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Optimising Air Traffic Management in Europe by the introduction of the Single European Sky

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Abstract

Europe´s airspace is facing an arduous situation due to its congestion, which leads to multiple delays and inefficient flights. Introducing the Single European Sky Air Traffic Management (SESAR) initiative will conquer a transformative shift in Europe´s Air Traffic Management (ATM), achieving more optimised and sustainable routes throughout the continent. Therefore, through the successful implementation of the SESAR initiative, we will enhance the performance of Europe´s ATMs in capacity, safety, efficiency, and sustainability. This paper evaluates Europe´s current airspace and highlights the positive impacts of the initiative in the different areas of improvement. Utilising current data provided by the airlines, qualitative methods are applied to prove the effect that SESAR will achieve on different routes. The research results demonstrate how introducing the SESAR will reduce flight distance, fuel consumption, and emissions. In conclusion, this research emphasises the significance of implementing the SESAR to update air traffic control throughout Europe. The aviation industry is experiencing a modernisation that is expected to result in lower operating costs, fewer delays, and a reduction in the environmental impact of their flights.

Keywords

Air traffic Management (ATM), airspace, SESAR, efficiency, sustainability

1. Introduction

As the number of flights continues to rise in Europe, the delays they experience likewise increase. In addition to delays, the congestion in Europe´s airspace causes problems related to capacity, efficiency, safety and environmental issues. All of these could be improved and even eradicated with the implementation of the Single European Sky Air Traffic Management (SESAR). Europe´s air traffic management is facing a complicated situation due to its fragmentation and heterogeneity, which leads to congestion problems where demand mismatches capacity.

According to Eurocontrol, the intergovernmental organisation in charge of air navigation security in Europe, flights across the continent are, on average, 42 km longer than the minimal route, costing 4 billion euros per year. Furthermore, the demand for European flights is increasing at a rate of 4.5% per year, a demand that the current capacity cannot support, resulting in a 3.3% increase in aeroplane movements (*Rosenow & Fricke, 2019*). In addition, Europe´s airspace experiences a lack of coordination since there is no common Air Traffic Control (ATC) system, with 22 different systems operating through 44 centres (*Luftraumntzer, 1989*). This all translates into a greater strain on Europe´s airspace infrastructure, which in turn causes delays and rises in operating costs, and presents difficulties for air control systems and airlines.

However, with the introduction of the Single European Sky initiative, flights will follow more direct routes, resulting in a tenfold increase in safety, a tripling of airspace capacity, a 50% reduction of ATM costs, and a 10% decrease in the environmental impact of aviation. The direct routing of the flight can be achieved by introducing the Free Route Airspace (FRA), allowing aircraft to fly directly from one destination to another following an orthodromic or loxodromic route at the highest flight levels. This study underpins this expectation through the example of the Madrid–Budapest route.

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The bibliometric network analysis below shows (*Figure 1*) 8 different concepts related to the research topic of the optimisation of air traffic management in Europe. Four of these eight concepts are important: air transport, aviation, air traffic control, and air traffic management.

Air transport is crucial for optimising air traffic management, as all the airlines' connectivity and competitiveness influence traffic. In addition, it is also important to understand how different airports operate, the types of traffic they handle, and whether they function as a point-to-point or a hub-and-spoke system. Undoubtedly, to have air transport, we need aviation procedures that include all the safety regulations and procedures and security. Safety and security in aviation serve distinct but interconnected purposes. Safety focuses on unintentional threats and risks associated with aviation activities. It aims to reduce and control risks related to aircraft operations, ensuring the well-being of passengers, crew, and assets. Safety measures address accidents, technical failures, and human errors. Security, on the other hand, deals with deliberate threats. It safeguards civil aviation against unlawful interference, such as terrorism, hijacking, or sabotage. Security measures aim to prevent intentional harm to planes, passengers, and airport facilities. In summary, safety prevents accidents, while security protects against intentional harm. Both are critical for a robust and reliable aviation system.

Apart from the four major topics, it is also important to mention sustainability and climate change. Air traffic involves various aspects of energetic and renewable efficiencies in different alliances and severely affects air pollution and ozone levels. In the present study, we will mention how conflict resolution can be made more efficient with the different data or how artificial intelligence can be considered to improve efficiency and safety in aviation.

