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Planning Catalonia's Airport System Based on Econometric Analysis

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Resum

El creixement continuat de l'aviació comercial en el món i específicament a Catalunya, únicament aturat amb l'esclat de la pandèmia, denota la necessitat de crear infraestructures resilients i responsables amb l'entorn que siguin eficaces a l'hora d'absorbir la demanda generada. Entendre l'abast dels aeroports (molt més que simples nodes de connexió) és imprescindible per abordar la tasca de potenciar el creixement econòmic de forma sostenible.

És per aquest motiu que aquesta tesis proposa un estudi holístic de la generació de la demanda, a partir de variables estructurals i econòmiques, per entendre, en primer lloc, cap a on es dirigeix el futur de l'aviació comercial a Catalunya, i en segon lloc, com distribuir els fluxos d'activitat aeroportuària pel territori per assolir una màxima eficiència econòmica i logística, sense perdre de vista els Objectius de Desenvolupament Sostenible de la ONU. A partir d'estudis estadístics i socioeconòmics, s'ha creat un model de demanda per als tres principals aeroports de Catalunya per a l'horitzó 2035 i s'han generat escenaris per entendre millor les possibles configuracions del sistema aeroportuari català.

Amb els diferents resultats s'ha pogut comprovar que el mercat de l'aviació civil a Catalunya té fortes arrels al territori (històriques i socioeconòmiques) i amb fortes expectatives de creixement per al següents anys. Aquest impuls s'ha de veure traduït en la millora de les diferents instal·lacions aeroportuàries, i a partir de criteris econòmics i de sostenibilitat (social, acústica i ambiental) s'ha pogut observar que la millor distribució dels fluxos d'aviació passa per una responsabilitat compartida. El caràcter complementari de les actuals instal·lacions crea sinergies al territori, que distribueix la riquesa generada de forma més equitativa, de la mateixa manera que divideix l'impacte ambiental. L'estructura actual del mercat aeronàutic de l'aviació comercial i civil a Catalunya acompanya aquesta redistribució de forces per equilibrar el territori i impulsar-lo de forma holística, responsable i decidida.

Abstract

The continued growth of the commercial aviation in the world, specifically in Catalonia (only hindered by the outburst of the pandemic), denotes the urge to build resilient and environmentally conscious infrastructures, capable of efficiently absorb the generated demand. Understanding the scope of airports (far more than mere nodes of transport) and their key role is fundamental to tackle its economic growth potential in a sustainable way.

Therefore, this thesis presents a holistic study of the demand generation- from structural and economic variables- to help understand, on the one hand, the journey towards the future of commercial aviation in Catalonia, and, on the other hand, the planification and distribution of the airport's activity flows throughout the territory to achieve maximum economic and logistic efficiency, without losing sight of the Sustainable Development Goals of the UN. Working on statistic and socioeconomic studies, a demand generation model has been created for the three most important airports of Catalonia in the 2035 horizon, as well as the study of different scenarios to understand better the possible configurations of the Catalan airport's system.

With the different results it has been proved that the civil aviation market in Catalonia has rooted strongly (both historically and economically) in the region, with solid forecasting performances for the next years. This increase must be translated into the enhancement of the different airport facilities. Following scientific criteria such as economics and acoustic, environmental and social sustainability, it has been observed that the most resilient configuration of aviation flows goes through a joint one with shared responsibilities between infrastructures. The complementary characteristic of the current infrastructure creates synergies in the region, enabling a more equative distribution of the wealth generated and the environmental impact. The nowadays structure of the commercial and civil aviation market in Catalonia supports this redistribution of powers to balance the region and potentiate it in a holistic, responsible and firm way.

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Abbreviations list/Glossary

GDP – Gross Domestic Product

UN – United Nations

SDG – Sustainable Development Goals

ICAO – International Civil Aviation Organization

EU – European Union

AENA – Aeropuertos Españoles y Navegación Aérea

ACI – Airports Council International

IATA – International Air Transport Association

CESDA – Centro de Estudios Superior de la Aviación

CAGR – Compound Annual Growth Rate

LCC – Low-Cost Carriers

BCN – IATA code for Josep Tarradellas Barcelona-El Prat airport

GRO – IATA code for the Girona-Costa Brava airport

REU – IATA code for the Reus airport

OPS – Operations

PAX – Passengers

Mpax – Millions of passengers

Kpax – Thousands of passengers

M€ - Millions of euros

1. INTRODUCTION

1.1 Aim of the project

Recurring debates over the future model of aviation have not only shaped the goals and objectives of the industry, but also regions and economies.

Catalonia stands as one of the most dynamic regions of Southern Europe, and with a population of more than 7.5 million people and a GDP of 249 billion euros (2019)[1] it is necessary to optimize and create an effective and sustainable ecosystem of infrastructure to deliver the economic growth it is expected to endure.

To do so, the airport system of the region plays a key role in the development of Catalonia. During the scope of this thesis, the aim to achieve will be to find the most economically, environmentally, and socially sustainable system that procures the needs and satisfies the demand generated in the region, to enhance and thrive economically whilst meeting the SDG (Sustainable Development Goals) for the UN 2030 Agenda [2].

Given that the topic is nowadays highly debated, the result demands an apolitical solution, based on data engineering.

[1] Extracted from Idescat [1].

1.2 Scope of the project

To achieve the mentioned objective, the scope of work will consist of different units of knowledge that will need to be achieved to fulfil the thesis hypothesis. Those units are described next, including those items that the thesis will not cover:

1.2.1 Study of background factors

- Analysis of the aviation market
  - To fulfil the objective of the thesis, it becomes primordial to ensure that the infrastructure development that is going to be proposed matches the industry's long-term trends and actions.

- UN's SDG compliance
  - A thorough study of the Sustainable Development Goals of the UN's 2030 Agenda will be carried, to understand which interfere with the thesis and how to best apply them to enhance the development of the world to a more sustainable one.

1.2.2 Present-day situation analysis

- Present day study of the infrastructure system in Catalonia
  - Focused on the aviation infrastructure this unit of knowledge will strive to achieve a full understanding of how all the Catalonia's infrastructures are organized and planned.

  - For data accessibility reasons, the infrastructure studied is limited to the three most important airports of Catalonia, the commercial airports of AENA's network in the region. The other three remaining airports of Catalonia are focused more on general aviation or do not present regular commercial flights [3] [4] [5]. As they do not exemplify the trends of the commercial aviation, the scope of this study will not cover them.

- Economic analysis of Catalonia
  - The thesis must focus on the airport system that will suit best the needs and demands of the population and the economy. This study will give a broad idea on how to best use the resources we have, to optimize the infrastructure and reduce costs.

1.2.3 Forecasting

- Determine the forecast of Catalonia's demand
  - Study the future demand and needs by economic zones and territories.
  - Implement different strategies of demand prognosis in the near and long-term future for a coherent demand forecast for the year 2035, including a macroeconomic model that links operations and passengers forecast with the principal indicators of the economy of the region.

1.2.4 Study of configurations to satisfy the demand generated

- Design of different airports systems based in different configurations
    - Based on the knowledge acquisition from the previous units of knowledge, alternative configurations of the actual system will be set on the table, based on the generated demand and different econometric criteria that comply with the UN's SDG. The initial assumption will follow a centralized project versus a spread through the region one.

- Preliminary design of each configuration
    - The study will then focus on a very superficial materialization of each plan-action based program.

- Design selection
    - The thesis will remark the most suitable option for the region and will develop its pros and cons, to give a more specific view of the opportunities presented by the chosen design.

1.2.5 Out-of-scope knowledge and actions

- The approach intended for the thesis will not intake several things that are described next
    - Some technical parts of the design of the infrastructure, including:
        - The runway orientation of possible new airports,
        - Movement area design (markings, beaconing, taxiway distribution),
        - Aeronautical signs,
        - Emergency services and control tower allocation.

1.3 Requirements

When implementing the solution, and before the research has been undertaken, some requirements must be put in place so that the final design matches the different set of goals that were established at the beginning. For the present thesis, the following requirements have been approved:

- The outcome of the study – all the possible solutions and configurations – must comply with the regulations in place for construction of airports, aerodromes, and heliports, in accordance with the Royal Decree 14/2009, of July the 22.

- The configurations must endure the compliance of the infrastructure following the Spanish regulations in the Royal Decree 862/2009, from the 14th of May, to start giving service to the region.

- A minimum requirement of complying with at least 2 of the UN's 2030 Agenda's SDG will be a must to validate a project [2].

- The cost of the whole operation must not surpass the amount of 1.7 billion euros, the projected cost for the ampliation of the Barcelona-El Prat airport.

- The project must consider the exchange nodes and the complimentary action of other (public) transports. For this reason, every configuration must count on an exchange node that enables the usage of public transport to link the infrastructure with the region.

- The configuration of airports must be able to endure the growth of the passengers for at least 10 years since design.

- All infrastructures constructed around influence of another infrastructure must have a specific and different target, to make sure that no interference is taking place in the study.

- The thesis must consider the COVID crisis and the effects on the air traffic. Multiple scenarios of the recovery of the aviation market will take place to give a broader idea of the realistic options.

- Other specifications and limitation that the scope of the work induces.

1.4 Justification

1.4.1 The Civil Aviation Industry

Since the beginning of the modern civil aviation, with the creation of the ICAO, the aviation industry has positioned as one of the most – if not the most – singular and catalyst industries of the world, especially in the last years of it, where the aviation has lived a special conjecture that has propelled the industry up to heights unknown, in which every 15 years its operations and passengers would double [6].

We understand by operations all aircraft movement involving take-off and landing in the facilities of an airport, airdrome or similar, and passengers as any person to use the industry on their behalf – that is, board a flight- without having any responsibilities on it (being cabin crew or member of the flight).

