways are documented below. The wider range currently applies to PtL. In this report (see FIGURE 7 below), the upper bound of a specific cost range applies to the Low scenario, while the lower bound is used for the High scenario. Assuming the underlying distribution of costs is symmetric, the average of the range applies to the Base scenario.
Much of the cost of HEFA is in the cost of feedstock; this, and availability of these feedstocks, are its major limitations. Most industrially mature feedstocks with high levels of sustainability potential are listed in Annex IX, Parts A and B, of the proposed revision of the Renewable Energy Directive [Ref8]. Since HEFA refines vegetable oils, waste oils or fats into SAF through a process that uses hydrogen (hydrogenation), the cost of (green) H2 presents the largest opportunity for HEFA production cost improvement, while the scarcity of feedstock means there should not be a major cost-reduction potential ([Ref7.]). The report assumes that the average cost per metric ton for HEFA would decrease from €1,200 today to €1,100 in 2025 and €1,000 by 2030 in constant €.

The costs of the gasification of municipal solid waste are driven by CAPEX investments; these present the opportunity for cost to decrease and a 4% per annum decline between 2025-2030 is assumed based on [Ref7.], from €1,700 per ton of jet fuel in 2025 (average cost).

For the Alcohol to Jet process, the cost of feedstock and alcohol (ethanol) production (refining) has a dominant effect on the economics of the overall process. Ethanol production is assumed to fall by about 1% per year and capital expenses by about 35% until 2030, starting with €1,900 per ton of jet fuel in 2025 to reach €1,700 in 2030 (average costs) ([Ref7.]).

For PtL, carbon feedstocks are synthesised with green hydrogen – via processes such as Fischer-Tropsch – to generate liquid hydrocarbons. While presenting the most sustainable option in the long term, PtL is currently significantly more expensive than traditional jet fuel, and the cost is driven by the cost of green hydrogen production as well as carbon capture. An average value of €3,000 per metric ton of jet fuel is here assumed in 2022, decreasing over time to €1,800 by 2030 for the Base scenario.

Assuming a net profit margin of 6.8%21 to reflect a SAF company’s required level of profitability, the evolution of the SAF prices for the High, Base and Low scenarios are shown in FIGURE 9, FIGURE 10 and FIGURE 11 respectively.

These figures show that certainty in demand growth is key for the necessary investment to increase SAF production capacity and become more efficient. Greater volumes achieved with the High scenario, and to a lesser extent, the Base scenario, will bring down prices more rapidly.

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21 As of January 2020, the average net profit margin for the oil and gas drilling industry was 6.8%.
FIGURE 9 – SAF PRICES PER SAF PATHWAY FOR THE HIGH SCENARIO (€ per metric ton)

FIGURE 10 – SAF PRICES PER SAF PATHWAY FOR THE BASE SCENARIO (€ per metric ton)

FIGURE 11 – SAF PRICES PER SAF PATHWAY FOR THE LOW SCENARIO (€ per metric ton)
In order to calculate the weighted average value of a metric ton of fuel taking into account the varying degree of SAF blending, this report has also considered the long-term energy trends for the projections of kerosene prices. The Reference Case of AEO2021 [Ref9.] serves as a reasonable baseline case that can be compared with the side cases that include alternative assumptions. It is mapped to both our reference scenario and Base scenario. Similarly, the High Economic Growth case and Low Economic Growth case of AEO2021, addressing the effects of economic assumptions on the energy consumption modelled in AEO2021, are mapped to the High and Low scenarios respectively. This leads to the evolution of kerosene prices plotted in FIGURE 12 below:

**FIGURE 12 – KEROSENE PRICE PROJECTION (€ per metric ton)**

Hence, considering the varying degrees of SAF blending as per FIGURE 2, and the SAF technology production outlook from FIGURE 6 and FIGURE 7 for the High and Base & Low Scenarios respectively, the weighted average price before tax of a metric ton of fuel (blending SAF with fossil kerosene) is shown on FIGURE 13 below:

**FIGURE 13 – EVOLUTION OF FUEL PRICES (€ per metric ton) FOR THE HIGH, BASE and LOW SCENARIOS**

3.1.1.6 EXTRA COSTS OF SAF BLENDING COMPARED TO THE REFERENCE SCENARIO (100% KEROSENE)

FIGURE 14 on the next page shows how for the period 2022-2030, the extra costs of SAF compared to 100% kerosene are estimated to be:

- **Base scenario:** €10 billion by 2030, with €2.1 billion in 2030 alone, based on 5% uptake

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- **High scenario:** €12.1 billion by 2030, based on 10% uptake
- **Low scenario:** €4.3 billion by 2030, based on 4% uptake.

However, these extra costs need to be balanced against the extra costs of the new energy taxation obligations, and the revision of the ETS directive, which applies only to kerosene.

**FIGURE 14 – INCREMENTAL FUEL COSTS FROM SAF BLENDING SHARES & SAF PRICE EVOLUTION FOR THE DIFFERENT SCENARIOS (IN € BN)**

![Graph showing incremental fuel costs from SAF blending shares & SAF price evolution for different scenarios.]

### 3.1.2 POTENTIAL CO₂ EMISSION REDUCTION

#### 3.1.2.1 NET SAVINGS

About exhaust emissions and net enhancements…

Exhaust emissions are substances emitted into the atmosphere from the exhaust discharge nozzle. While electric and hydrogen systems have the potential to be ‘true-zero’ carbon solutions, usage of SAF has no bearing upon exhaust CO₂ emissions. We have considered lifecycle (net) GHG emission savings. Lifecycle emissions include the emissions associated with: feedstock cultivation, feedstock harvesting, collection and recovery, feedstock processing and extraction, feedstock transportation to processing and fuel production facilities, feedstock to fuel conversion processes, fuel transportation and distribution, and fuel combustion in an aircraft engine.

The **Lifecycle Assessment (LCA)** methodology is used to calculate the net emission reduction achieved by using SAF.

**FIGURE 15 – LIFECYCLE DIAGRAM (source: NESTE)**

![Lifecycle diagram showing processes from renewables refinery, blending terminal, airport storage, refueller/hydrant, and fossil refinery.]

LCA includes (1) production at source (e.g. feedstock cultivation); (2) conditioning at source (e.g. feedstock harvesting, collection and recovery); (3) feedstock processing and extraction; (4) feedstock transportation to processing and fuel production facilities; (5) feedstock-to-fuel conversion processes; (6) fuel transportation and distribution to the blend point; and (7) fuel combustion in an aircraft engine.

Feedstocks can be broadly categorized into three groups - primary or co-products, by-products, and wastes and residues. [Ref10] provides the list of CORSIA Default Life Cycle Emissions Values that may be used by an aeroplane operator to claim emissions reductions from the use of CORSIA eligible fuels in a given year.

To calculate the net reduction in carbon emissions over the lifecycle of SAF fuel compared to traditional jet fuel, this report uses **EQUATION 1** below.
EQUATION 1: TOTAL EMISSIONS

$$Total\ Emissions = 3.16 \times (CJF + SAF \times \frac{LCA_{SAF}}{LCA_{CJF}})$$

where:

- Carbon dioxide (CO$_2$) is emitted during the combustion of kerosene jet fuel: 3.16 kg CO$_2$ are emitted per kilogram of kerosene
- CJF (conventional jet fuel) is the volume of kerosene (in metric tons)
- SAF is the volume of sustainable aviation fuel
- LCA$_{SAF}$ is the Life Cycle Emissions Values for SAF
- LCA$_{CJF}$ is the Life Cycle Emissions Values for kerosene

Various LCA values are from the “CORSIA Default Life Cycle Emissions Values for CORSIA Eligible Fuels”.$^{23}$

This report assumes that SAFs are produced from a feedstock that is defined as a waste, residue, or by-product or from feedstocks that have “low risk” for land-use change. Hence the actual core LCA value is the total LS.$^{24}$ LS includes emissions generated during ongoing operational activities (e.g. operation of a fuel production facility, feedstock cultivation), as well as emissions associated with the material and utility inputs to operational activities, such as processing chemicals, electricity, and natural gas. Emissions generated during one-off construction or manufacturing activities (e.g. fuel production facility construction, equipment manufacturing) are not included. This report assumes the following LCA values ([Ref10.])

### TABLE 1: LIFECYCLE EMISSIONS VALUES

<table>
<thead>
<tr>
<th>Fuel Conversion Process</th>
<th>LCA (total LS) (gCO$_2$/MJ)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hydroprocessed Esters and Fatty Acids (HEFA)</td>
<td>13.9</td>
</tr>
<tr>
<td>Gasification to Produce Fischer-Tropsch Jet Fuel</td>
<td>5.2</td>
</tr>
<tr>
<td>Alcohol (Ethanol) to jet (ATJ)</td>
<td>5</td>
</tr>
<tr>
<td>Power to Liquid (PtL)/eSAF</td>
<td>3$^{25}$</td>
</tr>
<tr>
<td>Kerosene</td>
<td>89</td>
</tr>
</tbody>
</table>

The study considers a weighted average LCA$_{SAF}$ value based on the share of the different SAF pathways for the different scenarios from **FIGURE 6** and **FIGURE 7**. As an example, in 2026 for the Base and Low scenarios, the share of SAF production by pathway considers 89.6% of HEFA, 5.2% of Gas/FT and 5.2% of ATJ, and, as a result the weighted average LCA$_{SAF}$ will be from **TABLE 1** above: (89.6% x 13.9)+(5.2% x 5.2) + (5.2% x 5), i.e. 12.98 gCO$_2$/MJ.

**TABLE 2** below provides the list of weighted average LCA$_{SAF}$ value for the different scenarios over the 2021-2030 period.

### TABLE 2: WEIGHTED AVERAGE LCA$_{SAF}$ VALUES FOR THE DIFFERENT SCENARIOS (IN gCO$_2$/MJ)

<table>
<thead>
<tr>
<th></th>
<th>2022</th>
<th>2023</th>
<th>2024</th>
<th>2025</th>
<th>2026</th>
<th>2027</th>
<th>2028</th>
<th>2029</th>
<th>2030</th>
</tr>
</thead>
</table>

---

23 ICAO, CORSIA Default Life Cycle Emissions Values for CORSIA Eligible Fuels, March 2021. This ICAO document is referenced in Annex 16 — Environmental Protection, Volume IV — Carbon Offsetting and Reduction Scheme for International Aviation (CORSIA) [Ref10.]

24 Lifecycle emissions factor for an eligible fuel in gCO$_2$/MJ.

25 At the time of writing this report, PtL/eSAF do not have default core life cycle values in [Ref10.]. This report assumes a value of 3gCO$_2$/MJ.
3.1.2.2 SAF CONTRIBUTION TO EMISSIONS REDUCTION PER SCENARIO

The higher the share of SAF, the greater the potential emissions reduction. In 2030, the net CO₂ emissions reduction from SAF blend shares of 10%, 5% and 4% for all flights in the EUROCONTROL NM area is modelled in TABLE 3 below, which shows their contribution to achieving the 55% target:

**TABLE 3: SAF CONTRIBUTION TO EMISSIONS REDUCTION PER SCENARIO**

<table>
<thead>
<tr>
<th>2030 EUROCONTROL NM Area</th>
<th>High 10% SAF uptake</th>
<th>Base 5% SAF uptake</th>
<th>Low 4% SAF uptake</th>
</tr>
</thead>
<tbody>
<tr>
<td>Savings from SAF</td>
<td>8.8% emission reduction</td>
<td>4.6% emission reduction</td>
<td>3.9% emission reduction</td>
</tr>
</tbody>
</table>

3.2 Ramping up kerosene taxes

3.2.1 CHARACTERISTICS OF THE REVISION OF THE TAXATION DIRECTIVE

The revision of the energy tax directive [Ref11.] progressively introduces a tax on fuel for intra-European flights over a transitional period of 10 years. Flights to and from airports outside of the EU are exempt as well as cargo-only flights. It defines the minimum levels of taxation applicable to motor fuels, as set out in Annex I of [Ref11.] according to the mentioned environmental performance (meaning for example that sustainable biofuels would be taxed at lower rates), and expressed in €/GJ.

The minimum level of taxation applicable after completion of the transitional period and before indexation is the following:

**TABLE 4: MINIMUM LEVEL OF TAXATION (€/GJ)**

<table>
<thead>
<tr>
<th>Fuels</th>
<th>Rate after completion of the transitional period - €.GJ</th>
</tr>
</thead>
<tbody>
<tr>
<td>Kerosene</td>
<td>10.75</td>
</tr>
<tr>
<td>HEFA</td>
<td>5.38</td>
</tr>
<tr>
<td>Gasification/Fischer-Tropsch</td>
<td>5.38</td>
</tr>
<tr>
<td>Alcohol to Jet</td>
<td>5.38</td>
</tr>
<tr>
<td>eSAF (Power to Liquid, PtL)</td>
<td>0.15</td>
</tr>
</tbody>
</table>

The revision of the energy tax directive considers a transitional period of ten years. This report assumes the start of the ten-year transition period on 1 January 2024. During that transition period, the following rules should apply:

- For Jet A1 fuel (Kerosene) used for intra-EU non-business and non-pleasure flights, the final minimum rate in [Ref11.] would be reached by the end of the transitional period of ten years and is fixed at one-tenth per year. This leads to the evolution of taxation as per TABLE 5 below.
- A zero-minimum rate should apply to sustainable biofuels and biogas, low-carbon fuels, renewable fuels of non-biological origin, advanced sustainable biofuels and biogas and electricity.