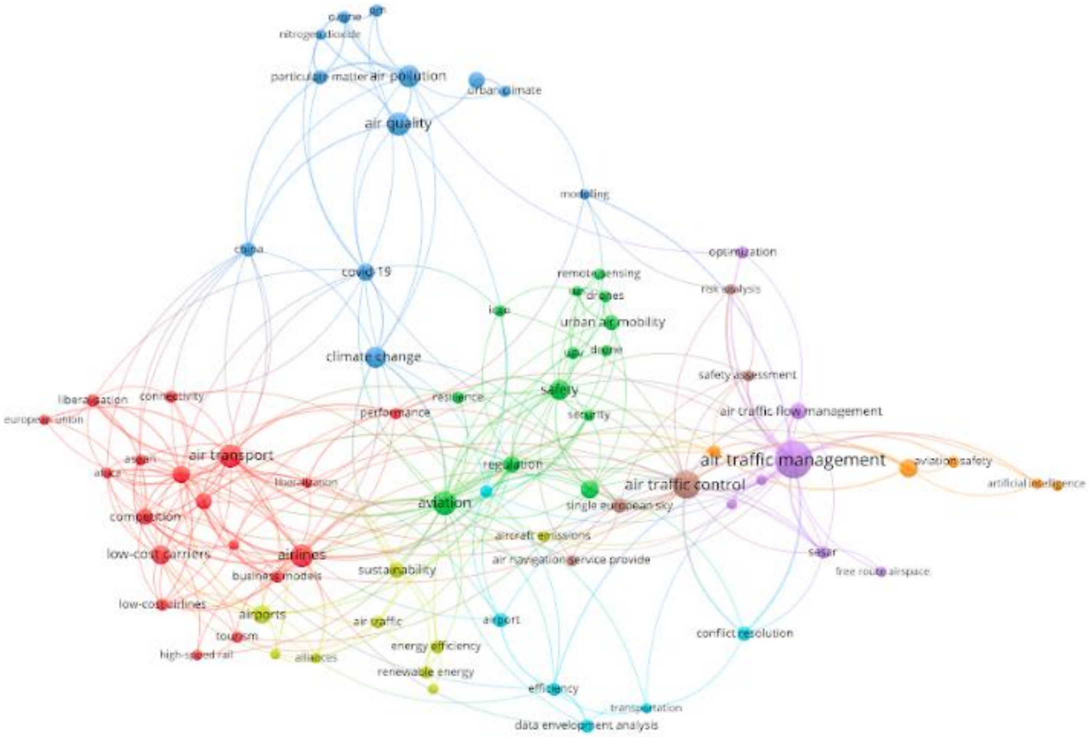

Figure 1: **Bibliometric network analysis for the concept of air traffic management optimisation**

Therefore, this paper demonstrates how implementing the SESAR initiative through European airspace will reduce operational costs and emissions while increasing capacity and efficiency. Throughout this article, we will explain the calculation methodology and present their results. These results are analysed, and then the article is concluded.

2. Data and methods

To prove how the introduction of the SESAR will improve European airspace efficiency, the Madrid–Budapest route is analysed using an orthodromic and a loxodromic route. Throughout the en-route phase, the concept of the Free Route Airspace is utilised instead of flying from one waypoint to another, which seems inefficient. However, to maintain the safety of the flight, the Standard Instrument Departure (SID - is a predefined route that guides an aircraft from takeoff to the en-route phase. It ensures safe and efficient departure by specifying specific routings, altitudes, and speed restrictions), the

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Standard Arrival Route (STAR - guide aircraft from the en-route phase to an initial approach fix).and the final approach procedures (The final approach is the last segment of an instrument approach procedure. It begins at the final approach fix and leads to the runway threshold) are maintained. In this article, these segments will be investigated separately.

The orthodromic route is the shortest distance between two points along a great circle. The equations below calculate the distance between Madrid and Budapest using the orthodromic route. For visualisation, see Figure 2:

$$\sin(\lambda_1 - \lambda_0) = tg(\varphi)tg(\theta) \quad (1)$$

$$sen(\theta) = \frac{sen(\theta_0)}{\cos(\varphi)} \quad (2)$$

$$sen(s) = \frac{sen(\varphi)}{\cos(\theta_0)} \quad (3)$$

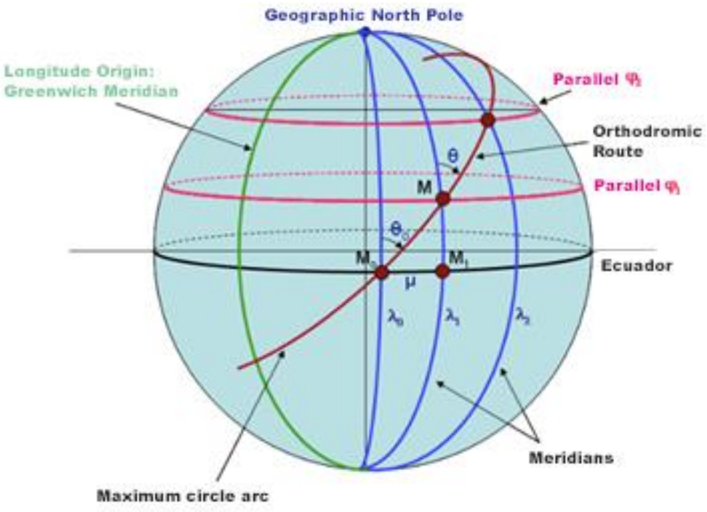

Figure 2: **Orthodromic Route**

Source: Pérez Sanz et al., 2013

Therefore, we will pursue the following procedure to determine the distance between these two airports using the orthodromic route.