Up until the last year, where with the disruption of the COVID-19 pandemic the mass reduction of movement and flights unleashed the largest aviation crisis of all times, the steady growth of the industry was unchallenged.

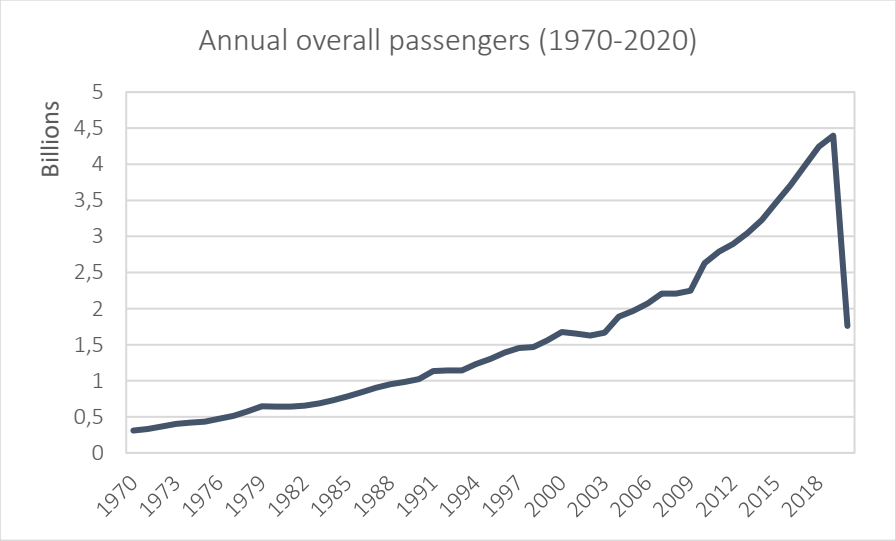


Figure 1. Annual overall passengers carried by the aviation industry (1970-2020) (Source: ICAO)

The main setbacks that the industry endured through its history have been closely related to world events, politic manoeuvres, and economic crisis. The correlation between these events and the evolution of the civil aviation is factual and strongly related. For every sudden change, the resilience of the industry has come up with a solution [7]. In the following page we list the major setbacks from the industry, easily seen in the above figure, quickly explaining the reasons and the changes that the industry endured:

- The recession that the world lived with the energy crisis in the 1970s is considered an industry changing event. Being one of the most notorious crises of the modern aviation – mainly for being the first one that engaged with the modern concept of civil aviation directly-, throughout the whole of the 70s the shortage of energy supplies reshaped the concept of the industry and ended with the "golden age of flying", where the luxury targeted audience shifted to the general public.

- The economic crisis of the ninety's lead to a redistribution of the market with the disappearance of two of the most consolidated airlines in the world, Pan Am and TWA (later in 2001). The flag carriers of each country gained presence in the market and the prices averaged and converged into the same metric.

- Being the most economically harmful event until the COVID pandemic, the 2001 terrorist attacks on the Twin Towers, on the 11th of September 2001, led to a fully restructuration of the market and the way its customers were involved with it. Security awareness was made primordial, and the whole customer/traveller experience transformed into a more hostile one, providing the security necessary to avoid such situation ever again. The whole of the industry redesigned itself and the passengers carried lasted two years to recover. That same recovery year, 2003, a SARS pandemic burst into the world, with little to no effect on the aviation ecosystem.

- The economic crisis of 2008 had its share on the aviation industry. The need of restructuration of traditional airlines was severely met with the change of the economic needs of the world population. To answer that demand, the aviation industry became flooded with low-cost airlines, especially in Europe and North America. The liberalization of the airspace helped them to consolidate, and a new model of business was born. The hub-&-spoke model slowly started to shift into a point-to point market distribution, as it allows for more flexibility and optimization of routes. The result became an exponential growth of traffic once the crisis had passed away.

- Finally, the COVID pandemic has put to test the resilience of the whole industry and its mechanisms to alert and prevent further crisis on the sector. The lockdowns and restrictions put in place to stop the pandemic from spreading have damaged severely the market of civil aviation, with empty airports and failing airlines - Figure 3 exemplifies the reduction of flights in merely one month-. The health and safety of the passengers have once again raised awareness throughout the globe and COVID passports seem to trigger the beginning of the restoration of the business. The regional markets have recovered faster than the intercontinental ones, and the statistical data showed that the year 2020 has seen a reduction of 60% of total passengers carried [8], carrying several total passengers similar to the year 2003. The ICAO estimates 3 to 4 years' time for the industry to fully recover.

Nonetheless, the aviation industry is still a core business for today's society, and it is expected to almost double the 2.7 trillion dollars earnings form 2016 up to a staggering 5.7 trillion dollars expected by 2036 [6]. The different innovations involved in the industry are the main reason for the industry's comeback after every crisis, even with global issues that collide with the whole industry itself: In a world where the restoration of the air connectivity is trying to merge with the climate change impositions [9], the resilience of the industry becomes a primordial asset to pursue a sustainable growth.

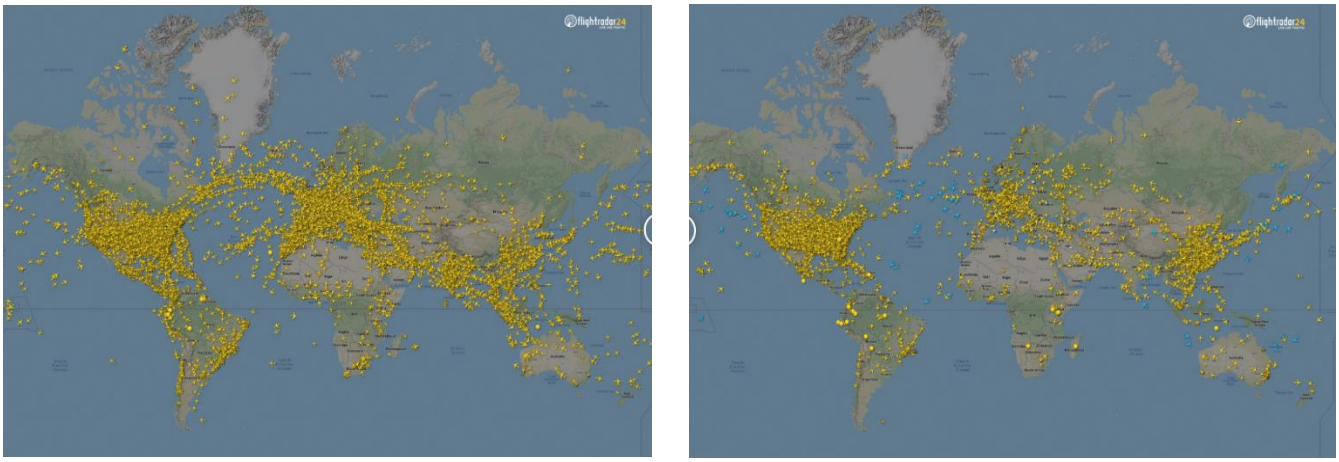


Figure 2. 7th March 2020 flights comparison to 7th April 2020 flights. Impact of the pandemic to the civil aviation industry (Source: FlightRadar24)

1.4.2 The Civil Aviation Industry and Infrastructure in Catalonia

In the previous section a review of the aviation industry historic trajectory has been carried out. These market and industry behaviours have changed the way the civil aviation works and is approached by the different sectors that work in it. Nevertheless, it is useless to understand the civil aviation without then implementing the outcome and possible solutions into a specific region.

The aim of this section, is, therefore, to provide this down-to-earth approach of the previous chapter, to highlight the roles that are involved locally in the structure of the whole aviation market.

In Europe – accountable for the 24% of the overall traffic, just behind the Asia-Pacific region (35%) and above the North America market (22%) –, the aviation industry held in 2019 12.2 million jobs and earned 823 billion dollars in the GPD of Europe [6]. The importance of this industry to the old continent has generated a packed airspace, where new connections fight for time slots to place the offer and meet the demand.

Catalonia, being one of the most economically dynamic regions of southern Europe – awarded with the best region to invest in southern Europe in 2020 and 2021 according to the Financial Times [10] – is no foreigner to this situation. The autonomous community presents a display of infrastructure to meet the demand of travellers and enterprises. The service-driven GDP and the importance of industries like the tourism and travel business generate a constant and growing demand [1] that – in the last years – has strained the today's airport infrastructure in some parts of the region.

	2016	2017	2018	2019	2020
GDP	**222.514**	**232.187**	**241.670**	**249.900**	**224.125**
Agriculture	1.944	2.095	2.058	2.198	2.307
Industry	40.640	42.059	43.270	44.267	41.031
Construction	10.132	10.766	11.457	12.141	10.581
Services	151.669	158.000	164.519	170.742	153.039
• **Commerce, transport and hospitality**	**51.833**	**54.342**	**56.017**	**57.638**	**43.354**
• Real estate, professional and other activities	67.804	70.800	74.511	77.323	71.661
• Public admin., education, health and social services.	32.032	32.858	33.991	35.782	38.025

Table 1. GDP distribution in Catalonia 2016-2020 (in millions) (Source: Idescat)

The distribution of the mentioned infrastructure to supply the demand in the region has not always been driven by the economic factors, rather than social and equity distribution throughout the terrain. All in all, the aviation infrastructure of Catalonia designed to satisfy the civil aviation market is distributed as follows:

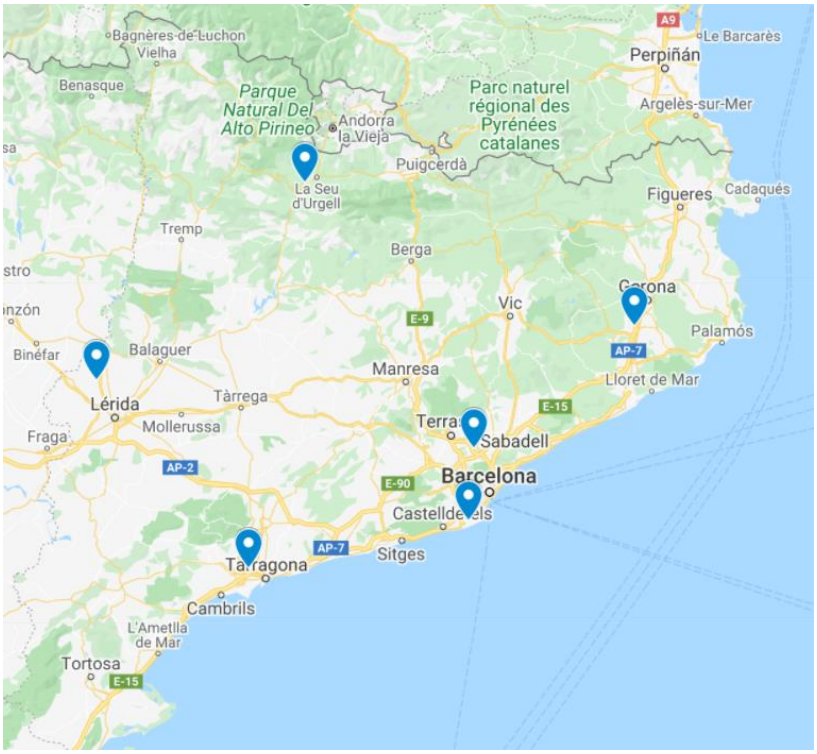


Figure 3. Airport system of Catalonia (Source: Own elaboration, Google Maps)

Josep Tarradellas Barcelona- El Prat airport

It is the principal airport of the region. With 52.7 million passengers in 2019, it ranked 6th in the busiest airports of Europe. Due to the COVID pandemic, the number of passengers of the next year descended to a historic minimum of 12.7 million. With a maximum capacity of 55Mpax, the airport is believed to reach its operating ceiling in about 4 to 5 years. Therefore, the need to implement a capacity enhancer to the existing infrastructure has become a primordial need for the airports' authority.

Girona – Costa Brava airport

Being the second most important airport in Catalonia, the Girona – Costa Brava airport has had at some point the ambition to serve as the secondary alternative airport of Barcelona [11]. In 2019 it carried almost 2.0 million passengers. Throughout its history, several low-cost carriers have placed an operative base on the airport due to cheaper taxes, and in 2009 the airport served a total of 5.5 million passengers, beating the record set until then. The 2008 crisis and the restructuration of the market saw a descent in operations, and since then it strives to keep other European connections.

Reus airport

Third largest airport of Catalonia [12], and last of the commercial airports operated by AENA, the Spanish regulator, its role is to serve the touristic area of the Costa Daurada, like the task of the Girona - Costa Brava. In 2019 carried a total of 1.05 Mpax. As the distance to the main Barcelona airport stands the same as the GRO airport (110km), the goal to serve as a secondary hub for the region can be difficult for the large transfer times. It has historically been a small and regional airport, but it has recently attracted attention due to the shared interests with the region tourist attractions and economic development.

Lleida - Alguaire airport

The airport of Lleida – Alguaire is the first airport to be operated by Aeroports de Catalunya, the regional operator for the Government of Catalunya. It is located 135 km west of the main Barcelona – El Prat airport and intends to serve the western part of the territory, covering as well the stational tourism of winter sports in the Pyrenees. During a long period of time the instability of flights gave the airport the title of a ghost airport, but recently some advances have been made to enhance the positioning of the airport and is taking a thorough renewal by accepting pioneer aviation and space projects. This new facet of the airport has started to see the outcome, translated into investment in the surroundings and attraction of new carriers [13].

Sabadell airport

This airport, even though operated by the Spanish regulator and operator AENA, serves as a corporative airport for general aviation. Therefore, commercial and civil aviation does not take place at a significant rate to become an important asset for the aviation infrastructure. Its proximity to the main Barcelona – El Prat airport positions the Sabadell airport as the centre of the emergency systems and tools for the region.

La Seu - Andorra airport

This last airport is intended to serve the Pyrenees and the neighbouring country of Andorra. Operated by Aeroports de Catalunya, this infrastructure was finished in 2010 and it provides charter flights from and to this inaccessible region of Catalonia. The first week of December saw the first commercial regular flight between the mentioned airport and the Adolfo Suárez Madrid-Barajas airport [3].

1.4.3 Challenges Ahead

The existing infrastructure, combined with the trends of the sector, demand an effective development and usage of it, compliant with environmental and social regulations to strive for a sustainable growth of the economy of the region.

The COVID situation has not only disrupted drastically the aviation market, but also the capacity for new investments. Although the economic crisis derived from the pandemic is expected to last until 2023 to 2025 (depending on the forecast), the different investment programs conceived around the world have given the dynamism and chance to build solemn and important infrastructure. In the European Union, the Next Generation funds aim to digitalize, and provide environmental and social equity to all its regions. The UN's SDG [2] also point toward a sustainable and responsible growth, and so, all future development should be made and thought in that direction.

When assessing this situation in the Catalonia context, the effective development of the aviation infrastructure would naturally mean to expand the existing infrastructure to ensure the demand generated can be supported. This way the impact of new infrastructures could be avoided, with the environmental positive outcomes that come with it. But the Barcelona airport is enclosed in between to natural protected areas, the "Natura 2000". The expansion over these lands would mean the destruction of natural and protected habitat at the end of the Llobregat river. Hence, the debate is served. Other alternatives have not been fully developed, and a holistic approach on the matter is still missing, including a regional perspective, and thinking more in the Catalonia area of influence or the Metropolitan Area of Barcelona rather than only the city itself.

Secondary airports can be enhanced to really serve the greater Barcelona conurbation and decongest the packed Catalonia airspace, another runway can be built in another location, the construction of a new airport… - this are all plausible options that need further study. Moreover, as the civil aviation never stays static, further investigation needs to be done to determine the future needs and trends of the industry and anticipate the possible outcomes and setbacks, to deliver an economically and sociable equity standards to the growth, without losing the strive for digitalization and economic empowerment of Catalonia.

2 CONTEXT AND BACKGROUND

When analysing the objectives that are wanted to be achieved, it becomes rather obvious the regional focus from where the thesis is structured. It is then primordial to fully understand the context of the Catalonia's infrastructure, to really see from where the actual airports have come from and this way to have a better view of where are they headed. All in all, to work for the infrastructure in concordance with the development of the region's goals, with the most accuracy and empathy possible, for then the growth will be truly sustainable, not only with the environment but with the whole surroundings of the infrastructure (socially, economically, and environmentally friendly).

To do so, the following sections aim to answer the questions "What is the current state of the airport infrastructure in Catalonia and how have we arrived to it?" and "What tools do we have at our disposal for working for the better future of the Catalonia's airport system?".

The project will focus on the three main civil airports of the region, as specified in the scope of the work. The little difference that makes the other two civil airports (Lleida-Alguaire and Andorra-La Seu), combined with the lack of transparency in data sharing and the little history they have do not qualify them as a real changer of the aviation infrastructure of Catalonia, as the scope of the work focuses on mid-term/long-term analysis only.

2.1 History of aviation infrastructure in Catalonia

The first commercial regular flight to ever take off and land in the Catalonia region took place on the 1st of September 1919, when three Breguet XIV that took off from Montadrau, near Toulouse, made technical stopovers in Barcelona, Alicante, Málaga and Tangier before reaching Casablanca carrying postal cards. The name of the company became worldwide famous: the Latécoère airline. Previous flights did already take place in the region, but they were not of the commercial type. This first commercial flight, then, was made possible because several days before, on the 29th of August of that same year, a Royal Order authorized stopovers in the Spanish territory.

This flight was the beginning of the industry in Spain and Catalonia, and from there several airdromes started to appear throughout the territory to host the aircrafts that steadily were conquering the skies. In Catalonia, the trend stayed the same and several infrastructures were opened. Some of them made it through the years and have now become the principal airports of the region, but most of them did not start with this ambition:

2.1.1 BCN: From La Volatería to the top 10 busiest airports in Europe [14]

The first motorized flight to take place in Spain in 1910 [15], near the delta of the Llobregat river, put in relevance three important things: the flat landscape of the delta was perfect for the aviation purposes, the Montjuic mountain needed to be kept away from the airdromes and that Barcelona had the ambition to build an effective airport. But the actual construction of the airport did not begin until after the Spanish Civil War (1936-1939). Up until then, the territory was filled with sprawling aviation infrastructures independent between them:

In 1916, an aerodrome was created near Prat de Llobregat, with the name of "La Volatería", as there were numerous birds flying in the delta of the river. It was from there that the memorable first scheduled flight between Barcelona and Mallorca took off. This was the first aviation infrastructure on the surroundings of the city of Barcelona.

Nevertheless, with the beginning of the commercial aviation, the airdrome become quickly obsolete and the airline in charge of the Toulouse-Casablanca air route created their own airdrome near the same area, the Latécoère airdrome (1920).

In 1923 there was still another airdrome constructed in the delta, the Canudas airdrome, in charge of the incipient civil aviation market.