**TABLE 5: MINIMUM LEVEL OF TAXATION (€/GJ) OVER THE TRANSITION PERIOD FOR JET A1 FUEL (KEROSENE)**

<table>
<thead>
<tr>
<th></th>
<th>2024</th>
<th>2025</th>
<th>2026</th>
<th>2027</th>
<th>2028</th>
<th>2029</th>
<th>2030</th>
<th>2031</th>
<th>2032</th>
<th>2033</th>
</tr>
</thead>
<tbody>
<tr>
<td>€.GJ⁴</td>
<td>1.075</td>
<td>2.15</td>
<td>3.225</td>
<td>4.3</td>
<td>5.375</td>
<td>6.45</td>
<td>7.525</td>
<td>8.6</td>
<td>9.675</td>
<td>10.75</td>
</tr>
</tbody>
</table>

²⁶ Although Member States may apply the same level of taxation to cargo-only domestic flights as well as to intra-EU air navigation of cargo-only flights where a Member State has entered into an agreement with one or several Member States.

²⁷ TABLE 4 indicates proposed Energy Taxation Directive (ETD) minima for SAF for information only, as zero-minimum rates apply to SAF over the transition period.

²⁸ The revision of the ETD, part of the ‘Fit for 55’ package, is a consultation procedure. It requires unanimity in Council, after consulting the European Parliament. This report assumes 2024 as the first year the EU’s ETD would enter into force in light of the current discussions and approval by the European Parliament and the Council of the EU.

²⁹ This mean flights between two airports located in the EU, including domestic flights.

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The logic behind revising the taxation directive is to switch from volume to energy content-based taxation; the reason for this is that one litre of biofuel typically has a lower energy content than one litre of the competing fossil fuel. Based on Annex III of [Ref12.], this report considers the following energy content:

**TABLE 6: ENERGY CONTENT BY WEIGHT (LOWER CALORIFIC VALUE, MJ/KG)**

<table>
<thead>
<tr>
<th>Fuel</th>
<th>Energy content by weight (lower calorific value, MJ/kg)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Kerosene</td>
<td>43</td>
</tr>
<tr>
<td>HEFA</td>
<td>44</td>
</tr>
<tr>
<td>Gasification/Fischer-Tropsch</td>
<td>44</td>
</tr>
<tr>
<td>Alcohol to Jet(^{12})</td>
<td>27</td>
</tr>
<tr>
<td>eSAF (^{33})</td>
<td>44</td>
</tr>
</tbody>
</table>

\(^{31}\) TABLE 6 energy content by weight for SAF for information only, as zero-minimum rates apply to SAF over the transition period.

\(^{32}\) Assuming ethanol from renewable sources.

\(^{33}\) At the time of writing this report, eSAF does not have a lower calorific value defined. This table assumes a value of 44 MJ/kg.

Between 2024 and 2030 therefore, taxation on kerosene applied to intra-European flights significantly increases aircraft operators’ costs over the period 2022-2030 by an estimated €28.85 billion in the Base scenario, rising to as high as €30.90 billion in the High scenario.

€28.85 billion in the Base scenario is equivalent to the cost of **674 Airbus A320neo** at their current market value (CMV)\(^{34}\).

\(^{10}\) The Commission is empowered to adopt delegated acts to supplement this Directive by adapting the energy content of transport fuels, as set out in Annex III, in accordance with scientific and technical progress.

\(^{12}\) TABLE 6 energy content by weight for SAF for information only, as zero-minimum rates apply to SAF over the transition period.

\(^{13}\) At the time of writing this report, eSAF does not have a lower calorific value defined. This table assumes a value of 44 MJ/kg.

\(^{14}\) Current Market Value (CMV), source Collateral Verifications, [https://www.cvllc.net/index.html](https://www.cvllc.net/index.html)
Ideally, revenues from the reviewed Energy Taxation Directive should be reinvested in decarbonisation solutions.

3.3 Carbon pricing and consequences

3.3.1 EU EMISSIONS TRADING SYSTEM (ETS)

CO₂ emissions from aviation have been included in the EU Emissions Trading System (ETS) since 2012. Under the EU ETS, all airlines operating in Europe, European and non-European alike, are required to monitor, report and verify their emissions, and to surrender allowances against those emissions. They receive tradeable allowances covering a certain level of emissions from their flights per year.

The EU ETS currently only applies to flights between airports located in the European Economic Area (EEA)³⁵. Aviation activities are also included in the Linking Agreement with Switzerland³⁶, and the ETS of Switzerland reflects the same principles as those of the EU ETS, in particular with regard to coverage, cap and allocation rules. In line with the Swiss Linking Agreement, a Delegated Act³⁷ has been adopted by the Commission, as regards the exemption from the EU ETS of incoming flights from Switzerland, as from 1 January 2024. Flights from the EEA to the UK remain in the scope of the EU ETS, while flights from the UK to the EEA have been excluded from the EU ETS³⁸ since 1 Jan 2021. We assume here that the UK system of carbon pricing will enable equal treatment of aircraft operators on EEA-UK routes, with the EU regulating departing flights to UK, and the UK being responsible for flights from the UK to the EEA.

The legislation adopted in 2008 was designed to apply to emissions from flights from, to and within the EEA – the EU Member States, plus Iceland, Liechtenstein and Norway. The EU, however, initially decided to limit the scope of the EU ETS to flights within the EEA until 2016, to support the development of a global measure by the International Civil Aviation Organization (ICAO). Regulation (EU) 2017/2392 amends the EU ETS Directive 2003/87/EC to continue the current limitations of scope for aviation activities, and to prepare to implement a global market-based measure from 2021. The amendments to the Directive extend the current derogation from full scope, whereby only flights between states within the EEA are covered by the system, rather than all flights arriving at or departing from EEA aerodromes, until the end of 2023.

The EU ETS in the proposed “Fit for 55” climate package³⁹ includes a number of key changes:

- New linear reduction factor: Starting in 2024, the overall number of emission allowances will decline at an annual rate of 4.2% (2.2% until then) to reach the new, more ambitious overall climate change target for 2030.

- The current level of free allowances will be cut by 25% annually starting in 2024, thus eliminating them completely by 2027. The move to full auctioning of allowances by 2027 should create a stronger price signal.

- ETS provides an incentive to aircraft operators to use SAF that complies with the sustainability criteria of RED II by attributing them zero emissions under the scheme.

³⁵ The geographical scope of application of Directive 2003/87/EC as set out in its Annex I, i.e. flights departing from airports in the EEA and arriving to other airports in EEA or to third countries and, incoming flights to airports in the EEA from third countries.

³⁶ Agreement between the European Union and the Swiss Confederation on the linking of their greenhouse gas emissions trading systems, 7th December 2017.

³⁷ Decision C(2020)3107.


³⁹ The package has yet to go through the EU’s ordinary legislative procedure before entering effect in its final form in the coming years, a process requiring approval by the Council of the EU and the European Parliament. It comes less than a year after the European Commission launched its revision process for the system as part of the 2030 Climate Plan under the European Green Deal.
- Routes between outermost regions, and other states than the Member State in which the outermost region is located, will be covered by the ETS. A time-limited derogation from the EU ETS is proposed for emissions from flights between an aerodrome located in an outermost region of a Member State and an aerodrome located in the same Member State.

Currently, the EU ETS temporarily exempts flights to and from outermost regions (e.g. Tenerife – Madrid; Berlin – Tenerife), as well as flights between two different outermost regions (Madeira - Azores) from 2013-2023. However, flights within the same outermost region are covered by the EU ETS (Lanzarote – Tenerife).

In 2012, 85% of allowances were allocated for free. In trading period 3 (2013-2020), 15% of allowances were auctioned and 82% allocated for free. 3% of the total quantity of free aviation allowances were set aside in a ‘special reserve’ for both new entrants and fast growing operators, i.e. operators who have seen an important growth in tonne-kilometre activities.

As mentioned above, free allocation for the aviation sector will be reduced compared to the 85% (82%+3%) in phase 3 of ETS.

Starting 2021, aviation emissions for flights departing the UK are no longer considered in the cap. Emissions for intra-EEA aviation in 2020 are capped at 38 million allowances, and will decrease each year by the linear reduction factor of 2.2% in 2021, 2022 and 2023. The allocation for 2024 will be based on the total allocation to active aircraft operators in 2023, reduced by the increased linear reduction factor of 4.2%. This will then be increased by the level of allocation that would have been made if routes between outermost regions, and other states than the Member State in which the outermost region is located, had been covered by the ETS in 2023.

This will result in the evolution of free allowances (and hence auctioning obligation) as shown in FIGURE 18 below:

**FIGURE 18 – PHASING OUT OF FREE ALLOWANCES OVER TIME AS PER “FIT FOR 55” PROPOSAL**

The phasing out of aviation’s free emissions allowances from 2024 onwards results in an increase of around 116 million allowances\(^\text{40}\) for auctioning in the period 2024-2030 even under the Base scenario (and over 98 million under the High scenario and 121 million under the Low scenario). Under the High Scenario, more efficient flights and lifecycle carbon savings with SAF lead to less CO\(_2\) emissions in the scope of the EU ETS.

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\(^{40}\) The study has also considered the routes covered by the UK ETS and Swiss ETS.
FIGURE 19 – PHASING OUT OF FREE ALLOWANCES OVER TIME AS OF CURRENT DIRECTIVE

The costs of purchasing units for compliance are simply the quantity of units that need to be purchased, multiplied by their price. FIGURE 20 below shows how carbon pricing has evolved since the start of 2021.

FIGURE 20 – CARBON PRICES (€/tonne) EVOLUTION IN 2021/2022 (source: Ember)

The ETS price acts as a disincentive for carbon-intensive industries, and usually a high carbon price induces operators to invest in carbon abatement measures. In 2021, the average carbon price was €54.

Driven by high gas prices and expectations of a tighter supply of CO2 allowances until 2030, carbon prices on the EU ETS are at record highs, reaching over €96.96 on 8th February 2022. This is over 2.5 times higher than in January 2020. The current situation of high energy prices is the result of interactions of four markets: gas, coal, electricity and ETS allowances (...). The ETS price is both affected by wider energy prices and it, in turn, affects them (...)41. However, the evolution of carbon prices very much depends on the timeframe considered, the perceived role of ETS in driving emissions down, and the dynamics of the ETS/energy markets. In addition, decarbonisation investment decisions are often more a function of price expectations of the emission abatement measures and return on investment.

Given current political developments, this study now assumes a carbon price of €200. This may be considered high, but as the world faces a global energy crisis, it seems prudent to adopt it (Annex 3 provides key figures when considering a lower carbon price at €120).

Although there will be fluctuations over the years, a linear progression is assumed between the average 2021 ETS price and a carbon price of €200 in 2030.

With a carbon price of €200/tonne, the revision of the EU ETS Directive results in significant differential costs to airspace users from 2024 onwards (€23.2 billion for the Base scenario, €19.6 billion for the High scenario and €24.1 billion for the Low scenario for the cumulative period 2022 to 2030). The High scenario is expected to be less impacted by the reduction of free allowances than the Base and Low scenarios.

### 3.3.2 CORSIA

#### 3.3.2.1 SECTORIAL BASELINE AND OFFSETTING REQUIREMENTS

CORSIA was adopted at ICAO’s 39th Assembly to address CO₂ emissions from international aviation. It forces airlines to buy credits that offset the rise in CO₂ emissions covered by the scheme. The aircraft operator purchases a number of emissions units equivalent to this offsetting requirement; each emissions unit is equivalent to one tonne of CO₂ output. The voluntary pilot phase of CORSIA occurs from 2021-2023, after which the voluntary first phase will be implemented between 2024-2026, followed by a mandatory second phase from 2027 onwards.

Until 2029 inclusive, the calculation of offsetting requirements is entirely based on a “sectoral” approach, and follows the following formulae:

#### EQUATION 2: CORSIA OFFSETTING REQUIREMENTS

\[
\text{Offsetting requirements} = \frac{\text{CO}_2 \text{emissions} \times \text{growth factor}}{\text{CO}_2 \text{baseline emissions}}
\]

where:

\[
\text{growth factor} = \frac{\text{CO}_2 \text{emissions} - \text{CO}_2 \text{baseline emissions}}{\text{CO}_2 \text{emissions}}
\]

Originally, CORSIA’s sectoral baseline was defined as the average of total CO₂ emissions for the years 2019 and 2020 on the routes covered by CORSIA offsetting in a given year from 2021 onwards (Assembly Resolution A40-19, paragraph 11). The drop in air traffic in 2020 led ICAO to exclude 2020 from the baseline until 2023. Hence:

#### EQUATION 3: GROWTH FACTOR FOR THE PERIOD 2021-2023

\[
\text{growth factor}_{\text{period 2021–2023}} = \frac{\text{CO}_2 \text{emissions} - \text{CO}_2 \text{baseline emissions}}{\text{CO}_2 \text{emissions}}
\]

#### EQUATION 4: GROWTH FACTOR FROM 2024 ONWARDS

\[
\text{growth factor}_{\text{year } n > 202} = \frac{\text{CO}_2 \text{emissions} - \text{CO}_2 \text{average 2019–2020 emissions}}{\text{CO}_2 \text{emissions}}
\]

---

42 CORSIA only applies to international flights.
For 2030-2032 the offsetting requirements consider a combination of a “sectoral” component and an “individual” component, with a 80% and 20% contribution respectively. As the individual component is based solely on the increase in CO\textsubscript{2} emissions of each operator, for the sake of simplicity EQUATION 2 has been used to estimate the offsetting requirements for routes under CORSIA for 2022-2030. Similarly, in the interest of simplification, it has been assumed that all international flights from 2022 to 2026 (inclusive) are between voluntarily-participating States.