To start, we first need the generalised coordinates we see below (*Coordinates Converter, 2024*):

- Adolfo Suarez Madrid Barajas (MAD: 40, 498332º, -3, 567598º)
- Budapest Airport Ferenc Liszt (BUD: 47,435273º, 19,253511º)

Accordingly, the longitude and latitude of each airport will be:

- MAD (φ_1 =40, 498332º, λ_1 = -3,567598º)
- BUD (φ_2 =47, 435273º, λ_2 = 19, 253511º)

Using the first expression from above (Eq. 1), we obtain that λ_0 has the value of -50,1694416, which makes sense, as it is the point where the route crosses the equator. This will be on the other side of the equator, on the negative side, as shown in Figure 3.

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If we divide the earth into quadrants, we can check if Madrid and Budapest are in the same quadrant if we subtract the coordinate value of the point that crosses the equator from the coordinate value of their longitude, which is less than 90.

- MAD $|\lambda_1 - \lambda_0| < 90$
- BUD $|\lambda_2 - \lambda_0| < 90$

As we expected from Figure 3, Madrid and Budapest are in the same quadrant. Therefore, we calculate their distance to the point that crosses the equator with equation 1. Thus, we obtain θ_0Then, using Equation 3, we get both distances s_1 and s_2, with the values of 58,5025475º and 75,2408343º, respectively. Finally, as shown in Figure 3, we calculate the result of s_2 minus s_1, getting 16,738382869º. This distance in Nautic miles is 1004,29 NM, and in kilometres, it is **1859,94 km**.

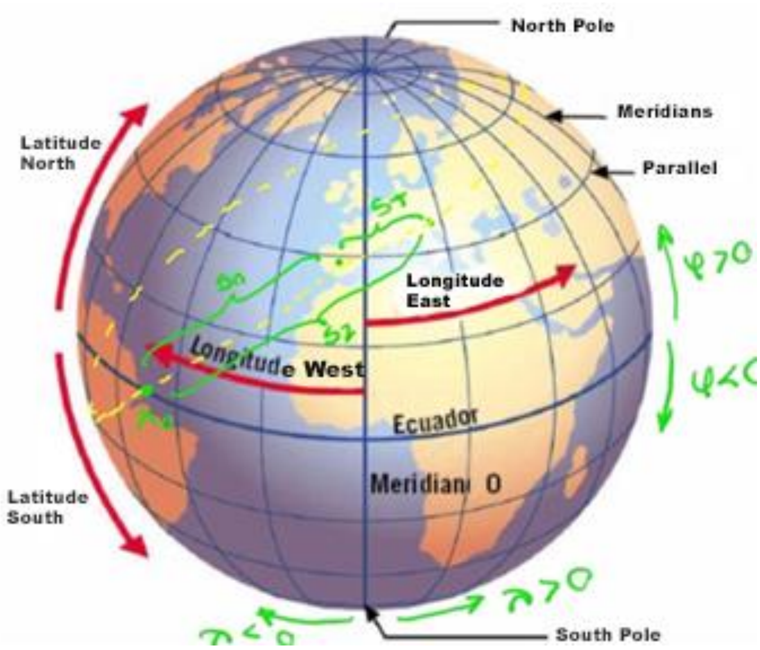

Figure 3: **Orthodromic Route**
Own compilation based on (Domínguez, 2014)

Once having calculated the distance using the orthodromic route, we will continue by calculating the loxodromic route. This route follows a rhumb line, which cuts the different meridians at the same angle, consequently maintaining a constant direction. To calculate this route, we will use the equations 4–7 below, explained by the trigonometric concepts in Figure 4.

$$ds_p = ds * sen(\theta) = \mathrm{r} * \mathrm{d}\lambda \quad (4)$$

$$ds_m = ds * cos(\theta) = \mathrm{R} * \mathrm{d}\varphi \quad (5)$$

$$\mathrm{d}\lambda * \cos(\varphi) = \mathrm{tg}(\theta) * \mathrm{d}\varphi \quad (6)$$

$$\lambda - \lambda_0 = tg(\theta_0) * \ln\left(tg\left(\frac{\pi}{4} + \frac{\varphi}{2}\right)\right) \quad (7)$$