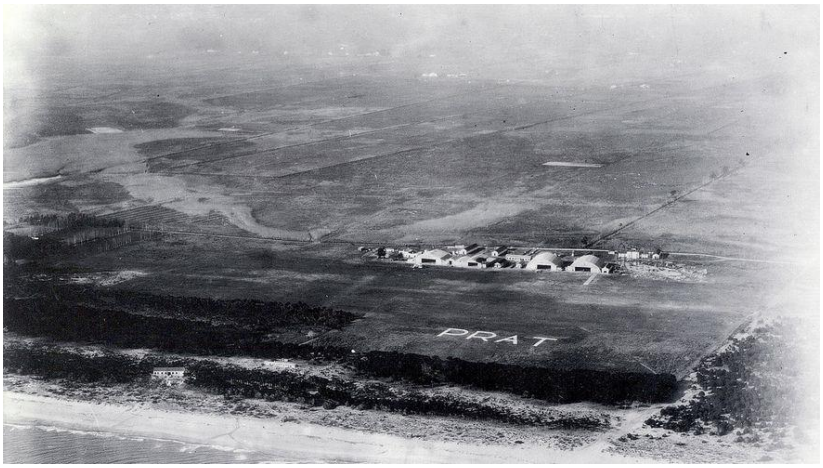


Figure 4: Aerial picture of the Volatería airdrome (Source: Marin-Fundación P. Iglesias)

The merge of these three different infrastructures did not take place until after the civil war, and in 1948 the construction of the first runway was completed, the 07/25 [16].

From there on, the steady growth of the infrastructure demanded the creation of a second ross runway, the 16/34 (that evolved to the 02/22 existing one), and in 1963 the first million of passenger's milestone was achieved. In 1968 the remodelling of the passenger's terminal, the creation of the control tower and the expansion of the runway got noticed by several international companies and in 1970 the Pan Am American airline began operations with the historic New York-Lisbon-Barcelona line, operated with a Boeing 747 [16]. That same year the "Puente Aéreo" between Barcelona and Madrid was inaugurated.

As years passed by the infrastructure grew obsolete, and with the Olympic Games celebrated in Barcelona in 1992 a huge remodel takes place. Terminals A and C are built from scratch and the existing terminal B grew in capacity. In 1990 the airport carried more than 10 million passengers.

The capacity covered by the built infrastructure began again to be obsolete at the beginning of the new millennia. The liberalization of the civil aviation led to an exponential grow of the airport from 1995 that consolidated the infrastructure as one of the top 15 airports in Europe. Therefore, at the awe of the 2000, a new plan was conceived for the airport: in 1999 the Spanish government approved the known as Plan Barcelona, which structured the future arrangements to be made to secure the growth of the infrastructure.

In 2001, due to the worldwide aviation crisis because of the 9/11 terrorist attacks, the Barcelona airport concentrated much of the operations that were previously held in the Girona and Reus airport, and thus minimizing the impact of the crisis significantly.

The Plan Barcelona, then, begun with the construction of a new control tower at the seaside of the 07L/25R runway, joined by a parallel runway (07R/25L) in 2004 (see *Figure 5*). The beginning of the runway service provided the airport the capacity of 90 ops/h, the ratio considered necessary to transform the airport into a hub. [17]

In 2006, nevertheless, the acoustic harmful effects on the nearby areas accelerated a new configuration of runways - segregated (meaning only the 07L/25R would be used for landings, and the 07R/25L would be for take-offs)-. As the take-off runway was shorter than the landing one, an exception ought to be made for some wide-bodies, taking-off through the 07L/25R – the longest one, initially reserved for only landings-.

This meant the effectiveness of the landing runway time to decrease, as some time had to be allocated for the wide bodies to take-off, and thus disabling the runway for other landings. This shortage decreased the maximum operations of the runways to 80 ops/h.

Figure 5: Barcelona – El Prat Runway layout. (Source: Own elaboration, Google Maps)

The main construction endured by the plan was not finished until 2009, where the new Terminal 1 of the airport was inaugurated. The existing terminals were renamed to T2A, T2B and T2C respectively. One year later the airport changed its official name to Barcelona- El Prat airport, due to the pressions of the local government.

From there on, the aviation infrastructure has remained the same, and it has seen a rapid growth of passengers and operations, accentuated by the beginning of Ryanair's operations in 2010 (previously held in Girona and Reus), the arrival of the A380 jumbo operated by Emirates in 2014 (being the first Spanish airport to host it), the expansion of Vueling and the creation of several long-range low-cost airlines such as Norwegian or Level. The bankruptcy of the Barcelona based Spanair airline did have an impact on the airport, but the demand was rapidly covered by Vueling (in the short/mid-range sector) and absorbed by Iberia in Madrid-Barajas airport for the long-haul flights. In 2018 the 50 million passenger's milestone is achieved, and therefore the airport begins to look after a new plan. The mindset has changed from the huge infrastructure boom in the beginning of the 2000, and the plans of expansion proposed then do not seem to fit the demands of the society, more environmentally and socially cautious.

2.1.2 GRO: The resilient Girona-Costa Brava airport

The aviation impulse of Barcelona had replicas all around the territory. In the province of Girona, the first flight was programmed for 1913, and many more followed during the decade of the 1920 [18]. It is then that several aviation institutions began to generate impulse into the industry, and with the momentum created several aviation clubs appear throughout the province- the creation of the airdrome of Figueres (1931) and Puigcerdà (1934) are direct consequences of this trend.

It is during this time that the expectation generated for the aviation industry brings the first tourists into the area, with several point-to-point flights in the province, looking after the Costa Brava and Pyrenees highlights. These flights, nevertheless, come to an abrupt stop when in 1939 the Generalitat loses all political power to develop the airdromes, as the Spanish Civil War comes to an end. From the seven operable infrastructures, only one will remain [18].

In 1957, the provincial political power encourages the creation of an airport. The terrain selected is a new plot of land different from the historic airdromes of the area, 10km south of Girona and 90km away from the existing Barcelona airport. The development of the infrastructure involves the creation of a new runway of 2200 meters of length and 45 meters wide and the platform for 9 aircrafts of medium size. The airport is named Girona-Costa Brava. The created infrastructure, nevertheless, it is not open to civil aviation until 1967, after the publication of several physical easements and construction of a passenger's terminal.

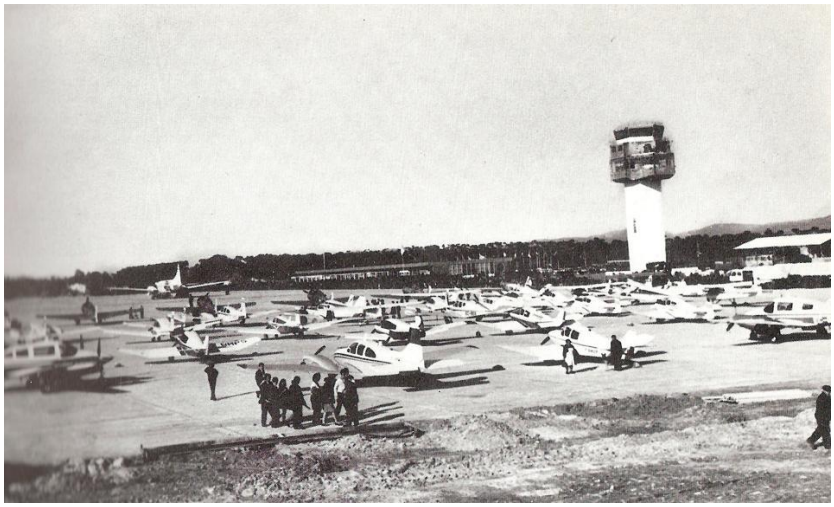


Figure 6: Inauguration Day of the Girona-Costa Brava airport, in 1967 [19].

The initial growth of the airport demanded the creation of new infrastructure, including a redesigned terminal building, an extension of the runway and the configuration of rapid exit ways, that were constructed throughout the 70s. During that same time, charter flights filled the slots of the airport, and the infrastructure lived a vibrant momentum. In 1978, however, most of that charter traffic started to migrate into Barcelona or other Mediterranean touristic spots. Therefore, the quick growth of passengers and operations saw a continued descent from 1983 onwards – that year a historic maximum of 830.000 passengers used the facilities-.

Nonetheless, the airport reconfigured itself ahead of the trend and reinvented. From 2003, with the creation of the low-cost carriers due to the liberalization of the European sky (1987), the airport outburst with activity, growing from the merely 500.000 passengers in 2003 to a staggering record of 5.5 million passengers through the airport facilities in 2008. After the economic crisis of that year, however, low-cost carriers operating in the airport shifted their services to other airports, mainly Barcelona-El Prat. Since then, the airport has again seen a gradual descent of passengers, that stabilized in 2014 around the annual 2.5 million. The resiliency of the airport has demonstrated its capability to transform to meet the challenges of the aviation industry and has paid the price of such rapid transformations.

2.1.3 REU: From military to civil aviation, a history of conversion

The third commercial and civil airport of Catalonia also has its roots in the awe of aviation. Several interests were taken by the region of the industry, but it wasn't until 1935 when the RACREUS (Real Aeroclub de Reus) was created, and the opportunity of an airdrome become a feasible option. That same year the club bought a plot of land and created two runways of 1100 and 825 meters that were operative the next year [20].

The site gained special relevance during the civil war (1936-1939), when the Republican Army bought the terrain and transformed it into a military air base. During the conflict up to three airdromes were created in the area, generating a "cluster" of aviation development on the region. Some aeronautical enterprises also established themselves in the area and the contribution to the industry, especially military aviation, become one of the primordial economies of the region [21].

Figure 7: The Republican army developed an aviation ecosystem in the region that endured throughout the conflict (Source: RACREUS)

After the war, the Army built a military base on the spot and the aviation club saw diminished the area of operation into a little hangar. The military base hosted the 23rd Hunter's regiment of the Airforce. That same airport also endured the creation of the Hunt School (prior to its relocation in Seville) and the War Sub Officers School. In 1957 the facilities were steadily opened to civil aviation as well, due to the tourism industry emerging in the Costa Daurada region. In the 60s the growth of charter flights saw an opportunity of business in the infrastructure built and the need of transformation become more evident than ever.

This renovation took place in 1974, with the creation of a terminal building and a platform for aircrafts, that was expanded through the 80s until it became evident the natural reason of the airport: the civil aviation. The closure of the school in 1992 pointed to that direction, but the army remained until 1998. From there on, the airport was only used by civil aviation.