CORSIA allows aircraft operators to reduce its offsetting requirements through the use of CORSIA eligible fuels. Weighted average LCA\textsubscript{SAF} values of TABLE 2 are equally considered to calculate the net emissions reductions compared to the reference scenario\textsuperscript{43}.

### 3.3.2.2 REDUCED CORSIA COSTS

Today, offsetting a ton of CO\textsubscript{2} under CORSIA costs about €1. This report assumes that prices might end up anywhere between €1 and €13 by 2030\textsuperscript{44}. The following distribution is assumed:

<table>
<thead>
<tr>
<th>Year</th>
<th>€/tCO\textsubscript{2}</th>
</tr>
</thead>
<tbody>
<tr>
<td>2021</td>
<td>1.00</td>
</tr>
<tr>
<td>2022</td>
<td>2.33</td>
</tr>
<tr>
<td>2023</td>
<td>3.67</td>
</tr>
<tr>
<td>2024</td>
<td>5.00</td>
</tr>
<tr>
<td>2025</td>
<td>6.33</td>
</tr>
<tr>
<td>2026</td>
<td>7.67</td>
</tr>
<tr>
<td>2027</td>
<td>9.00</td>
</tr>
<tr>
<td>2028</td>
<td>10.33</td>
</tr>
<tr>
<td>2029</td>
<td>11.67</td>
</tr>
<tr>
<td>2030</td>
<td>13.00</td>
</tr>
</tbody>
</table>

With SAF, the reduced CORSIA costs without the implementation of the SES, without ATM optimisation measures and without new aircraft technology, for the period 2022-2030 compared to the reference scenario is around €\textbf{-0.6 billion} for the High scenario, €\textbf{-0.3 billion} for the Base scenario and €\textbf{-0.2 billion} for the Low scenario. This logically reflects the relative extent of CO\textsubscript{2} reduction performance and relative progress toward cutting net CO\textsubscript{2} emissions with SAF amongst the three scenarios.

### 3.4 Extra costs of policy measures over 2022-2030 without SES implementation, operational optimisation and fleet upgrade

In summary, with a carbon price of €\textbf{200/tonne}, the extra cost of the policy measures (with 10%, 5% and 4% of SAF in 2030) without the implementation of the SES, without ATM optimisation measures and without new aircraft technology, for the period 2022-2030 compared to the reference scenario (a hypothetical ‘do nothing’ scenario assuming 100% kerosene use, and considering that the 2021 in-service fleet is progressively replaced with aircraft available for purchase in 2021) is around €\textbf{62 billion} for both the Base and High scenarios, and €\textbf{55 billion} for the Low scenario. Of those figures, the additional costs in 2030 alone comprise of around €14 billion in the Base and High scenarios and over €\textbf{12 billion} in the Low scenario.

<table>
<thead>
<tr>
<th>Cumulative costs over 2022-2030 (€ billion)</th>
<th>High (with 10% SAF uptake in 2030)</th>
<th>Base (with 5% SAF uptake in 2030)</th>
<th>Low (with 4% SAF uptake in 2030)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Extra fuel mix costs (SAF/kerosene)</td>
<td>€12.1</td>
<td>€10.0</td>
<td>€4.3</td>
</tr>
<tr>
<td>Extra ETS costs*</td>
<td>€19.6</td>
<td>€23.2</td>
<td>€24.1</td>
</tr>
<tr>
<td>Reduced CORSIA costs**</td>
<td>€-0.6</td>
<td>€-0.3</td>
<td>€-0.2</td>
</tr>
<tr>
<td>Extra taxation costs</td>
<td>€30.9</td>
<td>€28.8</td>
<td>€26.6</td>
</tr>
<tr>
<td>Total extra costs</td>
<td>€62.0</td>
<td>€61.8</td>
<td>€54.8</td>
</tr>
</tbody>
</table>

* Lifecycle carbon savings with SAF leading to less CO\textsubscript{2} emissions in scope of the ETS does not outweigh the costs associated with the phasing out of aviation free emissions allowances from 2024 onwards, leading to increased ETS costs compared to the reference scenario.

** Using 4%, 5% or 10% SAF actually reduces the cost of CORSIA compared with a 100% kerosene reference scenario, resulting in a reduction in each of the scenarios.

The extra costs for increasing the share of SAF are relatively low compared to EU-ETS and kerosene taxation costs. Therefore, the ReFuelEU Aviation initiative brings net emissions savings at an affordable cost. Finally, SAF is price-
elastic, and the law of supply and demand implies that increasing demand will reduce production costs. To put these extra costs into perspective, this would translate as per TABLE 9 into the following extra costs per flight in the EUROCONTROL NM area, and for intra-EEA flights (which carry a higher per-flight cost, as all of these flights would be subject to all of these policy measures). The calculations are based on an estimated 13.8 million flights a year in the NM area (High), 12.1 million (Base) and 11.0 million (Low) with the corresponding figures for intra-EEA area flights 6.4 million, 5.7 million and 5.1 million respectively:

**TABLE 9: EXTRA COSTS OF POLICY MEASURES PER NM AREA AND INTRA-EEA FLIGHT**

<table>
<thead>
<tr>
<th>Extra cost per flight in 2030 (€)</th>
<th>High</th>
<th>Base</th>
<th>Low</th>
</tr>
</thead>
<tbody>
<tr>
<td>Extra cost per flight in 2030, NM Area</td>
<td>€1,003</td>
<td>€1,160</td>
<td>€1,127</td>
</tr>
<tr>
<td>Extra cost per flight in 2030, intra-EEA</td>
<td>€1,809</td>
<td>€2,087</td>
<td>€2,139</td>
</tr>
</tbody>
</table>

Using the average total operating cost per flight for the Boeing 737 Next Generation (NG) and Airbus A320 family, the increase in operating costs from policy measures considering intra-EEA flights is shown in TABLE 10 below:

**TABLE 10: IMPACT OF POLICY MEASURES ON INTRA-EEA FLIGHTS FOR A320 FAMILY AND B737 NG**

<table>
<thead>
<tr>
<th>Operating cost per flight cycle (€2019)</th>
<th>A320 Family</th>
<th>B737 NG</th>
</tr>
</thead>
<tbody>
<tr>
<td>With Policy measures – High scenario</td>
<td>€9,712 / +22.89%</td>
<td>€10,051 / +21.95%</td>
</tr>
<tr>
<td>(€2019 / % variation)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>With Policy measures – Base scenario</td>
<td>€9,990 / +26.41%</td>
<td>€10,329 / +25.32%</td>
</tr>
<tr>
<td>(€2019 / % variation)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>With Policy measures – Low scenario</td>
<td>€10,042 / +27.07%</td>
<td>€10,381 / +25.95%</td>
</tr>
<tr>
<td>(€2019 / % variation)</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

4 **INDUSTRY-DRIVEN RESPONSES**

This chapter looks at how aviation-specific and industry-driven measures can help achieve the 55% emissions reduction by 2030, and offset the costs identified above, were no actions to be taken.

4.1 **Modernising airline fleets will cut fuel consumption**

4.1.1 **NEW AIRCRAFT PROJECTS**

This section presents the new projects considered, both evolutionary and revolutionary, which will come on top of the conventional fleet and aircraft programmes currently available on the market. Until 2030, progress in airline fleet efficiency will essentially be driven by evolutionary technologies related to:

- aerodynamics (winglets, blended wing, etc.)
- materials (additive manufacturing, composite, nanomaterials)
- aircraft equipment systems, and
- propulsion (higher bypass ratio, open rotor, higher turbine temperature, etc.).

We expect that six new types of aircraft will take off from 2025 to 2030. The first revolutionary ones to be rolled out are:

- **9-seater electric aircraft** in 2025 followed by a **19 seater** version in 2030

  A 9-seater electric design, with an entry into service (EIS) in 2025, is possible, although it could be a year or two later. One of the most promising designs appears to be the Tecnam P2012 P-volt (or Aura Aero ERA), since it is backed by

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46 Eviation Alice, Aura Aero ERA aircraft, Heart Aerospace
well-established OEMs that have extensive certification experience. It could replace types such as the Pilatus PC-12 or Cessna 208, as well as find usage as business/air taxi aircraft.

A development of a larger 19-seat type in 2030 is also credible, given that several companies are talking about such types at present. Again, many of the prospective types are from new-entrant manufacturers, where certification may be an issue. It would logically replace types such as the DHC-6 or Dornier 228s that are used on essential air service-type routes in Europe.

- **A 30-to-40 seater hybrid electric aircraft** (also in 2030)
  
  With electric motor and battery developments that should first come into use in the turboprop aircraft market, and public criticism involving short-haul flights, a turboprop alternative considering hybrid electric propulsion is considered here. This should in particular rely on heavily modifying a ‘to be retired’ turboprop (e.g. Dash 8-100) and replacing its traditional propulsion design with a hybrid design. The aircraft would have a set of battery packs to drive an electric motor working in tandem with the engine, providing the necessary horse power when needed most (in particular at take-off and landing). Around a 20% fuel efficiency improvement is expected compared to current conventional turboprops.

The successful rollout of these new types of aircraft is however heavily reliant on progress made on battery energy density and on access to battery raw materials.

More efficient conventional aircraft may also be expected to be rolled out such as:

- **two different turboprops with regional jet characteristics** and capabilities
  
  At present, Embraer has an important market share in the 70-130 seat regional aircraft class, following the cessation of the MHI SpaceJet programme. Thus, it is not under any great pressure to develop an all-new, or re-engined, version of the E-Jet E2 family. It is difficult to envisage any other manufacturers developing an all-new RJ in the 2030 timeframe. However, Embraer itself is likely to develop a 70-90 seat conventional turboprop in the late 2020s, with around 20% fuel efficiency improvement expected compared to current regional jets.

In addition, we also consider:

- a **new wide-body aircraft** potentially replacing the current A350 or B787; and
- a **new single aisle aircraft**.

  This new single aisle aircraft would replace the Airbus A320 & A321neo and successor type, as well as Boeing 737 Max 8/9/10 and Boeing middle of the market (MoM). The timing and level of technology development are obviously interlinked; an earlier, circa 2028-2030, EIS implies developments of today’s engines (i.e. improved upgrades of LEAP or PW1000G), unless the R-R Ultrafan can be successfully brought to market.

We expect the last two aircraft models to achieve around a 30% fuel efficiency improvement compared to the previous generation of aircraft.

These assumptions are further developed in **TABLE 11** on the next page.
TABLE 11: EXPECTED ENTRY OF NEW AIRCRAFT TYPES INTO SERVICE 2025-2030, PER SCENARIO

<table>
<thead>
<tr>
<th>New type of aircraft</th>
<th>Size</th>
<th>Technology</th>
<th>Range</th>
<th>Aircraft segment</th>
<th>2025</th>
<th>2026</th>
<th>2027</th>
<th>2028</th>
<th>2029</th>
<th>2030</th>
</tr>
</thead>
<tbody>
<tr>
<td>Electric aircraft (2 versions)</td>
<td>9</td>
<td>Revolutionary</td>
<td>&quot;Very short Short&quot;</td>
<td>Turboprop</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>19</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Turboprop with regional</td>
<td>70</td>
<td>Evolutionary</td>
<td>Short &amp; Medium</td>
<td>Turboprop</td>
<td></td>
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<tr>
<td>jet specifications / capabilities</td>
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<tr>
<td>Turboprop with regional</td>
<td>90</td>
<td>Evolutionary</td>
<td>Short &amp; Medium</td>
<td>Turboprop</td>
<td></td>
<td></td>
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<tr>
<td>jet specifications / capabilities</td>
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<tr>
<td>Hybrid-electric</td>
<td>30-40</td>
<td>Revolutionary</td>
<td>&quot;Very short &amp; Short&quot;</td>
<td>Turboprop</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Conventional aircraft</td>
<td>170</td>
<td>Evolutionary</td>
<td>Medium &amp; long</td>
<td>Single aisle</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>(re-engined and upgraded)</td>
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<td></td>
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<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Wide body aircraft (re-engined and</td>
<td>300</td>
<td>Evolutionary</td>
<td>Long</td>
<td>Wide-body</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>upgraded)</td>
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</tbody>
</table>

The new type of aircraft column highlights the main characteristics of the aircraft. The aircraft segment column presents the segment corresponding to the aircraft type previously defined.

4.1.2 CO₂ SAVINGS

To capture the aircraft CO₂ reduction opportunities, we use the Aircraft Assignment Tool (AAT)\textsuperscript{47} to convert the passenger demand forecast into detailed operations by aircraft type and airport pair for a given future year and scenario. This takes into account aircraft retirement and the introduction of new aircraft into fleets. The forecast operations have been processed using EUROCONTROL’s IMPACT model\textsuperscript{48} to assess the fuel burn and CO₂ emissions data.

We consider both the new projects in TABLE 11, and aircraft and engine technology improvements on the fleet aircraft programmes currently available on the market. Assuming that by 2030 about 1/3 of the total fleet has been replaced, the CO₂ percentage reduction on the reference scenario is 1.9% for the Base scenario, 2.8% for the High scenario and 1.1% for the Low scenario. Between 2022 and 2030, this removes 19 million tonnes of CO₂ in the Base scenario, 30 and 9 million tonnes of CO₂ in the High and Low scenario respectively.