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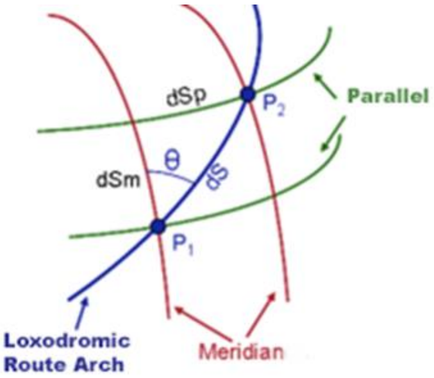

Figure 4: **Relations in the loxodromic route**
Source: Pérez Sanz et al., 2013

Logically, we start calculating the loxodromic route with the generalised coordinates, which are the same ones as in the orthodromic route.

- MAD (φ_1 =40, 498332º, λ_1 = -3,567598º)
- BUD (φ_2 =47, 435273º, λ_2 = 19, 253511º)

Accordingly, using the fourth equation, we get the direction of the route, θ_0, which has a value of -67,0681045º, se as Budapest is located to the northeast of Madrid. After calculating the direction, we will use Equation 1 of the orthodromic route to get λ_0, which will be -101,2948108º. This is a larger number than in the orthodromic route, as we must maintain the direction of the route. Lastly, we will calculate the distances s_1 and s_2 as the final distance.

$s = s_2 - s_1$= 7304,538818-6236,3220337= 1068,22 NM= **1978,34 km**

This is the distance between the two airports following a loxodromic route, which is more than 100 km longer than the length of the orthodromic route. However, if we consider the SID and the STAR as mentioned, we will follow the same procedure but calculate the distance with the coordinates of the SID's last point and the STAR's first point. Then, we will add the distance mentioned in the aeronautic charts taken from EUROCONTROL, separating the runway and the waypoint the aircraft will follow at departure and arrival. In this example, we used departure from PINAR and arrival from ULZAK and ATICO.

3. Results and discussion

Taking into account the estimations mentioned above and the distances between the waypoints that we obtain from the charts displayed in Figures 5, 6 and 7, i.e. the distances of the orthodromic and loxodromic route are the following:

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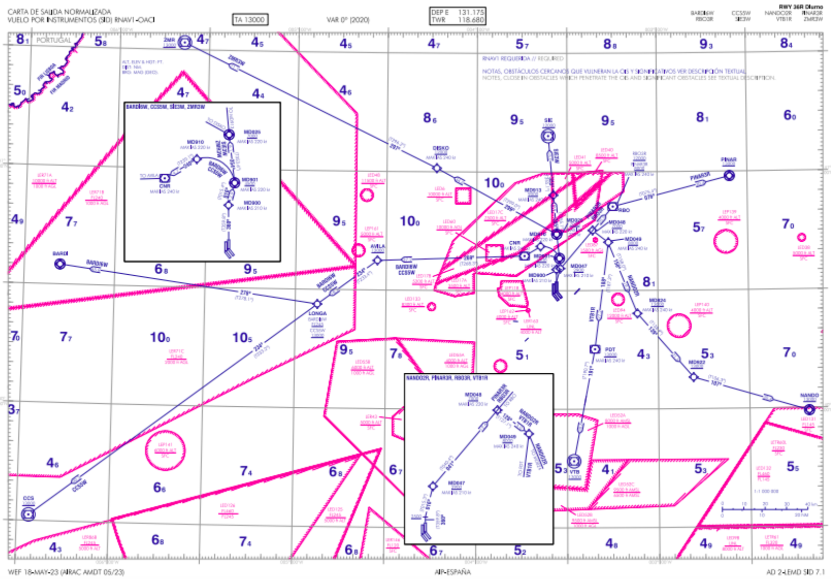

Figure 5:**SID7-RWY 36R Madrid**
(*ENAIRE*, *2023*)