The rise of the low-cost carriers in the early 2000s meant an important grow of passengers and operation in the airport, and in 2004 it surpassed the million passengers for the first time. The situation, nevertheless, was affected as well by the relocation of several operations into the Barcelona-El Prat airport from 2008 onwards, but the facilities have had the audacity to anticipate the changes. In the nearby areas the CESDA – a college dedicated to the formation of pilots – has also become an important asset for the infrastructure. The last improvements on the airport have involved the expansion of the terminal floor in 2021.

Figure 8: The impulse of the low-cost carriers has encouraged the renovation of the facilities of the airport, including the renewal of the terminal building floor (Source: AENA)

2.2 Today's situation of the airport system in Catalonia

2.2.1 Josep Tarradellas Barcelona- El Prat airport

The layout of the airport's infrastructure has stayed the same for over 10 years. Since the inauguration of the T1 terminal building no major changes have been undertaken, as the demand was secured for several years. The growth of the last years – excluding 2020/2021- has been exponential, and the need of expansion has raised interest again.

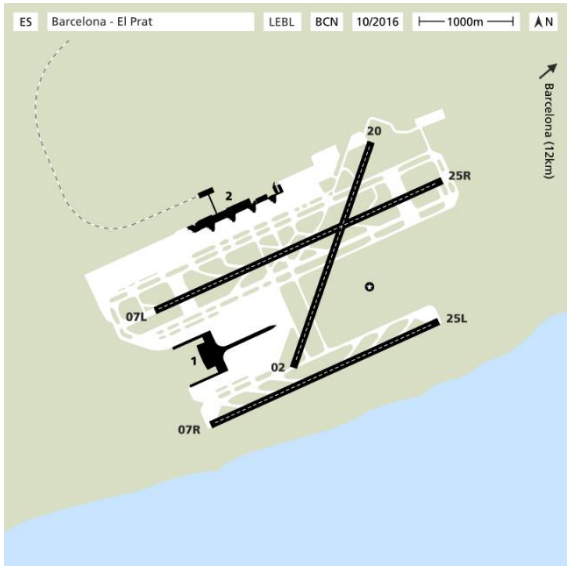


Figure 9: Today's configuration of the J.T. Barcelona-El Prat airport (Source: ACI)

Currently the airport serves 371 routes with 89 different airlines [22]. With 52.7 million passengers in 2019, the J.T. Barcelona-El Prat airport ranked 6th in the busiest airports of Europe. However, due to the COVID pandemic, the number of passengers in 2020 descended to a historic minimum of 12.7 million. Being the maximum capacity of the infrastructure 55Mpax, the airport is believed to reach its operating ceiling in about 4 to 5 years, depending on the recovery scenarios. Therefore, the need to implement a capacity enhancer has become a primordial need for the airports' authority.

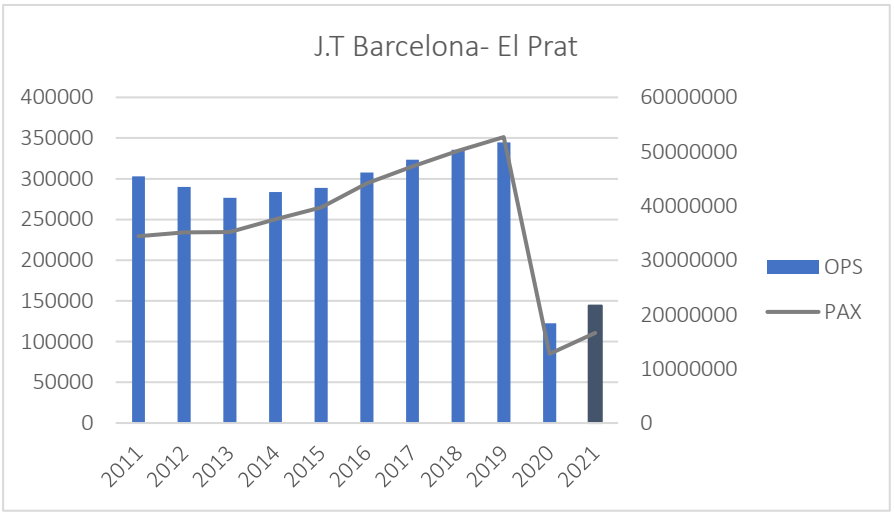


*Figure 10: Josep Tarradellas Barcelona-El Prat airport passengers. *2021 counted until November (Source: AENA, own elaboration)*

The pandemic has given some time to prepare the facilities for absorbing the operations and passengers for 4 to 5 years' time, the expected span for the infrastructure to be obsolete. The evolution of the passengers and the traffic generated play a key role on the behaviour of the airport, and the final prognosis of traffic will be closely correlated with the covid situation. To better explain the role of the pandemic, next is attached the difference of activity in the airport through the years 2019, 2020 and 2021:

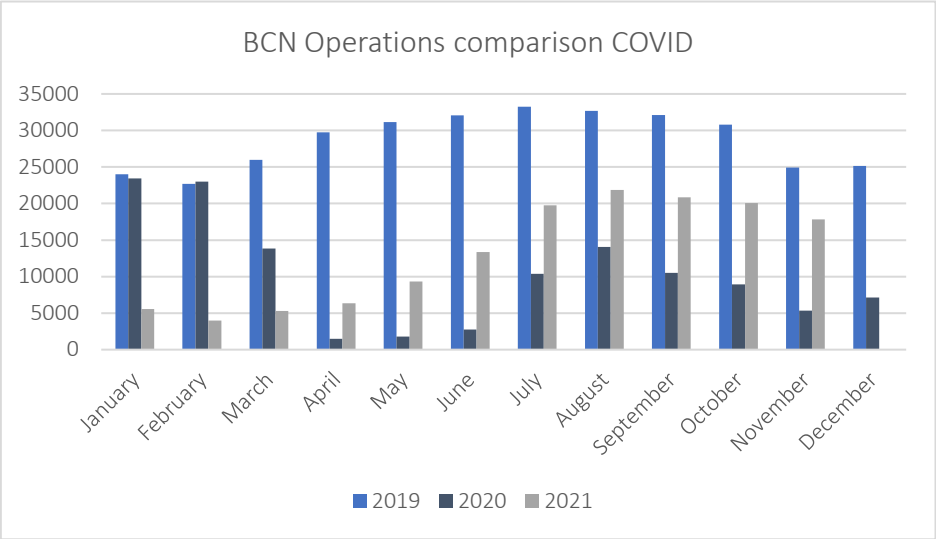


Figure 11: Operations comparison before/after the outburst of the COVID pandemic in BCN (Source: AENA, Own elaboration)

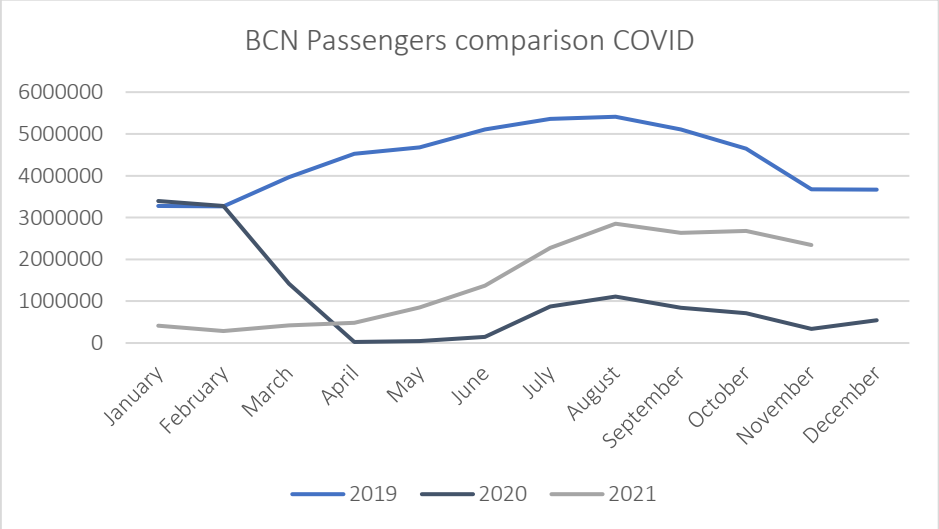


Figure 12: Passengers comparison before/after the outburst of the COVID pandemic in BCN (Source: AENA, Own elaboration)

With the operable ceiling of the facilities in mind, several projects are put in place to expand the airport [23], [24], not only with terminal surface, but with runways operability as well. The main existing proposals are the mentioned as follows:

- Use the existing infrastructure and repeal the 2006 agreement on the segregated runways operations [25]. This way, the airport would have the capability to run the 90 ops/h established to transform the airport into a hub without additional infrastructure but considering that the acoustic pollution would be too high for its surrounding neighbours.

- Expand the 07R/25L runway north-side to comply with the distance necessary to operate with the wide bodies as well. This way, the segregation of runways would continue to protect acoustically the surrounding villages and the segregation could be done efficiently, without having to change the regime of the longest runway (see History of aviation infrastructure in Catalonia: BCN). This project, nevertheless, faces one big setback: To expand the runway, a major construction process ought to be made on a natural protected area, and it should comply with the EU's regulation on that matter. As of 08/09/2021, the Spanish airport regulator system, AENA, proposed this option as preferrable, but the Government of Catalonia did not accept it as it would damage the protected area, Natura 2000. As the political quarrel hindered the technical solution, the Central Government of Spain dismissed the project.

- Build a new runway parallel on other locations, such as next to the twin ones existing now into the sea. This project has been initially dismissed for the effects on existing ecosystem and the high impact on the surrounding villages and neighbourhoods.

- Use alternative airports (GRO and REU, mainly) to capture the excess of traffic and build a network of airports serving the surroundings of Barcelona.