Bringing fleet renewal forward by 3-7 years is an even more efficient path to more rapid aviation decarbonisation, providing additional annual fuel and CO₂ emissions savings ranging from 1.7% to 5.3% over 2028-2030 (see section 7.2). Airlines’ strategy for aircraft replacement programmes could make a significant contribution in order to attain the -55% target with reduced reliance on market-based measures.

4.2 Operational improvements will optimise flight efficiency

4.2.1 INTRODUCTION

Operational improvements aiming at improving the carbon footprint of aircraft - and related airport - operations are a key set of measures where benefits can be achieved in the short to medium term, and as such may be considered low-hanging fruit in the move towards a net zero carbon emissions target. They consist primarily of optimising flight efficiency (by enabling the flying of optimal, more fuel-efficient trajectories), introducing specific operational measures that reduce fuel burn (such as measures that reduce holding/sequencing times), and minimising fuel burn in aircraft operations in all phases of flight (e.g. through better aircraft weight management and optimising fuel management practices).

It should be noted that reducing CO₂ emissions from ATM and operational measures is a shared task that may fall primarily on air traffic control (ATC) and aircraft operators/flight crew, but also involves many other operational stakeholders, such as airport operators, flight planning companies and the EUROCONTROL NM, all of whom need to play their part to maximise the potential for ATM and operational measures to support decarbonisation.

Most of the technical solutions enabling greener operations are available today; the main remaining challenge is thus to

\textsuperscript{47} Jointly developed by the European Commission, EASA and EUROCONTROL. See https://www.easa.europa.eu/eaer/appendix
\textsuperscript{48} https://www.eurocontrol.int/platform/integrated-aircraft-noise-and-emissions-modelling-platform
accelerate their deployment.

4.2.2 OPTIMISED FLIGHT TRAJECTORIES

If an aircraft were alone in the sky, using modern flight planning software and the latest meteorological data, the operator could plan for a minimal amount of fuel, knowing that no constraints could influence its optimal trajectory. On the ground, the flight could utilise the airport’s green energy to provide power on stand, and use an electric taxi solution to taxi directly to the runway with no restrictions for take-off. The flight could fly an optimal climb phase, following a parabolic arc to its most fuel-efficient cruising level, on a direct track from departure airport to destination. Once at the optimal top of descent point, the aircraft could then reduce thrust and follow an idle thrust descent down to the runway, to be followed by an electric taxi solution to the stand, and renewed use of airport green energy infrastructure in the turnaround phase.

These operations could be further enabled by weight (and thus fuel/CO₂) minimising operator practices, such as the use of lighter aircraft paint, optimised aircraft cleaning and maintenance processes, the use of zonal dryers to reduce condensation, and fuel efficiency software that monitors and optimises all aspects of fuel usage.

In the future, flights could benefit from novel solutions that not only reduce fuel burn but also actively remove it from flight phases. One example of such a measure is that of electric taxi solutions.

However, 100% flight efficiency is not achievable. All flights are subject to certain amounts of constraints. While safety is paramount, trade-offs have to be made between efficiency and capacity; departures and arrivals; civil and military traffic; delay and costs; horizontal and vertical flight efficiency, together with taking into account other factors such as the weather. Constraints may also include airport congestion and the limitations of flight planning software.

Minimising the carbon emissions generated by air traffic therefore requires a balanced approach that unlocks capacity across the whole network, while allowing each aircraft to achieve optimal flight performance, in view of the conditions of the day.

4.2.3 AIRSPACE MODELLING

In order to assess the expected fuel burn/CO₂ benefits that could be delivered by ATM and other operational measures by 2030, we have undertaken an analysis of the fuel burn/CO₂ impact on European airspace for the future scenarios.

The EUROCONTROL NM has developed a catalogue of airspace design projects for the ATS (Air Traffic Services) Route Network (ARN) Version 2021 – 2030. These projects are detailed in the European Route Network Implementation Plan (ERNIP) Part 2 (2021 – 2030) [Ref15.]. It considers the 385 packages of airspace proposals scheduled for implementation over 2021-2030 covering:

- A comprehensive cross-border implementation of Free Route Airspace (FRA), at least at and above FL310, in European airspace;
- An optimised route structure below FRA ensuring efficient connectivity in/out terminal airspace;
- A simplification of the RAD; and
- More efficient Flexible Use of Airspace (FUA) procedures and the associated system support to enable a better utilisation of civil/military airspace structures.

Using the EUROCONTROL STATFOR forecast, a baseline scenario was created for 2030 by assigning future traffic onto the 2019 route network. The traffic assignment was based on the standard EUROCONTROL NM “assignment on the shortest city pair” to create the traffic trajectories. A future scenario was then created for 2030 based on assigning the same 2030 traffic forecast to the route network, assuming the updates as laid down in [Ref15.] are implemented by 2030. By analysing the fuel burn/CO₂ predicted under these two scenarios, we estimate the fuel burn/CO₂ savings that may be expected from the implementation of the future route network between 2019 and 2030.

These scenarios were then run through the EUROCONTROL R-NEST49 modelling tool.

From the simulation results, which included a set of gate-to-gate fuel burn/CO₂ data for flights on each city pair, the data were analysed which provided the possibility to both estimate the performance impact of the new route network on each city pair; and to aggregate the data by different traffic zones to understand the total fuel burn/fuel burn savings that could be achieved in the updated route network in 2030, compared to the 2019 route network.

Once this analysis had been completed, an additional study was undertaken to further assess the fuel (CO₂) savings that could be expected from the expected implementation of ATM and other operational measures out to 2030, on top of those to be provided by the optimised route network. This study was undertaken by developing rules of thumb (RoT) based on the fuel burn/CO₂ saving benefits expected by a generic implementation of each operational measure. These RoT were applied to each airport / airspace where each operational measure was expected to be implemented.

49 https://www.eurocontrol.int/solution/rnest
4.2.4 RULE OF THUM (ROT) STUDY

4.2.4.1 GENERIC APPROACH

A list of ATM and other operational measures that are expected to be implemented in the NM area was compiled from various sources such as EUROCONTROL, the Single European Sky ATM Research (SESAR) programme, ICAO and other European ATM/operational stakeholder sources such as the Destination 2050 report. For more information, see Annex 2.

For each operational measure, a rule of thumb (RoT) fuel saving estimate was developed for a generic implementation of each measure based on a certain set of assumptions. These included assumptions for average fuel burn per flight, average movements per airport, and expected implementation dates for the various operational measures (e.g. based on SESAR and CP1 target implementation dates). It should be noted that where 2030 implementation data were not available, assumptions of the implementation rate were made on the conservative side.

For each RoT, and where sufficient data were available, a low/high estimation of potential benefits was assessed in order to demonstrate the range of fuel/CO\textsubscript{2} saving benefits possible, depending on the aggressiveness of the deployment scenario.

Other assumptions to be made included for those measures where a progressive performance improvement was estimated, again erring on the conservative side. For those measures where industry reports had estimated large benefits based on greater insight, the high-range benefit value was kept. A much more conservative value for the low-range value was introduced.

4.2.4.2 CARBON REDUCTION POTENTIAL AND SCENARIOS

For ATM and operational measures, investment in supporting technologies is influenced not only by market growth but also public perception as well as industry goals and standards. For example, the COVID crisis has led to the acceleration of support to prioritise the deployment of operational measures that reduce CO\textsubscript{2} as seen in the work developing updates of the new ICAO Global Air Navigation Plan. The High scenario assumes a high rate of benefits that push on from the more conservative approach of the other scenarios, and includes a wider deployment of ANS-related operational measures that may remove fuel/CO\textsubscript{2} from the fuel efficiency benefit pool as opposed to just reducing them. This scenario also includes assumptions related to operator actions; that investment is fully realised in maintenance and other weight reduction measures, together with aggressive investment in new avionics equipment and fuel efficiency software that support advanced operational procedures combined with the latest big data analyses.

Regardless of the widespread support for deployment of operational measures that contribute to a reduction in fuel/CO\textsubscript{2}, the Low scenario assumes that current deployment rates continue in line with current regulations, and that there is limited influence of external pressures to further address and support the decarbonisation process on top of what is already planned.

The Base scenario assumes medium-level investment that recognises the potential of ATM/operational measures as low-hanging fruit that support the decarbonisation of the aviation sector in the short to medium term, but also starts to be more ambitious in mobilising operators and air navigation services (ANS) providers to invest further, and prioritise investment in, and deployment of, those measures that may have environmental benefits as opposed to maximising capacity.

4.2.5 ATM / OPERATIONAL MEASURES TO IMPROVE FUEL EFFICIENCY

The ATM and operational measures addressed in this analysis come from multiple sources, as per section 4.2.8.

FIGURE 22 below shows that the ANS-related excess gate-to-gate fuel burn inefficiency in 2018-2020 was estimated to be around 6% of the unimpeded trajectory fuel burn. It should be noted however that the unimpeded trajectory may not represent the optimal profile (lowest fuel/CO\textsubscript{2}), as it does not take into account additional factors such as wind. In addition, it may be possible to identify further inefficiencies by using indicators that rely directly on fuel burn (CO\textsubscript{2} emissions) as opposed to operational proxies such as level or time. Furthermore, the introduction of new concepts into the ATM system may actually result in a larger efficiency benefit pool than is currently the case.
In 2020, the EUROCONTROL NM estimated that the average fuel inefficiency in the network was actually between 8.6 to 11.2% based on a statistical analysis of ETFMS fuel data [Ref16]. This analysis was undertaken by comparing the fuel burn for each flight in a city pair/aircraft type combination to a reference based on the 10th and 5th lowest fuel burn values for the individual aircraft type/city pair combination. It should be noted that these figures are not related to ANS/ATM alone, but also includes system inefficiency from a multi-stakeholder perspective e.g.:

- Airports, e.g. SIDs / STARs / NADPs;
- CFSP (Computerised Flight Plan Service providers), e.g. flight and fuel planning systems;
- Aircraft operators, e.g. lowest cost profile vs lowest environmental profile;
- ANSPs, e.g. military activity, runway throughput, etc.; and,
- The network itself, e.g. airspace design and constraints.

**4.2.6 Phases of Flight**

Based on the latest technological concepts and deployment strategies together with local expertise, aviation stakeholders have developed and deployed a number of operational measures to improve flight and fuel efficiency. Some of these measures may provide benefits for the aircraft at the gate-to-gate level, while others may be more applicable to a specific phase of flight. For the benefits of this analysis, the measures to be considered have been broken down per phase of flight.

### 4.2.6.1 Gate to Gate

As mentioned, the EUROCONTROL NM has developed a catalogue of airspace design projects for the ATS Route Network (ARN) Version 2021 – 2030 [Ref15]. These changes in route structure are modelled as gate-to-gate benefits.

### 4.2.6.2 Climb

Fuel inefficiency in the climb phase is usually as a result of an inefficient vertical profile or the additional distance flown as a result of noise-related measures. **Figure 22** estimates ANS-related inefficiency in the climb phase to be in the range of 0.06% of total fuel burn/CO$_2$. Fuel efficiency improvements in the climb phase are primarily estimated to arrive via optimised Continuous Climb (CCO) Operations and the deployment of new optimised PBN (Performance-Based Navigation) SIDs (Standard Instrument Departures). In 2018, EUROCONTROL estimated that for those flights currently flying non-CCO profiles, the average time in level flight from departure to the ToC was 168 seconds, with per-flight savings estimated at 15kg fuel/48kg CO$_2$. In addition, certain aircraft procedures such as rolling take-offs may also help reduce fuel burn in the take-off phase, while optimised flight planning processes may help to optimise the vertical profile, taking into account existing constraints that are visible to flight planners.

### 4.2.6.3 Cruise

Fuel inefficiency in the cruise or en-route phase has many sources. **Figure 22** estimates ANS-related horizontal flight inefficiency in the en-route phase to be around 2.26%. In addition, ANS-related vertical flight inefficiency is estimated to be around 1.06%. Flights in Europe may suffer fuel burn inefficiency in the en-route phase by flying indirect routes or having to adapt to airspace constraints, such as military areas. Alternatively, fuel inefficiency may arise from flights being level capped to reduced congestion in upper airspace sectors or to join/leave optimal cruising altitudes late/early in order to keep separation between other climbing/descending aircraft and overflights. On average, an increase of 1 minute in distance flown may result in additional fuel burn of around 40kg fuel, while cruising at 2,000 feet below the optimal cruising level may have a fuel burn penalty of around 2%.

In addition, an aircraft operator may choose a trajectory that is optimised in terms of weather (resulting in flying a longer route...
to benefit from optimised winds that result in lower fuel burn), or may fly a longer route that results in a lower overall cost to the airline even if it does not have the lowest fuel burn costs.

Any operational measure that can improve horizontal and/or vertical flight efficiency will improve fuel efficiency. Measures to reduce fuel inefficiency that arises due to ATM or ANS-related constraints include FRA, whereby flights are able to fly any trajectory they wish between a designated airspace entry/exit point; and FUA, whereby military airspace is released for civil use as soon as it is no longer required.

Additional enablers to optimising fuel inefficiency include the provision of MET data en-route to enable the flight crew to optimise their profile based on the latest data, optimised speed control and optimised routing options facilitated by the EUROCONTROL NM’s flight efficiency proposals.