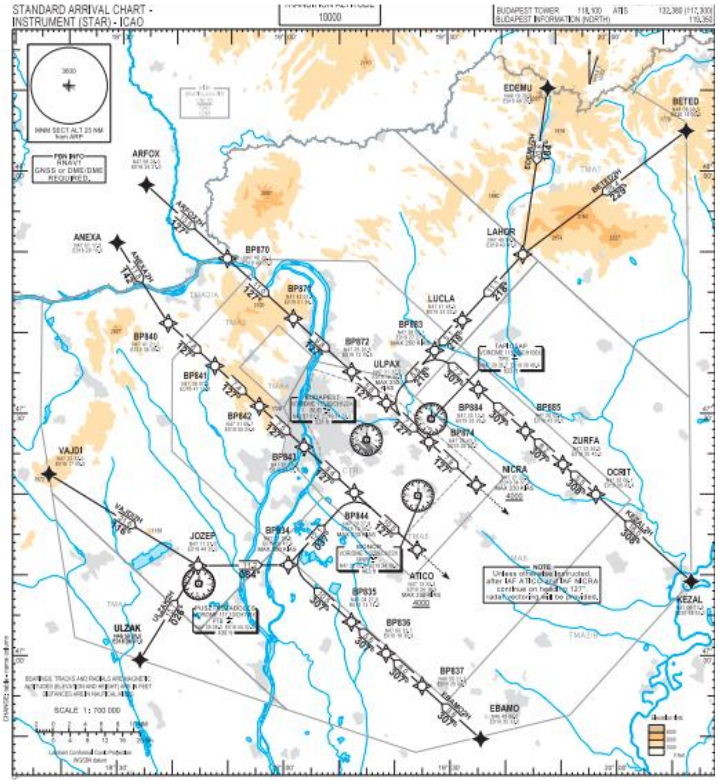

Figure 6: **STAR 31R/31L**
(*Eurocontrol*, *2022*)

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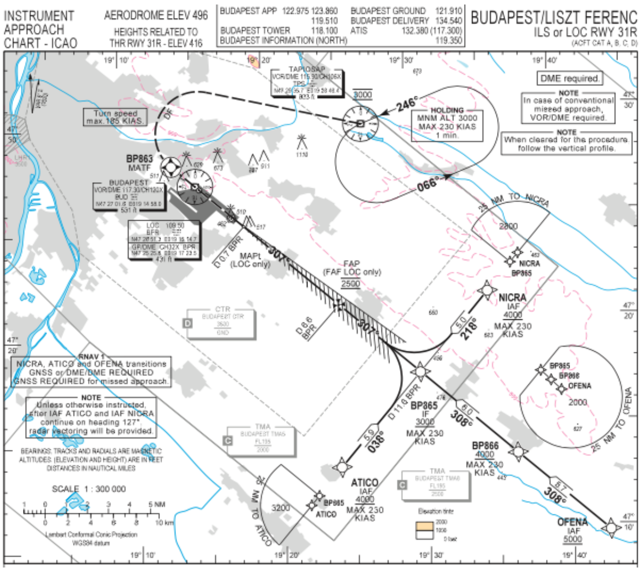

Figure 7: **Instrumental Approach chart-RWY31R**
(*Hungarocontrol, n.d.*)

On the one hand, the total distance in the orthodromic route would be 2026,87 km composed of the following distances between waypoints and the en-route distance:

Table 1: **Distance – Orthodromic route**

Waypoints	RWY 36R-PINAR	PINAR-ULZAK	ULZAK-ATICO	ATICO-RWY 31R
Distance	50.9 NM	978.52 NM	47.5 NM	17.5 NM

Own Compilation

On the other hand, the total distance in the loxodromic route would be 2031,98 km composed of the following distances between waypoints and the en-route distance:

Table 2: **Distance – Loxodromic route**

Waypoints	RWY 36R-PINAR	PINAR-ULZAK	ULZAK-ATICO	ATICO-RWY 31R
Distance	50.9 NM	981.27 NM	47.5 NM	17.5 NM

Own Compilation

A shorter flight distance implies less fuel consumption and reduced emissions. With the distances displayed above of the orthodromic and loxodromic routes, fuel consumption and the emissions of harmful gases such as CO_2 and NO_x will be reduced.

Using the fuel consumption data in litres per hour for each aircraft model of each airline that flies the route Madrid -Budapest, we reach the following fuel consumption using the orthodromic route.

Table 3: **Fuel consumption orthodromic route**

Airline	Aircraft model	Flight hours with the orthodromic route (h)	Total fuel with orthodromic route (l)
Iberia	A320	2.96	9247.9
Ryanair	B738	2.8	8664.3
Wizz Air	A321	3.1	9038.4

Own Compilation

In the same way, using the loxodromic route:

Table 4: **Fuel consumption loxodromic route**

Airline	Aircraft model	Flight hours with the loxodromic route (h)	Total fuel with loxodromic route (l)
Iberia	A320	2.9667	9271.2
Ryanair	B738	2.90	8686.2
Wizz Air	A321	3.10	9062.2

Own Compilation

4. Analysis

To determine whether implementing the free route airspace is a successful way of improving the efficiency of the European airspace, we will compare our results of distances, fuel consumption, and emissions to the current airline data. Table 5 compares the main airlines that fly this route with each model of aeroplane they use:

Table 5: **Distances and fuel consumption of the current flight routes**

Airline	Aircraft model	km	Flight Hours (h)	Fuel Consumption (l/h)	Total fuel consumption (l)
Iberia	A320	2089	3.05	3125	9531.25
Ryanair	B738	2082	2.97	3000	8900
Wizz Air	A321	2093	3.2	2916.7	9331.2

Own Compilation

If we compare the data of Tables 4 and 5, we see how the distance and the fuel consumption are considerably lower following an orthodromic or loxodromic route. This is shown in Figures 8 and 9, depicting that the distance flown and the fuel consumption with the orthodromic route is the most advantageous.