Average ops/week	6.626
Average pax/week	1,0 M
Taxiing stands	230 taxiing places 73 airbridges
Reference altitude (m)	4
Reference temperature (ºC)	29
Largest operating airplane	A380-800
Most common airplane	A321/B-737
Runway(s)	02/20 (2.528x45m) 07L/25R (3.352x60m) 07R/25L (2660x60m)

Table 2: Technical data from JT Barcelona-El Prat airport (Source: AENA)

2.2.2 Girona – Costa Brava airport

Being the second most used airport in Catalonia, the Girona – Costa Brava airport has the ambition to serve as the secondary alternative airport of Barcelona [11]. In 2019 it carried almost 2.0 million passengers. The 2008 crisis and the restructuration of the market saw a descent in operations, when all major airlines operating in the airport moved to Barcelona – El Prat for better connectivity.

It consists of a single runway airport – 02/20, that can operate a maximum of 19 operations per hour – and one terminal building with 15 boarding gates, and it was initially designed to boost the tourism in the nearby areas. The Girona airport currently has an infrastructure with capacity for 7,2 million passengers [26], with a catchment area under 60minutes of 5,7 million people. Data reveals that 91% of the flights are low-cost carriers, and a 6% more are charter flights. Most of the passengers that use the facilities – 73% - are tourists, being the main market UK in both nationality and number of destinations offered from the airport [26].

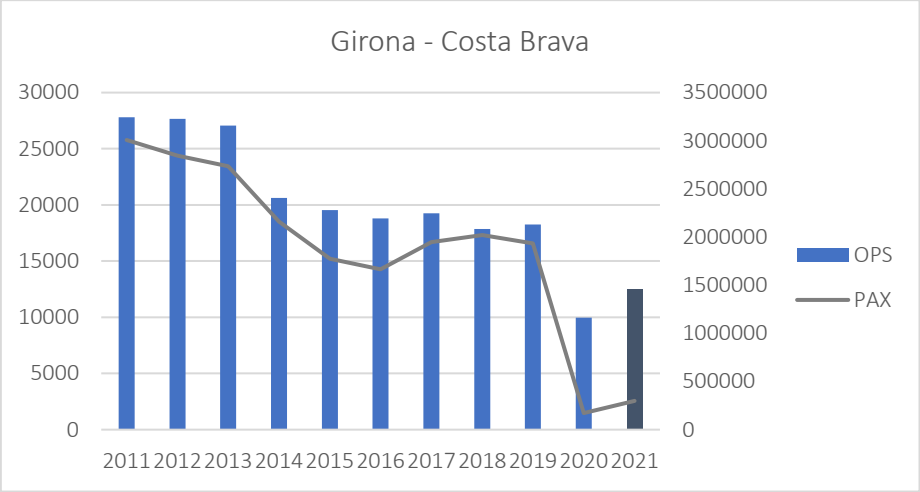


*Figure 13: Girona – Costa Brava airport operations and passengers. *2021 counted until November (Source: AENA, Own elaboration)*

In 2019, the infrastructure handled 1,9 million passengers and 18.253 operations [26]. During the pandemic, those figures dropped by a 91,1% in passengers and 45,3% in operations. The smaller reduction of operations is explained by the taxiing facilities of the airport where several foreign and national aircraft have hibernated during the crisis, as well as the exponential growth of the cargo operations in the airport, with a stunning figure of 318,1% of increase during the 2020.

Figure 14: Layout of the Girona – Costa Brava airport (Source: Google Maps, Own elaboration)

The impact of the COVID pandemic has had seriously diminished the passengers and operations of the airport. Throughout the 2021, nevertheless, the operations level has raised to almost the 2019 registrations [26]. In the following graph the evolution of the airport's activity can be seen, segregated by operations and passengers throughout the years 2019, 2020 and 2021:

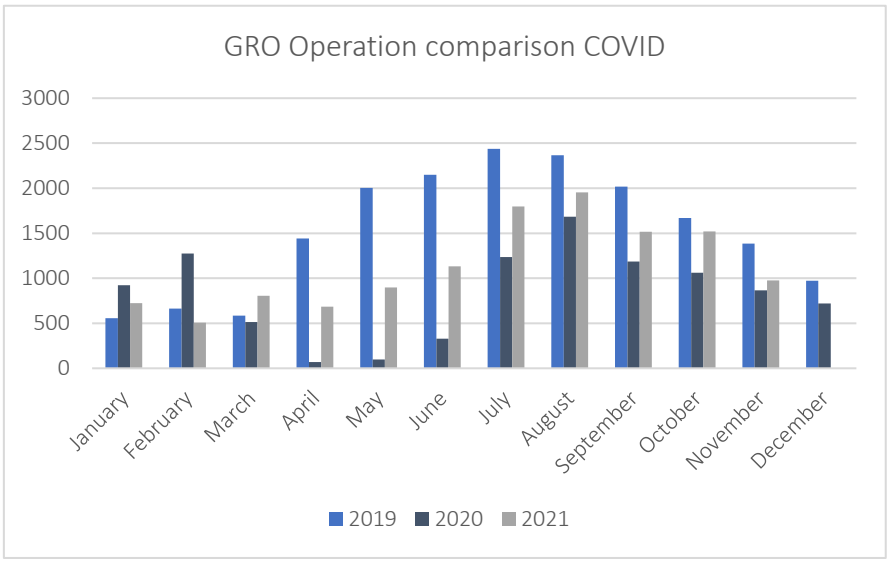


Figure 15: Operations comparison before/ after the outburst of the COVID pandemic in GRO (Source: AENA, Own elaboration)

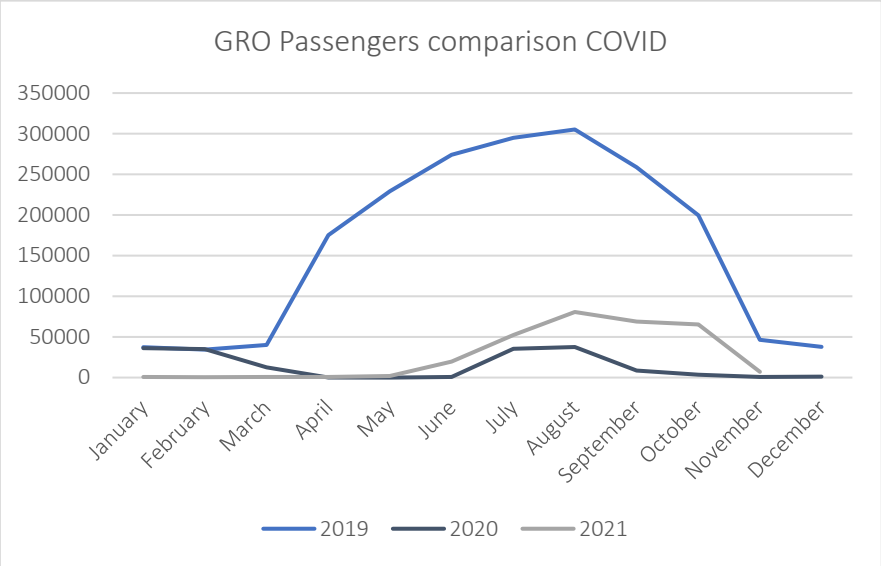


Figure 16: Passengers comparison before/ after the outburst of the COVID pandemic in GRO (Source: AENA, Own elaboration)

The main issue with the airport is that it presents a very pronounced stationarity calendar. As seen in Figure 16: Passengers comparison before/ after the outburst of the COVID pandemic in GRO (Source: AENA, Own elaboration)Figure 16, almost all activity (90%) [26] in the facilities is held during the summer season, from the months of April to October. This seasonality disables a steady growth as the variations between months prevent the continuity of the records in the infrastructure. The pandemic has left record breaking operations and passengers, with only 70 passengers and operations in April 2020; but that same year, in August, nearly 40.000 passengers used the facilities. These variations weld a sustainable development for the infrastructure.

The future development of the airport necessarily goes through the reactivation of its economy and activity to revert the diminishing trend that has been installed in it. The regulator of the infrastructure has initially dismissed the idea of a sub-hub of the Barcelona's main airport, as the distance (85km) would hinder fast connection times [11]. Nevertheless, the nature of the infrastructure is also to support the Barcelona's area of influence. A future connection with the high-speed rail system is intended to reduce connection times with the metropolitan area, and other plans include the remodulation of the existing terminal to accommodate a maximum of 10Mpax.

Average ops/week	351
Average pax/week	37,2 K
Taxiing stands	18 taxiing places
Reference altitude (m)	143
Reference temperature (ºC)	30
Largest operating airplane	B767-300
Most common airplane	B-737/800
Runway(s)	02/20 (2.400x45m)

Table 3: Technical data from Girona-Costa Brava airport (Source: AENA)

2.2.3 Reus airport

Third largest airport of Catalonia [12], and last of the commercial airports operated by AENA in the territory, nowadays its role is to serve the touristic area of the Costa Daurada, similar to the task of the Girona - Costa Brava. The 60min catchment area amounts to a population of 3.1M people and the historic data confirms the low-cost and touristic character of the airport, with 66% of low-cost carrier operations in the facilities and 93% of the passenger profile coming for holidays [27]. The percentual of low-cost airlines can seem low enough when compared to the other studied airports (70% BCN and 91% GRO), but the REU airport still counts with an important contribution of the general aviation, including the CESDA flight academy, that makes up for an important part of the missing traffic. That is the reason why the operations in the airport seem to be unrelated with the number of passengers, because many of the manoeuvres that take place in the facilities include multiple take-offs and landings, which end up accounting for the total operations of the infrastructure. It consists of one runway and one terminal building split in departures and arrivals, and can operate a maximum of 18 ops/h. It's the only airport studied that presents a specific timetable: in Summer the airport is opened from 6Am to 22PM and in winter from 7AM to 21PM.