In the coming years, new measures may appear that can have an impact on not just improving flight efficiency but also on removing fuel burn from the flight efficiency benefit pool. These measures may include the provision of User Preferred Routings (UPR) over the North Atlantic (as opposed to the OTS – Organised Track System), or formation flights where following aircraft benefit from the lift generated by a leading aircraft, resulting in lower fuel burn.

**4.2.6.4 DESCENT**

FIGURE 22 estimates ANS-related vertical flight inefficiency in the descent phase to be around 0.62%. Such inefficiency may be primarily caused by an inefficient Top of Descent (ToD) point. An ideal descent profile consists of an idle descent from ToD. If this profile is interrupted by airspace constraints – be they present to remove flows from congested sectors or to separate conflicting traffic flows – resulting in inefficient intermediate level segments, corresponding fuel burn increases will arise. In fact, EUROCONTROL has estimated that for those flights currently flying non-CDO profiles, average time in level flight from the ToD to 2500ft was 217 seconds, with per-flight savings estimated at 46kg fuel/145kg CO₂.

Solutions may include implementing CDO from ToD using altitude windows aligned to the typical flight profiles of the aircraft fleet that fly each approach whilst an Extended Arrival Manager (XMAN) can reduce descent phase fuel burn by slowing aircraft down prior to the start of the descent phase, reducing the time spent at lower, more inefficient levels.

Novel solutions may include the provision of a downlinked ToD point that may help to provide ATC with sufficient information to facilitate an optimised descent profile.

**4.2.6.5 APPROACH**

FIGURE 22 estimates ANS-related horizontal flight inefficiency in the en-route phase to be around 1.34%. The vast majority of this inefficiency comes from the need to sequence and organise traffic so that runway usage can be optimised in a safe and sustainable manner. While individual solutions may improve runway throughput, and thereby potentially increasing capacity, any solution that decrease the arrival delay or sequencing time can result in reduced fuel burn.

In addition to the 3D profile, inefficiencies can also result from time. While the XMAN can help flights to absorb delay at higher levels, the AMAN (Arrival Manager) helps to optimise the arrival sequence of aircraft so as to ensure a safe and minimal separation between succeeding aircraft. Solutions such as Point Merge systems can enhance sequencing, while the new re-categorisation of wake vortex separations into six categories and eventually to pairwise separations, together with a focus on time-based separations, can reduce both time in the approach phase and taxi time for departures. The addition of new infrastructure such as a GBAS (Ground Based Augmentation System) together with new approaches such as increased glide slopes, or new PBN solutions, can result in increased accessibility, reduced missed approaches, and reduction in the size of the ILS critical area, all resulting in a corresponding reduction in fuel burn and emissions.

**4.2.6.6 GROUND**

In FIGURE 22, ANS-related inefficiency is estimated to be around 0.61% for taxi-out and 0.28% for taxi-in. Ideally, an aircraft will taxi direct from stand to runway and vice versa; therefore, any ground constraints will have an impact on fuel burn. Such constraints may include taxi queues, crossing traffic, etc. Reduction in ground separation may be exacerbated by bad weather. As aircraft weight has a high impact on fuel burn, the amount of fuel burn associated with taxi-out is usually considerably higher than that associated with taxi-in.

There are many measures that may result in a reduction in taxi time and a corresponding reduction in fuel burn and emissions. These range from direct benefits from the deployment of concepts such as A-SMGCS (Advanced Surface Movement Guidance and Control System) or ‘Follow the Greens’ technology, indirect benefits such as those arising from a reduction in the size of the ILS critical area (GBAS), or a reduction in the departure queue allowing enhanced throughput (RECAT).

In addition, fuel burn can be considerably reduced by aircraft operator actions such as ‘less than all engine taxi’, should the airport layout facilitate such procedures without penalising other aircraft. New concepts currently being used in a few locations, but anticipated to be more extensively used in the future, should allow the removal of fuel burn from the fuel inefficiency benefit pool if taxi fuel burn can be lowered by the use of electric taxi solutions.
With many operational measures from ATC, airports and operators resulting in a similar benefit mechanism, i.e. a reduction in taxi time/taxi fuel burn, care should be taken to avoid overlaps and overestimations of benefits by multiple sets of solutions.

4.2.6.7 OPERATOR ACTIONS – REDUCING WEIGHT

In addition to measures to improve ATM and ANS-related fuel efficiency, there is also considerable potential for aircraft operators to enhance their procedures and processes to improve fuel efficiency from their perspective. A large majority of these measures are based upon the premise of reducing aircraft weight and other related practices.

A lighter aircraft results in lower fuel burn; an aircraft also burns fuel simply to carry fuel. IATA estimates that for an aircraft to carry additional weight, the extra fuel carriage that is attributable to that extra weight is typically in the order of 2.5 to 4.5% of the additional weight, per hour of flight.

Whilst aircraft operators have many choices to make to reduce aircraft weight, e.g. by utilising lighter weight seating, an Electronic Flight Bag (EFB) restricting the amount of duty-free goods sold on board, etc., the measures included in this analysis are restricted to those that have been demonstrated to provide fuel efficiency improvements.

With the availability of fuel efficiency software and QAR (Quick Access Recorder) data comes the possibility to analyse fuel burn in many different slices. In addition, enhanced fuel burn predictability provides flight crew with more confidence in their flight planning processes. This may enable a reduction in discretional fuel, which together with last minute fuel (and water) uptakes, based on the final most accurate aircraft load, and a reduction in fuel tankering, may significantly enable the required fuel onboard to be optimised to a minimum that still lies within safe limits.

4.2.6.8 OPERATOR ACTIONS – NON-FUEL

In addition to focusing on measures that reduce fuel carriage directly or minimise aircraft weight, there are other measures that can make the aircraft lighter and/or more aerodynamic, and thus also deliver more fuel-efficient flights. These include the use of lighter aircraft paint, the use of zonal dryers to reduce water condensing in the fuel tanks (up to several hundred kilogrammes may collect), and enhanced cleaning and maintenance procedures.

In addition, FMS (Flight Management System) updates and the development of new avionics to support advanced flight procedures can provide enhanced functionalities to aircraft and allow further optimisation to the flight profile in real-time, as opposed to flight profiles generated before the top of climb.

4.2.7 RESULTS

The SES provides the necessary policy and regulatory framework to enable the industry to deliver the necessary airspace modernisation.

The R-NEST analysis reveals that a 2.48% fuel and CO₂ saving benefits is expected as a result of the implementation of the airspace changes detailed in ERNIP Part 2, from 2019 out to 2030.

The RoT study, based on the planned implementation of ATM and other operational measures, out to 2030, is estimated to provide additional fuel burn/CO₂ savings of between 4.53-8.4% depending on the level of implementation by each stakeholder. These results can be further broken down into flight phase and operator savings, as can be seen in TABLE 12 below. Within each flight phase there may be several benefit mechanisms, e.g. reduction in taxi time, reduction in vectoring, reduction in distance flown, etc. With the assignment of each measure to a flight phase, it should be noted that it was part of the validation process to ensure that the different measures with potentially the same benefit mechanism did not duplicate the amount of benefits available and overestimate the overall benefits.

Based on the analysis, the expected fuel savings in 2030 per flight phase and operator category are estimated to be in the following ranges:


### TABLE 12: FUEL BURN / CO2 SAVINGS FROM OPERATIONAL IMPROVEMENTS

<table>
<thead>
<tr>
<th>OPERATIONAL MEASURES – LOW HANGING FRUITS</th>
<th>High</th>
<th>Base</th>
<th>Low</th>
</tr>
</thead>
<tbody>
<tr>
<td>Climb</td>
<td>0.61%</td>
<td>0.33%</td>
<td>0.04%</td>
</tr>
<tr>
<td>En-route</td>
<td>2.28%</td>
<td>1.71%</td>
<td>1.13%</td>
</tr>
<tr>
<td>Descent</td>
<td>0.12%</td>
<td>0.12%</td>
<td>0.12%</td>
</tr>
<tr>
<td>Approach</td>
<td>0.56%</td>
<td>0.46%</td>
<td>0.35%</td>
</tr>
<tr>
<td>Taxi</td>
<td>1.89%</td>
<td>1.43%</td>
<td>0.97%</td>
</tr>
<tr>
<td>Ground</td>
<td>0.3%</td>
<td>0.30%</td>
<td>0.3%</td>
</tr>
<tr>
<td>Operator - reducing weight (fuel)</td>
<td>1.01%</td>
<td>1.01%</td>
<td>1.00%</td>
</tr>
<tr>
<td>Operator - non fuel actions</td>
<td>1.63%</td>
<td>1.13%</td>
<td>0.62%</td>
</tr>
<tr>
<td><strong>TOTAL</strong></td>
<td><strong>8.4%</strong></td>
<td><strong>6.46%</strong></td>
<td><strong>4.53%</strong></td>
</tr>
</tbody>
</table>

### 4.2.8 DATA SOURCES

#### 4.2.8.1 ICAO

ICAO, the International Civil Aviation Organization, has previously carried out analyses on the environmental savings expected from the global deployment of the operational measures contained with the ICAO Aviation System Block Upgrade (ASBU) Framework blocks 0 and 1, based on States’ planned implementation of each operational measure out to 2025. This work developed RoT fuel saving benefits for a generic deployment of each operational measure based on trials, case studies and other factual data together with States’ actual implementation plans.

This work has been further supplemented by other work within ICAO’s Committee of Aviation Environmental Protection (CAEP). This work undertook a bottom-up analysis to estimate the potential for fuel and emissions savings from each wedge of the ICAO basket of measures, in order to facilitate the creation of a potential long-term aspirational goal for CO2 reduction, out to 2070. This work also involved developing RoT fuel saving benefits for a generic deployment of each measure, noting that for some future concepts, readiness and attainability estimates were based upon expert judgement as opposed to using concrete implementation plans, as they were so far in the future.

Some of these RoT have been detailed in ICAO Doc. 9988, Guidance Material for the Development of States’ Action Plans.

#### 4.2.8.2 CP1

CP1 or Common Project 1 is a new European regulation ensuring the continuation of sustainable ATM modernisation and digitalisation through SESAR deployment, with the aim to accelerate the digitalisation of European ATM towards a greener aviation sector. CP1 builds upon the achievements and the lessons learned from the pilot phase to continue the modernisation efforts of the European ATM industry and deliver a more scalable and environmentally sustainable ATM system.

CP1 contains the ATM functionalities and sub-functionalities that have reached suitable maturity for their implementation, requiring synchronisation of activities, and addressing the essential operational changes defined in the EU’s ATM Master Plan (ATM MP). A specific implementation timeline has been set for these ATM functionalities and sub-functionalities, with the overall final implementation deadline set to 31 December 2027.

#### 4.2.8.3 SESAR

In 2016 the SESAR Joint Undertaking delivered its SESAR 1 performance assessment. This performance assessment was based upon validation exercises undertaken by SESAR partners to assess the benefits and maturity of different SESAR solutions, and highlighted the expected fuel saving performance from a number of SESAR solutions that were planned to be implemented out to 2030. For each measure, an assessment was provided on the fuel savings associated with the implementation of each operational measure, together with an estimation of the number of flights which would benefit from the implementation of the operational measure. These data then enabled individual fuel savings estimated to be broken down into generic fuel savings per network flight.
4.2.8.4 INDUSTRY

In 2020 a number of industry groups delivered reports to demonstrate how the European aviation industry could reach net zero CO₂ emissions. These reports included ‘Destination 2050’, where five key European aviation stakeholders, representing European aircraft manufacturers, airlines, airports and ANSPs, came together to plan a route to achieve net zero [Ref17.]. In a second report, Waypoint 2050, the Air Transport Action Group (ATAG), representing the full spectrum of the global aviation business, delivered a commitment by 2050 to halve aviation’s CO₂ global emissions compared with what they were in 2005 [Ref18.].

Both these reports have focused sections related to ATM and other operational measures, and include sources of information that are not always available to aviation stakeholders, such as fuel saving benefits that can be attributed to airline activities such as enhanced flight planning processes, weight reduction and aircraft cleaning and maintenance.

4.2.8.5 THE EUROCONTROL NETWORK MANAGER

The EUROCONTROL NM manages the European route network across ECAC States, together with comprehensive agreements in place to provide network services with Morocco and Israel as well as other States.

The EUROCONTROL NM has a Flight Efficiency Team responsible for liaising with aircraft operators to help them identify optimal routes which may not be available under normal flight planning processes, and improve both horizontal and vertical flight efficiency possibilities based on the dynamic network situation. This team is able to identify city pairs where flight efficiency can be optimised, and share the information with interested stakeholders so that they can further improve their tactical route planning.

5 INDUSTRY-DRIVEN RESPONSES CAN MAKE A SIGNIFICANT CONTRIBUTION

FIGURE 23 to FIGURE 25 show the CO₂ forecast for the three scenarios by addressing all IFR (Instrument Flight Rules) flights, estimated for their emissions within the EUROCONTROL NM area. They also show (rounded numbers) the emissions situation in 2030.

The reference scenario bounds the first wedge on the charts to define the expected growth in CO₂ emissions in 2030 in the EUROCONTROL NM area without any action being taken to improve the carbon efficiency of these flights. Using the assumptions defined in Chapter 4, the effects of airspace modernisation (yellow wedge), operational measures (orange wedge), and aircraft technology (red wedge) are added to deliver fuel efficiency improvements. The use of SAF is then re-enforced (pale blue wedge), resulting in a combined net emissions saving. The green dotted line sets at 34 MtCO₂ in 2030 the required cut of emissions by 55% compared to 1990 levels for the EUROCONTROL NM area.