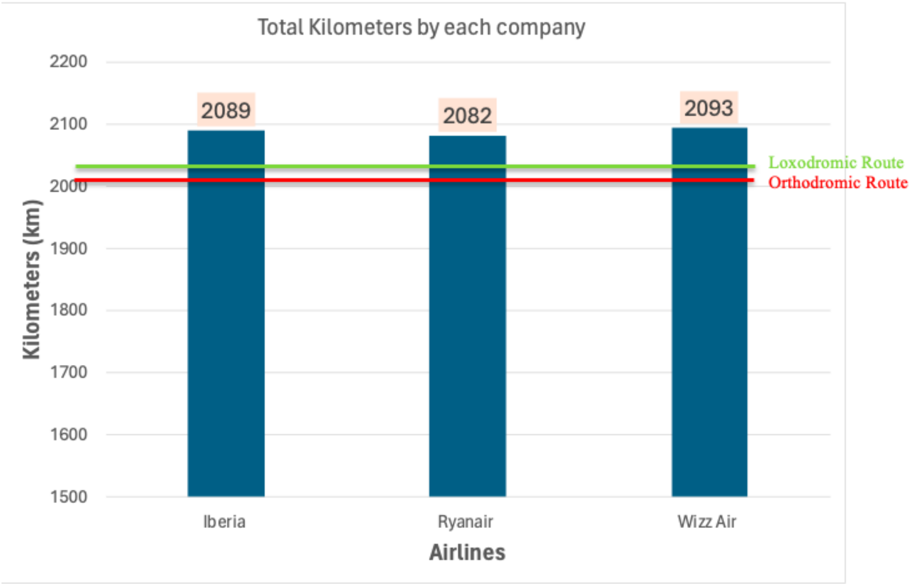

Figure 8: **Kilometers by each airline**
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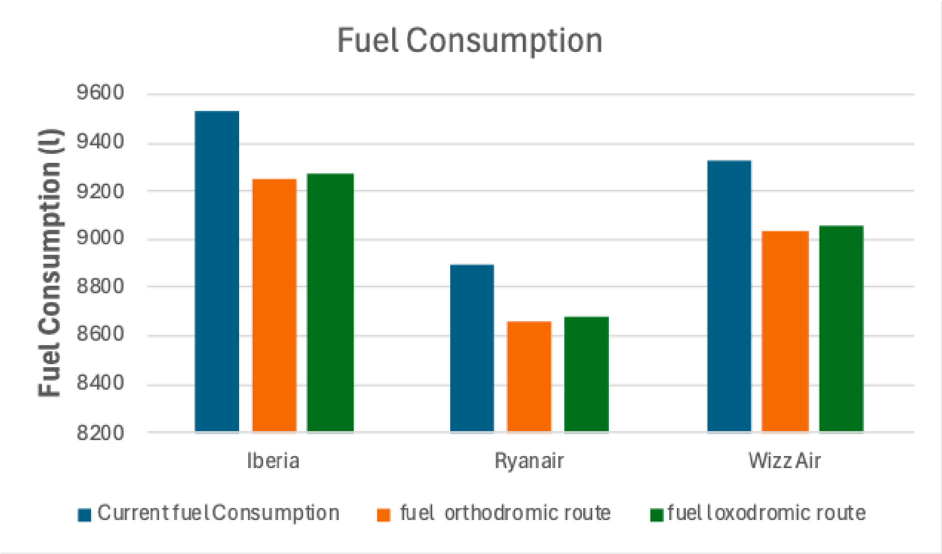
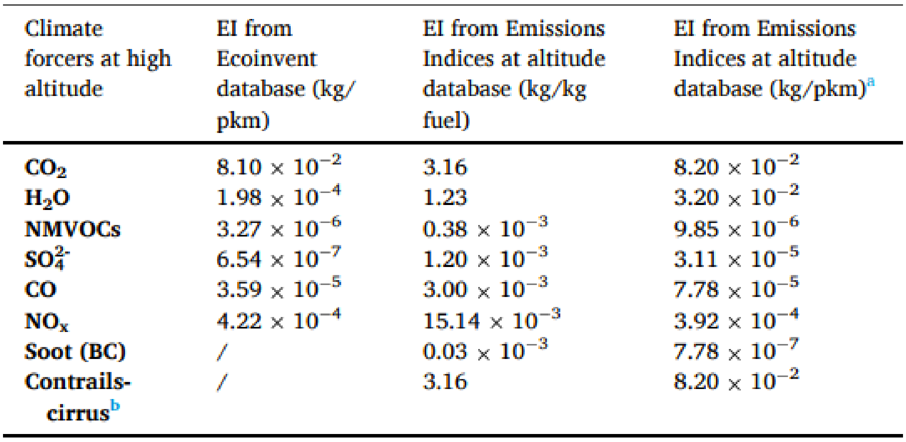