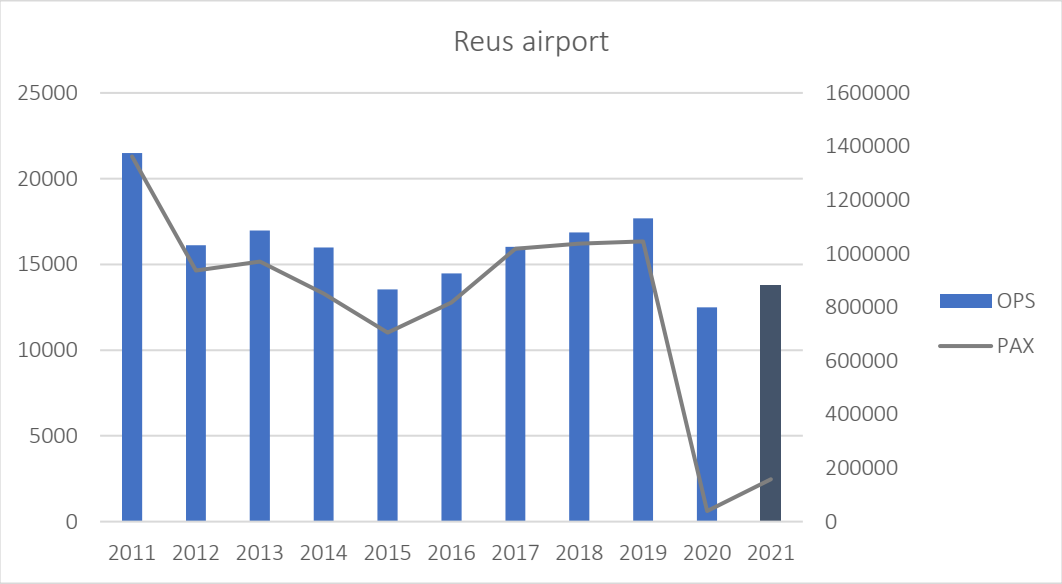


*Figure 17: REU airport operations and passenger evolution 2011-2021. *2021 until November (Source: AENA, Own elaboration)*

In 2019 the airport carried a total of 1,05 Mpax. As the distance to the main Barcelona airport stands at 110km, the goal to serve as a secondary hub for the region can be difficult for the large transfer times. It has historically been a small and regional airport, but it has recently attracted attention due to the shared interests with the region tourist attractions and economic development.

The infrastructure activity is highly concentrated on the summer season – up to a 98% of the traffic takes place from April to October-. With the new developments the airport has improved the capacity up to 1,6 million passengers.

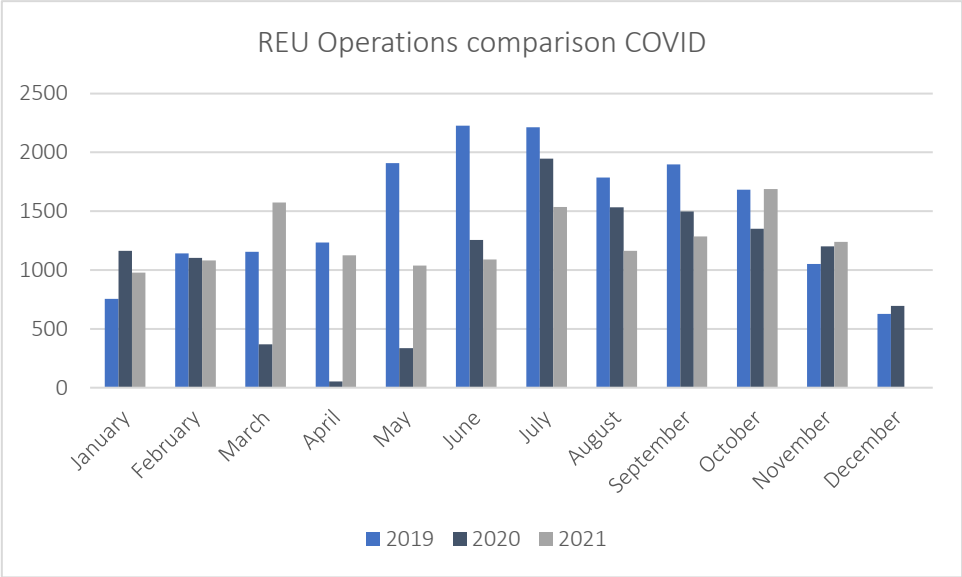


Figure 18: Operations comparison before/ after the outburst of the COVID pandemic in REU (Source: AENA, Own elaboration)

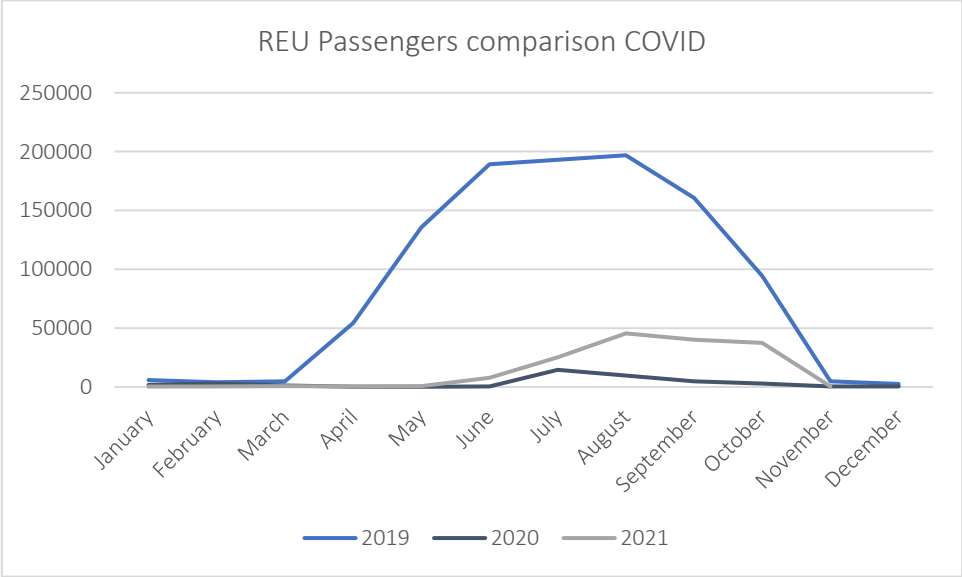


Figure 19: Passengers comparison before/ after the outburst of the COVID pandemic in REU (Source: AENA, Own elaboration)

Average ops/week	340
Average pax/week	20,1 K
Taxiing stands	12 taxiing places
Reference altitude (m)	71
Reference temperature (ºC)	29
Largest operating airplane	B767/300
Most common airplane	B-737/800
Runway(s)	07/25 (2459x45m)

Table 4: Technical data from Reus airport (Source: AENA)

Figure 20: Aerial view of the layout of REU's airport (Source: AENA)

2.3 SDG: Sustainable Development Goals for an enhanced solution

2.3.1 The 17 goals and the aviation industry

To provide the best solution to the present study, there is a need to understand the values that will drive the development of the future's world, that is, the UN's SGD (Sustainable Development Goals) for the 2030 Agenda. These milestones pretend to articulate the worldwide growth to pursue total equity and integrity in all parts of the globe [28]. The list is formed by 17 different topics to commit for a sustainable development (See Annex A). They are, nevertheless, recommendations only, so there is no real encouraging of pursuing them (all other UN programs allocate sanctions if minimum standards are not achieved). The achievement of these goals would improve the overall quality of life for everyone, and a grow of the world economic activity, relying on safe and responsible sources and procedures.

As a leading industry in today's economy, the commercial and civil aviation stays no further than the other industries in complying with the different recommendations. Since the launch of the project in 2015, several companies have strived to become leaders in achieving the goals, and thus becoming coherent with the context in which they develop their operations and services. The aviation sector holds a key role in 15 of the 17 goals, with different actions to take- big or small – that empower the change needed. The compliance with this goals will be considered when assessing the different design configurations for the Catalonia's airport system.

The implication of such industry to the SGDs is described next:

Figure 21: United Nations Sustainable Development Goals of the 2030 Agenda (Source: UN)

End poverty in all its forms everywhere: The partnership "Change for Good" between UNICEF and different airlines to collect coins from passengers raised 160 million dollars to help improve the lives of millions of children around the world [29]. Even though air transport has a limited role to play in assisting individuals in severe poverty, increased connectivity aids economic growth, which in turn raises living standards. Aviation employs 65,5 million people globally, directly and indirectly [29].

End hunger, achieve food security and improved nutrition and promote sustainable agriculture [30]. Over 70 million people have experienced hunger due to the pandemic, adding up to a total of 720 million unnourished people. In 2019, more than 35,000 tonnes of food and goods were transported by air to aid victims and health crisis sufferers [31]. Whilst aviation is also in charge for carrying perishable goods around the globe, the very core of the aviation's role in this goal is to deliver vital humanitarian aid in areas needed.

Ensure healthy lives and promote well-being for all at all ages: Life-expectancy and health services are on the spot in this item. Through a programme backed by 15 Brazilian airlines, 99% of Brazil's urgent medical exports (including organs and blood) are transported by air, free of charge [32]. The safety and speed of this mode of transport has enabled quick responses to health issues around the globe. In Spain – being the number one country of transplants in the world [33] -, Vueling is the leader in organ air transport with 51% of deliveries in 2019 and 42% in 2020, despite the COVID crisis [34], [35].

Ensure inclusive and equitable quality education and promote lifelong learning opportunities for all: Because of COVID, a further 9% of children fell behind the minimum reading proficiency levels [36]. However, an estimated of 4 million students worldwide study abroad, being air travel the first mean of communication [37]. This enablement enhances education throughout the world, especially in impoverished areas, and improves prospects for those who access the multiple programmes around the globe. Airbus is currently hosting a global competition with UNESCO to challenge students to innovate for the future of aviation [38].