To achieve this goal of reducing emissions, market-based measures (ETS and CORSIA) are then considered (dark blue wedge).

In the Base scenario (FIGURE 23 below), the hypothetical “no improvements” trajectory for CO₂ emissions in the EUROCONTROL NM area defines a growth in emissions to 210 Mt. This serves as the reference against which the following anticipated improvements are measured:

- 5.1 MtCO₂ saving from airspace modernisation
- 13.2 MtCO₂ saving from operational measures
- 3.8 MtCO₂ from modernising airline fleets (renewal of the fleet on top of the 2021 in-service fleet replacement with aircraft available for purchase in 2021)
- 8.1 MtCO₂ saving from sustainable aviation fuels
- 145.5 MtCO₂ saving from market-based measures
FIGURE 23 – CONTRIBUTION OF POLICY AND INDUSTRY DRIVEN MEASURES OVER 2022-30 IN REACHING -55% (BASE SCENARIO)

FIGURE 24 – CONTRIBUTION OF POLICY AND INDUSTRY DRIVEN MEASURES OVER 2022-30 IN REACHING -55% (HIGH SCENARIO)
Industry-driven measures including increased use of SAFs are translated in FIGURE 26 for the three scenarios into savings in CO₂ emissions, and their proportional contribution to achieving the -55% target in 2030:

**FIGURE 26 – CO₂ EMISSIONS SAVINGS & CONTRIBUTION TO -55% TARGET IN 2030**

<table>
<thead>
<tr>
<th></th>
<th>High</th>
<th>Base</th>
<th>Low</th>
</tr>
</thead>
<tbody>
<tr>
<td>Savings from ATM improvements</td>
<td>25.5 MtCO₂ / 12.4%</td>
<td>18.3 MtCO₂ / 10.4%</td>
<td>13.0 MtCO₂ / 8.3%</td>
</tr>
<tr>
<td>Savings from fleet upgrade</td>
<td>6.1 MtCO₂ / 3%</td>
<td>3.8 MtCO₂ / 2.1%</td>
<td>1.9 MtCO₂ / 1.2%</td>
</tr>
<tr>
<td>Savings from SAF</td>
<td>18.0 MtCO₂ / 8.8% emission reduction</td>
<td>8.1 MtCO₂ / 4.6% emission reduction</td>
<td>6.1 MtCO₂ / 3.9% emission reduction</td>
</tr>
<tr>
<td>Emission Reduction Potential</td>
<td>49.6 MtCO₂ saving / 24.1%</td>
<td>30.2 MtCO₂ saving / 17.2%</td>
<td>21.0 MtCO₂ saving / 13.4%</td>
</tr>
</tbody>
</table>

In other words, industry-driven measures (including higher than mandated SAF uplift) could represent from **13.4%** to **24.1%** of the net emissions savings in 2030, depending on the pace of decarbonisation. The vast majority of the remainder would thus need to rely on market-based measures such as ETS and CORSIA.
6 REDUCED COSTS FROM INDUSTRY-DRIVEN MEASURES

If the emissions reductions from operational improvements and fleet upgrades could be achieved by 2030, fuel consumption could also be reduced by 17.2% in the Base scenario, 24.1% and 13.4% in the High and Low scenarios respectively. These improvements in terms of fuel efficiency would reduce costs in terms of smaller volume of fuel used, decrease the cost of taxation on kerosene, lower the costs related to the number of allowances to be bought for ETS/CORSIA, and reduce extra costs related to SAF, as less SAF is required.

6.1 Volumes of SAF

In 2030, for 4.6% of the EUROCONTROL NM area’s carbon savings to be met through the use of SAF in the Base scenario, 3 Mt of SAF production would be required. For the period 2022-2030, the SAF production is estimated to be 14.3 Mt (FIGURE 27). This corresponds to:

- 12.4 Mt of HEFA fuel
- 0.93 Mt of fuel from gasification integrated Fisher-Tropsch process
- 0.93 Mt of jet fuel from ethanol
- 0.02 Mt of eSAF

FIGURE 27 – REQUIRED SAF PRODUCTION (IN MT) 2022-2030 FOR THE BASE SCENARIO
Under the high scenario, the SAF production requirements to cover the demand in the NM area over 2022-2030 reaches 27.7 Mt (6.6 Mt in 2030).

In the Low scenario, the level of required SAF production is of 10.7 Mt over 2022-2030 (2.2 Mt in 2030).

Operational improvements and fleet upgrade have reduced the required SAF production volume over 2022-2030 by 1.2 Mt for the base scenario (3.1 Mt for the high and 0.6 Mt for the low scenarios).

**6.2 ETS allowances and CORSIA offsetting requirements**

The phasing out of aviation’s free emissions allowances from 2024 onwards results in an increase of around 77 million allowances for auctioning in the period 2024-2030 even under the Base scenario (and over 47 million under the High scenario and 93 million under the Low scenario). Compared to the numbers in section 3.3.1, emissions reductions from industry-driven measures result in 39 million less allowances for the base scenario (51 million for the high scenario and 28 million for the low scenario).
Over 2022-2030, CORSIA’s offsetting requirements from international flights within the EUROCONTROL NM area will be **228 million tonnes** in the Base scenario as shown in **FIGURE 30 (282 million tonnes)** in the High scenario (**FIGURE 31**) and **183 million tonnes** (**FIGURE 32**) in the Low scenario.

For the three scenarios, due to the COVID-19 pandemic, offsetting is almost zero for the three scenarios until 2023. CORSIA offsetting requirements rapidly plateau and start to decline from 2027/2028 onwards. Carbon savings and reduced offsetting requirements through the use of SAF outweigh the implications of traffic growth.

Industry-driven measures result in a **85 million** tonne reduction in the Base scenario, **142 million** in the High scenario and **60 million** in the Low scenario.

**FIGURE 30 – CORSIA OFFSETTING REQUIREMENTS FOR THE BASE SCENARIO (IN MT)**
6.3 Lowering the cumulative cost of decarbonisation measures

6.3.1 REDUCED FUEL COSTS

Compared to the reference scenario, industry-driven measures drastically reduce the fuel costs (mix SAF/kerosene) by €11.4 billion in the Base scenario (by €18.5 billion in the High scenario, and by €22.4 billion in the Low scenario).
FIGURE 33 – DIFFERENTIAL FUEL COSTS – 2022-2030 (IN € BILLION)

6.3.2 EXTRA ETS COSTS

Against the reference scenario, ETS costs augment to €14.9 billion over 2022-2030 in the Base scenario (€8.7 billion in the High scenario and €18.3 billion in the Low scenario).

FIGURE 34 – DIFFERENTIAL ETS COSTS – 2022-2030 (IN € BILLION)

6.3.3 REDUCED CORSIA COSTS

For the period 2022-2030 compared to the reference scenario, the cost of CORSIA allowances is reduced by €0.8 billion for the Base scenario (€1.4 billion for the High scenario and €0.6 billion for the Low scenario).
6.3.4 EXTRA TAXATION COSTS

Between 2024 and 2030, taxation on kerosene applied to intra-European flights increases aircraft operators’ costs by an estimated €26.2 billion in the Base scenario, rising to €27.40 billion in the High scenario and by €24.7 billion in the Low scenario.

6.3.5 OVERALL DECARBONISATION EXTRA COSTS

Combining FIGURE 33 to FIGURE 36, FIGURE 37 shows the yearly differential net costs for airspace users over 2022-2030. Clearly the Base scenario is the most expensive. Starting in 2027, the High scenario shows a downward trend that is likely to continue beyond 2030. The curve for the differential costs for the High scenario intersects the Low scenario curve in 2025-2026. Hence, from that point onwards, the extra costs of decarbonisation are passed on to passengers at lower prices than in other scenarios.
FIGURE 37 – YEARLY DIFFERENTIAL COSTS FOR THE EUROCONTROL NM AREA, ALL FLIGHTS (IN € BN)

**TABLE 13** compares the costs “before” (i.e. the extra cost of policy measures without industry-driven measures, as per **TABLE 8**) and “after” those industry-driven measures have been applied.

**TABLE 13: OVERALL DECARBONISATION EXTRA COSTS (IN € BILLION)**

<table>
<thead>
<tr>
<th>Cumulative costs over 2022-2030 (€ billion)</th>
<th>High (with 10% SAF uptake in 2030)</th>
<th>Base (with 5% SAF uptake in 2030)</th>
<th>Low (with 4% SAF uptake in 2030)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Before industry measures</td>
<td>After industry measures</td>
<td>Before industry measures</td>
</tr>
<tr>
<td>Extra fuel mix costs (SAF/kerosene)</td>
<td>€12.1</td>
<td>€18.5</td>
<td>€10.0</td>
</tr>
<tr>
<td>Extra ETS costs</td>
<td>€19.6</td>
<td>€8.7</td>
<td>€23.2</td>
</tr>
<tr>
<td>Reduced CORSIA costs</td>
<td>€-0.6</td>
<td>€1.4</td>
<td>€-0.3</td>
</tr>
<tr>
<td>Extra taxation costs</td>
<td>€30.9</td>
<td>€27.4</td>
<td>€28.8</td>
</tr>
<tr>
<td>TOTAL cumulative costs</td>
<td>€62.0</td>
<td>€16.4</td>
<td>€61.8</td>
</tr>
</tbody>
</table>

**TABLE 14**, by subtracting the extra costs including industry-driven measures (“after industry measures”) from the policy measure-only costs (“before industry measures”), reveals the degree to which implementing industry-driven measures can drastically reduce the cost of the decarbonisation measures, resulting in a **€32.9 billion** cost reduction in the Base scenario, and by **€45.7 billion** in the High scenario.
TABLE 14: CUMULATIVE POTENTIAL INDUSTRY-DRIVEN SAVINGS FOR THE 3 SCENARIOS (IN € BILLION)

<table>
<thead>
<tr>
<th>Cost savings from industry-driven measures 2022-2030 (€ billion)</th>
<th>High (with 10% SAF uptake in 2030)</th>
<th>Base (with 5% SAF uptake in 2030)</th>
<th>Low (with 4% SAF uptake in 2030)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fuel cost mix savings (SAF/kerosene)</td>
<td>€30.6</td>
<td>€21.4</td>
<td>€26.7</td>
</tr>
<tr>
<td>ETS cost savings</td>
<td>€10.9</td>
<td>€8.3</td>
<td>€5.9</td>
</tr>
<tr>
<td>CORSIA cost savings</td>
<td>€0.7</td>
<td>€0.5</td>
<td>€0.4</td>
</tr>
<tr>
<td>Taxation cost savings</td>
<td>€3.5</td>
<td>€2.6</td>
<td>€1.9</td>
</tr>
<tr>
<td>Cumulative cost savings</td>
<td>€45.7</td>
<td>€32.9</td>
<td>€34.8</td>
</tr>
</tbody>
</table>

However, even if the cost of decarbonisation measures can be reduced, airlines face additional costs. The impact of the COVID-19 outbreak on airline revenues and losses suggests that higher prices are likely to lead to an increase in ticket prices, and lower passenger demand. Based on the EUROCONTROL airline operating cost model developed for this study, and a carbon price of €200/tonne, these extra costs are converted into average extra costs per flight as per TABLE 15 below:

TABLE 15: AVERAGE PER FLIGHT EXTRA COSTS FOR THE 3 SCENARIOS

<table>
<thead>
<tr>
<th>Area</th>
<th>High</th>
<th>Base</th>
<th>Low</th>
</tr>
</thead>
<tbody>
<tr>
<td>Intra-EEA flights</td>
<td>€894/flight</td>
<td>€1325/flight</td>
<td>€1345/flight</td>
</tr>
<tr>
<td>EUROCONTROL NM (all flights)</td>
<td>€215/flight</td>
<td>€521/flight</td>
<td>€411/flight</td>
</tr>
</tbody>
</table>

Using the average total operating cost per flight for the A320 family and B737NG, TABLE 16 estimates the cumulative operating cost increase from all decarbonisation measures for intra-EEA flights in 2030:

TABLE 16: INCREASED PER FLIGHT OPERATING COSTS FOR THE 3 SCENARIOS, A320 FAMILY /B737NG

<table>
<thead>
<tr>
<th>Operating cost per flight cycle (€2014)</th>
<th>A320 Family</th>
<th>B737 NG</th>
</tr>
</thead>
<tbody>
<tr>
<td>With all measures − High scenario (€2019 / % variation)</td>
<td>€8,797 / +11.31%</td>
<td>€9,136 / +10.85%</td>
</tr>
<tr>
<td>With all measures − Base scenario (€2019 / % variation)</td>
<td>€9,228 / +16.77%</td>
<td>€9,567 / +16.08%</td>
</tr>
<tr>
<td>With all measures − Low scenario (€2019 / % variation)</td>
<td>€9,248 / +17.02%</td>
<td>€9,587 / +16.32%</td>
</tr>
</tbody>
</table>

7 WHAT-IF ANALYSES

7.1 Speed optimisation

This ‘what if’ analysis simulates the effect of (lower) speeds on fuel consumption and emissions and the impacts that longer block times will have on airline costs. The effects on CO₂ emissions and aircraft capital and maintenance costs are estimated.