Figure 9: **Fuel consumption**
Own compilation

Consequently, a reduction in fuel consumption also implies a reduction in emissions. Therefore, it is important to examine each kilogram of fuel's impact on the environment. Out of all the emissions, the ones that most affect the atmosphere would be CO_2 and NO_X (*Benito, 2014*). CO_2 is the principal greenhouse gas due to kerosene combustion, and NO_X is responsible for creating ozone at high altitudes. The increasing presence of these gases in the atmosphere leads to global warming. Looking at Figure 10, we can study kilograms of each gas that would be put out in the atmosphere by one kilogram of fuel:

Table 5: **Emissions indices of climate change components**



Climate forcers at high altitude	EI from Ecoinvent database (kg/pkm)	EI from Emissions Indices at altitude database (kg/kg fuel)	EI from Emissions Indices at altitude database (kg/pkm)[a]
CO_2	8.10×10^{-2}	3.16	8.20×10^{-2}
H_2O	1.98×10^{-4}	1.23	3.20×10^{-2}
NMVOCs	3.27×10^{-6}	0.38×10^{-3}	9.85×10^{-6}
SO_4^{2-}	6.54×10^{-7}	1.20×10^{-3}	3.11×10^{-5}
CO	3.59×10^{-5}	3.00×10^{-3}	7.78×10^{-5}
NO_x	4.22×10^{-4}	15.14×10^{-3}	3.92×10^{-4}
Soot (BC)	/	0.03×10^{-3}	7.78×10^{-7}
Contrails-cirrus[b]	/	3.16	8.20×10^{-2}

Source: (*Watson et al., 2024*)

Having the indices of each gas and the fuel consumption of each route and airline, the data presented in Figures 11, 12, and 13 can be calculated. These show the reduction of the amount of each gas if we used an efficient route.

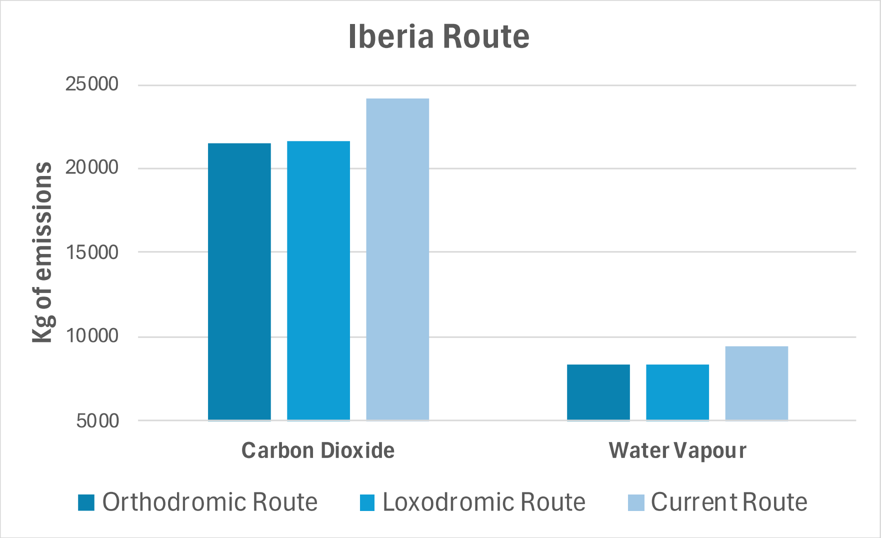


Figure 11: **Iberia´s gas emissions**
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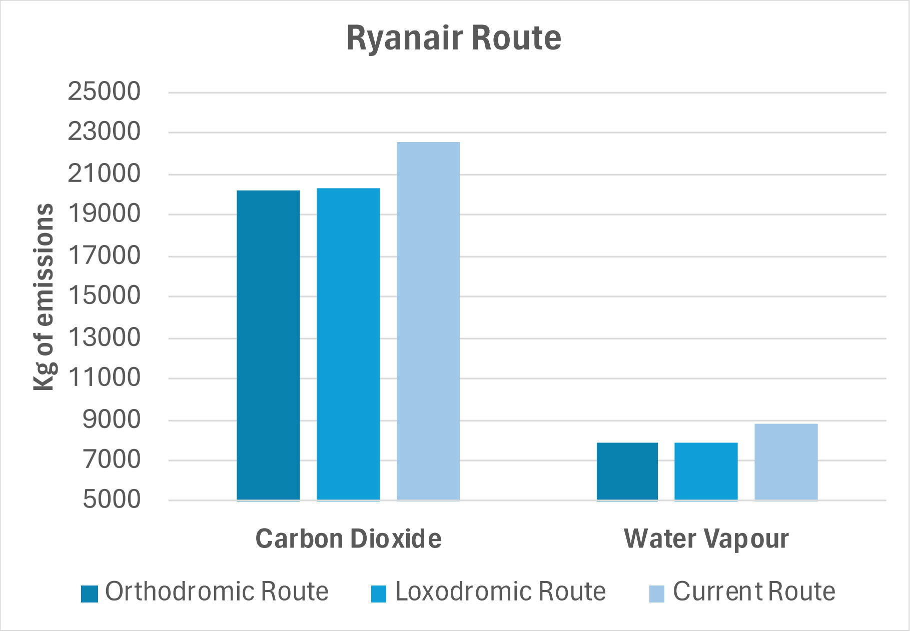

Figure 12: **Ryanair´s gas emissions**
Own Compilation

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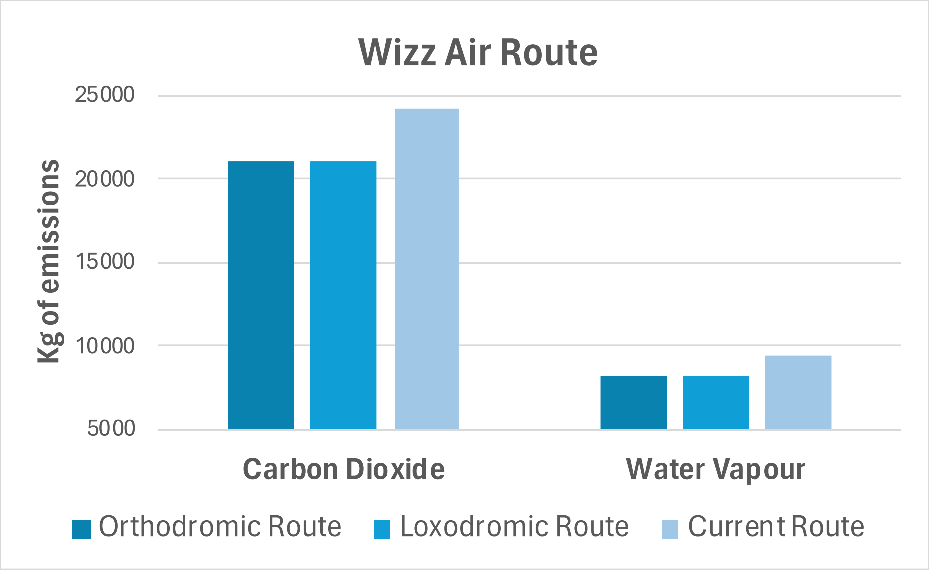

Figure 13: **Wizz Air´s gas emissions**
Own Compilation

5. Conclusion

It has been proven that the current state of European airspace is inefficient compared to other similar airspaces, such as the one in the USA. These inefficiencies include delays, suboptimal routing, and excessive fuel consumption, which contribute to increased operational costs and harm the environment. This study has demonstrated how the implementation of the SESAR initiative across Europe represents a pivotal advancement in revolutionising air traffic management and creating a more sustainable aviation ecosystem.

The case study of the Madrid–Budapest route demonstrates the advantages the SESAR initiative can accomplish. By adopting improved route planning techniques and switching from waypoint navigation to Free Route Airspace, we can reduce travelled distance; thus, the amount of fuel consumed can also be decreased. This implies cost savings for the companies and contributes to environmental preservation by minimising the carbon footprints associated with air travel. In addition, by maintaining the departure and arrival procedures on our route, commonly followed by the SID and the STAR, we approach the same goal and enhance the safety of our flights.

Furthermore, the successful implementation of the SESAR initiative may lead the European aviation industry towards sustainable growth, improved operational efficiency, and global competitiveness. As we navigate the complexities of the modern aviation landscape, the SESAR initiative stands out as a beacon of progress, pointing the way towards a time when air transport is economical, inventive, and dependable and ecologically conscious.

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