Three speeds have been considered:

- Nominal speed: the cruise speed corresponding to nominal operating conditions as defined in the aircraft flight manual
- **Maximum Range Cruise (MRC):** the speed that minimises fuel consumption for a given mission. This speed is equivalently defined as maximising mission range for a fixed amount of fuel.
- **Long Range Cruise (LRC):** speeds faster than MRC that achieves 99% of the efficiency of MRC, defined with respect to Specific Ground Range (SGR). LRC provides a trade-off between increased fuel consumption and shorter flight times.

Longer block times will of course have several impacts on airline costs:

- higher utilisation if the airline flies the same flights, otherwise lower utilisation if there is not enough time to fly the same number of sectors during the day (which of these cases applies will depend on the difference in time and on the airline)
- higher crew costs if the airline flies the same flights, and the longer block times mean that the maximum crew duty period is exceeded and another crew is required that day
- higher maintenance costs if the airline flies the same flights (for those costs which are flight hour-related, not those costs which are flight cycle-related)

While it is hard to model crew costs as these are very airline-dependent, we do model aircraft capital costs and maintenance costs.

Our Route Estimation Model estimates that aircraft speed reduction from nominal to LRC would reduce, network-wide, fuel burn/CO$_2$ emissions by 0.3% at almost constant costs. Reducing cruise speed from nominal to MRC would reduce CO$_2$ emissions by 1% with a negative impact on airline costs of 0.2%. Despite uncertainties in converting the additional flight times into airline costs, the output does provide a notional effect of slower cruise speeds on capital and maintenance costs.

### 7.2 Earlier Aircraft Acquisition / Leasing

Airlines and other aircraft operators make decisions about aircraft acquisition based on an analysis of the lifetime economic value of the aircraft in their service, and the ability of that aircraft to generate profit for them. The profitability of the aircraft will depend on many factors: GDP and economic activity, fuel prices, taxation, network structure and product offered to customers, airport and airspace congestion, and so on. Building on aircraft acquisition and fleet modelling, this analysis identifies the emission savings and projected earnings/anticipated costs generated by bringing acquisition/leasing of more efficient aircraft forward by 3 and 7 years.

The EUROCONTROL Fleet Cost Model enables us to assess the lifecycle costs and compare profitability, by flight and by year, of two aircraft types. This allows us to compare older with newer existing aircraft (e.g. Airbus A320CEO and A320NEO), as well as existing vs. new-technology aircraft (for example ATR72-600 and the planned 2030s Airbus Zero.e hydrogen-powered turboprop). The following aircraft have been considered:

**TABLE 17: LIST OF AIRCRAFT FORMING THE SCOPE OF THE ACCELERATED RENEWAL**

<table>
<thead>
<tr>
<th>Current Types</th>
<th>Current and future types</th>
</tr>
</thead>
<tbody>
<tr>
<td>Airbus A220-300</td>
<td>Airbus A220-500</td>
</tr>
<tr>
<td>Airbus A319CEO</td>
<td>Airbus A220-300</td>
</tr>
<tr>
<td>Airbus A320CEO</td>
<td>Airbus A320Neo</td>
</tr>
<tr>
<td>Airbus A321CEO</td>
<td>Airbus A321Neo</td>
</tr>
<tr>
<td>Boeing 737-800</td>
<td>Boeing 737MAX8</td>
</tr>
<tr>
<td>Embraer 190</td>
<td>Embraer 190E2</td>
</tr>
</tbody>
</table>

Current Market Value (CMV) and monthly Market Lease Rate (MLR) are based on data from September 2021. Average sector length (flight distance) of 600 nm is a rounded-off figure based on our data; certain aircraft are assumed to deviate from this (e.g. A321neo, since it is also used on longer sectors; Embraer 190 and 190E2, since these types are often used on shorter sectors). The block time and block fuel are calculated for each type based on the indicated sector length and using EUROCONTROL’s BADA (version 3.15).

New technology aircraft may require a longer refuelling or recharging time between flights and therefore may be used less than conventional aircraft. Additionally, new technology aircraft may incur an insurance surcharge until the insurance industry has accumulated sufficient experience of these aircraft in operation. Both of these factors are captured.

The Fleet Cost Model defines the maintenance costs per block hour and the maintenance reserve (MR) per month as well as crew salaries and per-diems for crews in different airline types. It also defines the assumed annual aircraft utilisation in block hours: low-cost carriers typically target higher utilisation than network carriers, for example, while regional carriers may achieve lower utilisation than network carriers.

It is assumed that aircraft capital costs rise year by year. When an airline refleets with an aircraft, the cost of the aircraft is taken
to be that of the year of refleeting, and the annual cost is assumed to remain level for the duration of the airline operating that aircraft (equivalent to a lease without annual escalation, or a levelised repayment of a bank loan).

### 7.2.1 FUEL EFFICIENCY BENEFITS OF AN ACCELERATED FLEET REPLACEMENT

Refleeting three years earlier, and refleeting seven years earlier have been considered, relative to the replacement trend considered in section 4.1. The resulting impacts on fleet CO\textsubscript{2} emissions have been estimated with EUROCONTROL’s IMPACT model. Fuel efficiency improvements are provided in TABLE 18 and TABLE 19 below:

#### TABLE 18: FUEL EFFICIENCY IMPROVEMENTS – REFLEETING 3 YEARS EARLIER

<table>
<thead>
<tr>
<th></th>
<th>High</th>
<th>Base</th>
<th>Low</th>
</tr>
</thead>
<tbody>
<tr>
<td>-3Y</td>
<td>2028: -1.72%</td>
<td>2028: -1.98%</td>
<td>2028: -2.10%</td>
</tr>
<tr>
<td></td>
<td>2029: -1.74%</td>
<td>2029: -1.99%</td>
<td>2029: -2.14%</td>
</tr>
<tr>
<td></td>
<td>2030: -1.67%</td>
<td>2030: -1.99%</td>
<td>2030: -2.21%</td>
</tr>
</tbody>
</table>

#### TABLE 19: FUEL EFFICIENCY IMPROVEMENTS – REFLEETING 7 YEARS EARLIER

<table>
<thead>
<tr>
<th></th>
<th>High</th>
<th>Base</th>
<th>Low</th>
</tr>
</thead>
<tbody>
<tr>
<td>-7Y</td>
<td>2028: -3.99%</td>
<td>2028: -4.63%</td>
<td>2028: -4.82%</td>
</tr>
<tr>
<td></td>
<td>2029: -4.16%</td>
<td>2029: -4.88%</td>
<td>2029: -5.12%</td>
</tr>
<tr>
<td></td>
<td>2030: -4.20%</td>
<td>2030: -4.88%</td>
<td>2030: -5.28%</td>
</tr>
</tbody>
</table>

New aircraft designs emit less, either incrementally in the short term (newer versions of current-generation aircraft, such as the A320neo/A321neo and the Boeing 737MAX) or as a step change in the longer term (brand-new aircraft designs using non-fossil fuels, such as battery-electric 19-seaters). Fuel burn/emissions modelling in section 4.1 has defined a baseline year as a notional year when the refleeting will take place. Earlier refleeting three or seven years before the baseline year gives additional annual fuel and CO\textsubscript{2} emission savings ranging from 1.7\% to 5.3\% over 2028-2030. The higher sensitivities of the Base and, to a greater extent, of the Low scenario reflect the less optimistic assumptions made as well as the distribution of different aircraft size classes in the three scenarios.

Airline strategy for aircraft replacement programmes could make a significant contribution in terms of reaching the -55\% target with a reduced reliance on market-based measures.

A rapid evaluation of aircraft profitability for airlines under the -3Y and -7Y fleet replacement programme is provided in the section below.

#### 7.2.2 AIRCRAFT PROFITABILITY

The Fleet Cost Model is based on the Net Present Value (NPV) of a single “line of flying” in an airline’s fleet, in other words “one aircraft worth” of flying. This flying can be performed by one aircraft for the duration of the analysis, or by an aircraft which is then replaced by another aircraft. The replacement aircraft is assumed to be broadly similar in size and capability; clearly, replacing an A320 by a 19-seater electrical aircraft would result in much lower revenues (as well as costs) and therefore a very negative NPV; this would not be a meaningful comparison.

The Net Present Value (NPV) is the value of all future cash flows (positive and negative) over the entire life of an investment discounted to the present.

\[
NPV = \sum_{i=1}^{n} \frac{C_i}{(1 + r)^i}
\]

\(C_i\): net cash flow at time \(i\)
\(r\): discount rate\textsuperscript{51}
\(i\): time of the cash flow

The Net Present Value (NPV) is the value of all future cash flows (positive and negative) over the entire life of an investment discounted to the present. The NPVs related to accelerating the acquisition of the newer aircraft of TABLE 17 are calculated over a 15-year period starting in 2028. The higher the rate, the less influence cash flows further in the future will have on the NPV. The European Commission has proposed a discount rate of 0.51\% for the Eurozone for the calculation of NPVs in State Aid cases, but this is much lower than the discount rates typically used in project appraisals. A notional discount rate of 5\% is set here. The results of a 3- and 7-
year earlier reflecting are presented in TABLE 20 and TABLE 21 respectively.

### TABLE 20: NPVs – REFLECTING 3 YEARS EARLIER

<table>
<thead>
<tr>
<th>Replacement by…</th>
<th>High</th>
<th>Base</th>
<th>Low</th>
</tr>
</thead>
<tbody>
<tr>
<td>Airbus A220-300 by Airbus A220-500</td>
<td>€5,194,438</td>
<td>€5,201,310</td>
<td>€5,474,405</td>
</tr>
<tr>
<td>Airbus A319ceo by Airbus A220-300</td>
<td>€3,195,474</td>
<td>€3,229,514</td>
<td>€4,582,334</td>
</tr>
<tr>
<td>Airbus A320ceo by Airbus A320neo</td>
<td>€8,825,235</td>
<td>€8,865,910</td>
<td>€10,482,425</td>
</tr>
<tr>
<td>Airbus A321ceo by Airbus A321neo</td>
<td>€-1,698,377</td>
<td>€-1,636,402</td>
<td>€826,638</td>
</tr>
<tr>
<td>Boeing 737-800 by Boeing 737MAX8</td>
<td>€5,194,940</td>
<td>€5,247,853</td>
<td>€7,350,753</td>
</tr>
<tr>
<td>Embraer 190 by Embraer 190E2</td>
<td>€-1,820,406</td>
<td>€-1,819,797</td>
<td>€-1,795,578</td>
</tr>
</tbody>
</table>

### TABLE 21: NPVs – REFLECTING 7 YEARS EARLIER

<table>
<thead>
<tr>
<th>Replacement by…</th>
<th>High</th>
<th>Base</th>
<th>Low</th>
</tr>
</thead>
<tbody>
<tr>
<td>Airbus A220-300 by Airbus A220-500</td>
<td>€19,240,845</td>
<td>€19,269,911</td>
<td>€19,827,942</td>
</tr>
<tr>
<td>Airbus A319ceo by Airbus A220-300</td>
<td>€16,957,335</td>
<td>€17,101,318</td>
<td>€19,865,620</td>
</tr>
<tr>
<td>Airbus A320ceo by Airbus A320neo</td>
<td>€28,444,234</td>
<td>€28,616,282</td>
<td>€31,919,407</td>
</tr>
<tr>
<td>Airbus A321ceo by Airbus A321neo</td>
<td>€5,152,629</td>
<td>€5,414,774</td>
<td>€10,447,654</td>
</tr>
<tr>
<td>Boeing 737-800 by Boeing 737MAX8</td>
<td>€19,485,786</td>
<td>€19,709,601</td>
<td>€24,006,586</td>
</tr>
<tr>
<td>Embraer 190 by Embraer 190E2</td>
<td>€2,366,974</td>
<td>€2,369,551</td>
<td>€2,419,039</td>
</tr>
</tbody>
</table>

The resultant NPVs for aircraft types considered are higher for the Low scenario as for the latter, profitability to airlines from operating the fleet is hampered by a higher reliance on fossil kerosene, and proportionally higher ETS and taxation costs. Hence, earlier acquisition, relatively, yields the best results.

The outputs of the model are only as accurate as the input data. Some of these data are highly accurate (for example fuel burn sourced from BADA, new aircraft prices acquired from a specialist data provider, and current fuel prices). Other data (e.g. maintenance costs and maintenance reserves) are based on assumptions since they are not publicly available. Nonetheless, the model still allows meaningful comparisons to be made between the profitability of different aircraft under different assumed conditions.

The combined potential reduction of CO₂ emissions in TABLE 18 and TABLE 19, as do the positive NPV for most of the aircraft in TABLE 20 and TABLE 21, show that earlier acquisition of newer aircraft is the most efficient path to more quickly decarbonising the aviation industry.
8 CONCLUSION

This report has provided a quantitative assessment as well as some guidance on the potential effectiveness and associated costs of decarbonisation measures, enabling the industry to achieve a 55% CO\textsubscript{2} emissions reduction by 2030. It is based on the European Commission’s proposed policy measures, while considering variability in SAF uptake.

- It clearly shows that the High scenario, boosted by a higher level of revenues, results in an increased investment in measures to reduce emissions from aviation. The most promising decarbonisation potential arises from SAFs, improved operational measures and new aircraft technology. This is the preferred trajectory, offering the most promising decarbonisation capability by 2050 at a lower cost.
- The Low scenario negatively affects the revenues, profitability and investment capabilities of airspace users. It is highly reliant on market-based measures, obliging airlines to rely significantly on carbon trading and offsetting measures. With fewer allowances available in the future, such a heavy reliance on market-based measures is clearly a risk factor to consider. In addition, this scenario exposes the weakest resilience in any future economic downturn.
- The middle Base scenario, despite slower traffic growth, still enables positive investment decisions in more efficient technologies, but not to a degree that would deliver lower costs than the Low scenario. These results demonstrate that without financial support and extra incentives, the costs of decarbonisation measures can slow down the potential of the aviation industry to decarbonise.

KEY FINDINGS OF THIS REPORT

1. A 55% CO\textsubscript{2} emissions reduction target by 2030 is achievable in ALL scenarios, but this relies heavily on market-based measures.

2. The High scenario with the most traffic is counterintuitively the most efficient to reach net zero emissions by 2050 at lower cost, as higher revenues will drive increased investment in new technology.

3. Policy-driven decarbonisation measures will add €54.8-€62.0 billion in additional costs across the EUROCONTROL Network Manager area over the period 2022-2030 if all industry-led actions are excluded, such as ATM optimisation (including SES), fleet update/renewal, and increased SAF usage…

4. …but applying industry-driven measures can drastically reduce the cost of decarbonisation measures by €32.9 to €45.7 billion over the same period.

5. The most important industry-driven measure is increasing SAF usage; for this to become a reality, the ReFuelEU Aviation initiative is essential in enabling a swift ramp up of SAF production and usage.

6. For the period 2022-2030, the extra cost of a 5% SAF blending share compared to 100% kerosene is estimated to be €10 billion in the base scenario, reaching €2.1 billion in 2030.

7. Industry-led measures can deliver 13.4%-24.1% of the net emissions savings, depending on the pace of decarbonisation.

8. To reduce CO\textsubscript{2} emissions quicker, airlines should accelerate the pace of fleet renewal by 3-7 years to ensure they operate the most efficient new technology.

9. We need to accelerate aviation decarbonisation by prioritising actions, fostering the transition (e.g. by offering financial support and encouraging alliances), and balancing taxation with the need for aviation to recover.
9 POTENTIAL OPTIONS TO ACCELERATE AVIATION DECARBONISATION

PRIORITISE ACTIONS WHICH RESULT IN THE HIGHEST REDUCTIONS IN NET CO₂

1. Accelerate the development of CO₂ efficient and disruptive technologies while improving current fleet technology. This could be enabled by alliances and partnership at EU or pan-European level (Horizon Europe, ETS Innovation Fund, Modernisation Fund, NextGenerationEU).

2. Encourage accelerated fleet renewal to significantly reduce CO₂ emissions, while maintaining connectivity.

3. Building on the EU legally-binding blending shares, encourage the industry to uptake higher levels of SAF on a voluntary basis where the market allows.

4. In particular, push for a larger share of e-SAF to motivate higher investment in green hydrogen production facilities.

5. Facilitate access to feedstock of the SAF pathways and availability of renewable energy for producing e-SAF, which will require a massive volume of renewable electricity and green hydrogen.

6. Drive a thriving European SAF market through proportionate financial incentives to promote higher SAF uptake along with the regulatory measures. Proportionality in financial support should be driven by the efficiency and relative extra cost of the SAF as well as its potential to support the trajectory to net zero emissions.

FOSTER THE TRANSITION THROUGH FINANCIAL SUPPORT AND ALLIANCES

1. Motivate public and private investors to fund sustainable solutions for the aviation sector via green funds, grants, state-backed loans, contracts for difference, etc. (incl. by the EU Taxonomy).

2. Ensure a coordinated approach between the aviation industry, electricity producers, the (e)-SAF industry and other actors in the supply chain to synchronise development and deployment of the different sustainable solutions (by joining alliances, such as the European Clean Hydrogen Alliance or the Alliance for Renewable and Low Carbon Fuels Value Chain and the Alliance for Zero-Emission Aviation).

3. Engage the aviation sector as a strategic partner to contribute to defining the European energy decarbonisation strategy.

BALANCE TAXATION WITH THE NEED FOR AVIATION TO RECOVER

1. Monitor closely the impact of taxation on aviation to ensure fair tax treatment with other transport modes, avoid double taxation and carbon leakage, and preserve connectivity.

2. Monitor the variations of the carbon market to assess inter alia the effects of potential energy crises and to mitigate the risks of carbon market volatility on the competitiveness and economic sustainability of European aviation.

3. Earmark if possible revenues collected from aviation-related taxes to foster aviation innovation and increase its funding capabilities.
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[Ref3.] European Commission, ‘Fit for 55’ package, adopted by the Commission and communicated on 14 July 2021, including in particular an initiative to increase the production and the uptake of sustainable alternative fuels, a revision of the EU Emissions Trading System (ETS) and a revision of the Energy Tax Directive.

[Ref4.] EUROCONTROL Aviation Outlook 2050 Main Report, April 2022.


[Ref6.] European Commission, Fit for 55 package, Adopted by the Commission and communicated on 14 July 2021 including in particular an initiative to increase the production and the uptake of sustainable alternative fuels, a revision of the EU Emissions Trading System (ETS) and a revision of the Energy Tax Directive.


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[Ref15.] EUROCONTROL, ERNIP Part 2 – ARN version 2021-2030.


## ANNEX 1 – DEFINITION AND ACRONYMS

<table>
<thead>
<tr>
<th>Acronym</th>
<th>Definition</th>
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<tbody>
<tr>
<td>AMAN</td>
<td>Arrival Manager</td>
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<tr>
<td>ANS</td>
<td>Air navigation services</td>
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<td>ANSP</td>
<td>Air navigation service provider</td>
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<tr>
<td>ARN</td>
<td>ATS Route Network</td>
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<tr>
<td>ASBU</td>
<td>Aviation System Block Upgrade</td>
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<tr>
<td>A-SMGCS</td>
<td>Advanced Surface Movement Guidance and Control System</td>
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<tr>
<td>ATM</td>
<td>Air Traffic Management</td>
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<tr>
<td>ASTM</td>
<td>ASTM International, formerly known as American Society for Testing and Materials</td>
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<tr>
<td>ATAG</td>
<td>Air Transport Action Group</td>
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<tr>
<td>ATC</td>
<td>Air traffic control</td>
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<tr>
<td>ATM</td>
<td>Air traffic management</td>
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<td>ATM MP</td>
<td>ATM Master Plan</td>
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<tr>
<td>ATJ</td>
<td>Alcohol to Jet</td>
</tr>
<tr>
<td>ATS</td>
<td>Air traffic services</td>
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<tr>
<td>BADA</td>
<td>EUROCONTROL Base of Aircraft Data tool</td>
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<tr>
<td>CAEP</td>
<td>ICAO Committee of Aviation Environmental Protection</td>
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<tr>
<td>CBA</td>
<td>Cost benefit analysis</td>
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<td>CCO</td>
<td>Continuous climb operations</td>
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<tr>
<td>CDO</td>
<td>Continuous descent operations</td>
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<tr>
<td>CFSP</td>
<td>Computerised flight plan service provider</td>
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<tr>
<td>CMV</td>
<td>Current Market Value</td>
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<tr>
<td>CORSIA</td>
<td>Carbon Offsetting and Reduction Scheme for International Aviation</td>
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<tr>
<td>CP</td>
<td>Common Project</td>
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<tr>
<td>EAO</td>
<td>EUROCONTROL Aviation Outlook</td>
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<tr>
<td>EEA</td>
<td>European Economic Area</td>
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<tr>
<td>EFB</td>
<td>Electronic Flight Bag</td>
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</tbody>
</table>
EFTA  |  European Free Trade Association
--- | ---
EIS  |  Entry into service
ERNIP  |  European Route Network Implementation Plan
ETFMS  |  Enhanced tactical flow management system
ETD  |  European Taxation Directive
ETS  |  Emission Trading System
EU  |  European Union
FMS  |  Flight Management System
FRA  |  Free Route Airspace
FUA  |  Flexible Use of Airspace
GBAS  |  Ground Based Augmentation System
GHG  |  Greenhouse Gas
GPU  |  Ground Power Unit
HEFA  |  Hydroprocessed esters and fatty acids
ICAO  |  International Civil Aviation Organization
IFR  |  Instrument Flight Rules
ILS  |  Instrument Landing System
IMPACT  |  EUROCONTROL Integrated Aircraft Noise and Emissions Modelling Platform
LRC  |  Long Range Cruise
MLR  |  Market Lease Rate
MRC  |  Maximum Range Cruise
MSW  |  Municipal solid waste
NGO  |  Non-governmental organisation
NM  |  EUROCONTROL Network Manager
NPV  |  Net Present Value
OEM  |  Original equipment manufacturer
OTS  |  Organised Track System
<table>
<thead>
<tr>
<th>Abbreviation</th>
<th>Description</th>
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<tbody>
<tr>
<td>PBN</td>
<td>Performance Based Navigation</td>
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<tr>
<td>PtL</td>
<td>Power to Liquid</td>
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<tr>
<td>QAR</td>
<td>Quick Access Recorder</td>
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<tr>
<td>RECAT</td>
<td>Wake turbulence re-categorisation</td>
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<tr>
<td>R-NEST</td>
<td>EUROCONTROL Research Network Strategic Monitoring Tool</td>
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<tr>
<td>RoT</td>
<td>Rule of Thumb</td>
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<tr>
<td>SAF</td>
<td>Sustainable aviation fuel</td>
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<tr>
<td>SES</td>
<td>Single European Sky</td>
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<tr>
<td>SESAR</td>
<td>Single European Sky ATM Research (programme)</td>
</tr>
<tr>
<td>SGR</td>
<td>Specific Ground Range</td>
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<tr>
<td>TCO</td>
<td>Total Cost of Ownership</td>
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<tr>
<td>ToD</td>
<td>Top of Descent</td>
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<tr>
<td>UPR</td>
<td>User Preferred Routing</td>
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<tr>
<td>WEF</td>
<td>World Economic Forum</td>
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<tr>
<td>XMAN</td>
<td>Extended Arrival Manager</td>
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ANNEX 2 – MEASURES COVERED IN THE RULE OF THUMB STUDY

The measures that have been used in the RoT study have been identified from multiple sources. Primarily they come from EUROCONTROL, SESAR and other European stakeholder sources. From the operator side, the primary source is the Destination 2050 report. In addition, measures were identified from the ICAO stock-taking process together with supporting information from ICAO Manuals. The RoT study includes the following operational measures:

- Increased glide slope (IGS)
- Reduced pairwise wake separation between arrivals
- Advanced Approach Procedures with Vertical Guidance (A-APVs)
- RNAV1 STARs
- PBN to xLS procedures
- Point Merge in complex TMAs
- Wake vortex re-categorisation (RECAT)
- Reduced flap landing
- Remote Tower installation
- RNP AR Approach procedures
- Time-Based Separation
- Continuous Climb Operations (CCO)
- Reduced pairwise wake separation between departures
- RNAV1 SIDs
- Rolling line up/Take off
- Advanced Flexible Use of Airspace (AFUA)
- Air Traffic Flow Management (ATFM)
- Dynamic airspace configurations / sectorisation
- Flight efficiency optimisation through NM proposals (including GRRT and Rerouting tools)
- Formation Flights
- Global ATFM Demand capacity (DC) balancing
- Enhanced Short Term ATFCM measures
- MET enhancements
- Optimised flight planning procedures
- Business and mission trajectories
- Arrival manager (AMAN)
- Extended Arrival Manager (XMAN)
- Continuous Descent Operations (CDO)
- Precision approaches using GBAS CAT I/II/III systems
- ASAS spacing
- APU off (use of GPU)
- Reduction in fuel tankering
- Reduction in discretionary fuel
- Use of fuel efficiency software suites to monitor fuel usage
- Last-minute fuel and water uplift
- FMS updates
- Use of thinner paint for aircraft liveries
- Use of zonal dryers for removing condensation
- Optimised ground maintenance procedures
- Enhanced arrival / departure management in TMA and en-route
- Electric taxi solutions
- Reduced ground taxi solutions
- Datalink clearance
- Enhanced taxi surveillance in non-optimal conditions
ANNEX 3 – KEY FIGURES CONSIDERING A LOWER CARBON PRICE AT €120

Given current political developments, the study has assumed a carbon price of €200/CO$_2$ tonne. This may be considered high, but as the world faces a global energy crisis, it seems prudent to adopt it. An alternative could have been to use, say, €120, a figure about €20 higher than peak price in 2021.

**FIGURE 38 – YEARLY DIFFERENTIAL COSTS FOR THE EUROCONTROL NM AREA, ALL FLIGHTS (IN € BN)**

![Graph showing yearly differential costs for the Eurocontrol NM area, all flights (in € BN)](image)

With a carbon price of €120/tonne, the extra cost of the policy measures (with 10%, 5% and 4% of SAF in 2030) for the period 2022-2030, “after” the industry-driven measures have been applied, is around €23.4 billion for the Base scenario (reaching €5.2 billion in 2030), €13.1 billion for the High scenarios, and €13.3 billion for the Low scenario. Although they show an absolute value of elasticity of less than 1, the three scenarios are diversely affected by a variation in carbon price. A 67% increase (from €120 to €200/CO$_2$ tonne) in carbon price results in a 23.6% increase in cumulative costs for the base scenario (see TABLE 13) and 24.9% increase for the High scenario. The Low scenario is the most affected and shows a 50.4% increase.

The High scenario remains the most promising decarbonisation pathway. The curve for the differential costs for the High scenario intersects later the Low scenario curve in 2029 (vs. 2025-2026 with a carbon price at €200/tonne). Hence, from that point onwards, the extra costs of decarbonisation are passed on to passengers at lower prices than in other scenarios.