Achieve gender equality and empower all women and girls: Even though there is still a remarkable gender gap in the aviation industry, 41% of the workforce is now employed by women [39]. The hostess image and branding has changed completely away from the reification, but there is still encouraging to be done for engineering positions. The creation of the International Aviation Women's Association is looking forward to closing the gap, and numerous airlines have marketed services free of harassment for female customers, such as women-only seats or no centre sitting [39].

Ensure availability and sustainable management of water and sanitation for all: Water scarcity has sadly been a recurring debate over the las few years. New aviation washing techniques have proven to save 95% of water usage during the cleaning stages of a widebody [40]. Even though it is not a direct industry, aviation can still help reduce water waste and become more coherent in the water constrained areas. Water Management Plans, such as the one endured by the Canberra Airport [41], can reduce waste and use stormwater to fulfil its activities.

Ensure access to affordable, reliable, sustainable, and modern energy for all: The biofuel and other sustainable alternative fuels (SAFs) for aviation are gaining relevance in the aviation sector [57]– [60]. Up to 2021 there were more than 160.000 commercial flights that took place with non-fossil fuels. They are known to be up to 80% less carbon-intensive than traditional ones [46]. LAX, in partnership with United, has a project in place to use sustainable fuel for its operations [47].

Promote sustained, inclusive, and sustainable economic growth, full and productive employment, and decent work for all: In 2019, before the pandemic, the aviation industry employed a total of 87,7million jobs, and produced 3,5 trillion dollars' worth of economic activity (3,5% of total GDP) [48]. Being one of the tech-edge industries of the world, the employment opportunities the industry has to offer are skilled and high-valued. The connectivity helps other industries to generate more decent work and growth, and so it acts as a catalyst.

Build resilient infrastructure, promote inclusive and sustainable industrialization and foster innovation: The infrastructure potential needed to support the aviation industry is innovative, and recently, focused on sustainability. $51,4 billion were invested in the construction of infrastructure, mainly in developed areas. Airports in Europe amounted to 4,4% of EU's GDP in 2018 [49]. The need of innovation is intrinsic within the industry and generates affordable and sustainable options that replace the old versions continuously.

Reduce inequality within and among countries: The service that air traffic provides has proved fundamental for many regions and economies. The end of the golden age of flying and the appearance of the low-cost carriers have cheapened the air traffic fares around 70% of the average price for the same ticket in 1970 [37]. The liberalization of the aviation industry led to the worldwide availability, and the connectivity that projects is a main catalyst in reducing inequalities.

Make cities and human settlements inclusive, safe, resilient, and sustainable: The 21.187 unique air routes that unite different parts of the globe act as an inclusivity tool that fosters collaboration [50]. The implementation of quick transport methods allows for the different settlements to be more dynamic and enable growth, making them more resilient and capable. Nevertheless, the connectivity in between public transports needs to be enhanced, for a more sustainable transportation.

Ensure sustainable consumption and production patterns: Even though nowadays the aviation laws restrict the recycling of the aircrafts to very specific parts, the exponential growth on the resiliency of the new materials used for construction and the longer lifespan of the aircrafts are helping to shift the mindset and working around new ways to reuse and upcycle the materials. Furthermore, new construction techniques are providing the same results with very limited usage of CO_2 and water. Airport infrastructure also is seeing new techniques and materials. For instance, Galapagos Airport's terminal is built on 80% recycled materials from the old terminal [51].

Take urgent action to combat climate change and its impacts: The aviation industry only amounts for the 2% of the global carbon emission levels (far less than expected), and that is because the ongoing innovation that the industry endures [67]– [70]. The results have been recently targeting the sustainability of the industry. The airlines are more interested in fuel efficiency not only because of their environmental impact being lessened but also because more fuel efficiency means less fuel to cover the same route and thus less costs for the airline. It is believed that a flight today produces half the CO_2 than the same flight in 1990. Several agreements have been reached from ICAO and FAA for stating the guidelines to a 2050 carbon neutral industry [63]– [65].

Conserve and sustainably use the oceans, seas and marine resources for sustainable development: Where airports are built into the sea, as happens in some small islands, preservation of the neighbouring marine ecosystems takes special importance in natural protected areas. The relevance of this goal in aviation, nevertheless, is minimum as little activity involves the marine environment. Some examples include the Auckland Intl. Airport, where they developed a cleaning system of the stormwater before it reaches the ocean.

Protect, restore and promote sustainable use of terrestrial ecosystems, sustainably manage forests, combat desertification, and halt and reverse land degradation and halt biodiversity loss: The welfare of animal life can also be affected by the land use of the surroundings of its ecosystems, such as the infrastructure involving an airport. In Spain, the airport's regulator AENA compensates the environmental damage creating replicas of the ecosystem in the nearby areas so that the wildlife can continue its course unaltered.

Promote peaceful and inclusive societies for sustainable development, provide access to justice for all and build effective, accountable and inclusive institutions at all levels: The creation of the agency ICAO (International Civil Aviation Organization) strives to ensure a minimum of standards in the industry to provide a safe, thorough, and inclusive service to everyone in the industry. This institution fosters communication and exchange of opinions and creates a safe environment to speak up, as it is stated in the Chicago Convention [59].

Strengthen the means of implementation and revitalize the global partnership for sustainable development: Foster collaboration in achieving the mentioned goals is fundamental for a holistic completion The existing network of airlines, traffic management organizations, airports and aircrafts are capable to provide the communication and connectivity needed to achieve the desired level of partnership to ensure the completion of the 17 goals. Even inside the industry, several alliances have been created to align interests and become better at achieving the milestones for the 2030 agenda. The Single European Sky is an example of a symbiosis between the EU and the aviation industry to increase the efficiency of the European airspace.

2.3.2 The SDGs and the aviation industry: Case studies

As we intend to mould the airport infrastructure of Catalonia to become the most resilient one, it is first necessary, then, to reflect on the goals that can be best taken in mind when configurating the skies and infrastructure. To do so, the intention of this section is to shed a light on how other paramount airports around Europe have coped with the 17 SDGs and finally compare to select which would be the most suitable ones to cover in this scope of the work.

Schiphol airport

Being the third busiest airport in 2019 - with 71,7 million passengers -, and the 4th in 2020 [60], Schiphol is one of the major hubs of Europe, and therefore, holds a great responsibility when fighting the climate change.

The sustainability strategy of the Schiphol Group, the regulator of the main airport of The Netherlands, is focused in four main areas [61]:

- Sustainable aviation: The future of aviation must be covered also by the infrastructure implied in a journey, that is, airports and facilities, aeronautical aids and of course, the aircraft. To achieve this sustainability, the Schiphol Group proposed a series of policies to encourage zero net carbon footprint aviation sector. Moreover, the regulator is working towards a sustainable passenger journey and to empower the smart and clean mobility in the surroundings of the airport. With these actions, the airport intends to align with several SDGs – Industry, Innovation and infrastructure (9); Climate action (13) and Partnership for the goals (17).

- Circular economy: The second pilar of the sustainability plan for Schiphol airport is to stress the importance of the circular economy. With the implementations of different actions, such as the reuse and upcycle program, the circular design principles, and the closed loops, the airport aims to achieve 0 waste in its facilities, serving different SDGs (12: Responsible consumption and production and 17: Partnership for the goals)

- Community: The third focus area of the plan is to understand the effects of the infrastructure on the neighbouring areas. On the one hand, the airport has undertaken a healthy and inclusive workplace transformation, to become more inclusive and encourage equality. On the other hand, the group has taken over the air noise and quality enhancement, to provide a better quality of life for the neighbours. With these actions, a decent work and economic growth (8), a sustainable city and community (11), and the partnership for the goals (17) are put in place.

- Energy positive: The last core item of the projected path is to conceive an airport with 0 emissions, fostering carbon neutral mobility, the usage of renewable energy and building sustainably. With this, the following SDGs are being tackled: Industry, innovation and infrastructure (9), Climate Action (13) and Partnership for the goals (17).

Figure 22: The shape of the fields next to the Schiphol airport help reduce the noise in the surrounding areas considerably (Source: Schiphol airport)

Heathrow airport

Historically being the busiest airport of Europe, since the 2020 rise of the new Istanbul Airport, Heathrow has always had environmental problems on its own. Acoustic and environment pollution are already over the permitted levels, and an expansion project does not seem to content all parts, with a huge opposition rising for an alternative solution – expanding the Gatwick airport, for a more even distribution of wealth and lesser environmental and acoustic impact. The problematic in London can sound familiar with the Barcelona-El Prat airport circumstances. Nevertheless, the airport endured a broad study on how to best implement the SDGs [62] and came up with the following standards:

The plan is divided into for areas for action and comprises the following items:

- A great place to work: This chapter involves all procedures to enhance the working community in Heathrow. With different programs – Careers, not just jobs; Culture of sustainability; Safe and well – the airport strives to become a competent, equalitarian, and safe environment to work in. Several SDGs are worked in that area including no. 3, 4, 5, 8, 9, 10, 11, 12 and 16 [62].

- A great place to live: This chapter focuses on the pacification of the surroundings of the airport. With proactive communication with neighbouring areas, the facilities better understand and worry for the respite for residents, the quality of air, locally and to build a sustainable community. With these actions the alignment with SDGs number 3, 8, 11 and 13 is fulfilled [62].

- A thriving sustainable economy: The main function of the airport is to boost the economy and enhance communication between regions. With Heathrow's role in connecting UK, applying a sustainable supply chain, and working on the next economy (circular economy), the regulator ensures a safe, non-perishable procedures that increase economic activity and generate pipeline and revenue (SDGs number 8, 9, 10,12, 13) [62].

- A world worth travelling: This broader pillar of the document points towards the sustainable flight and the zero-carbon airport, reassuring the role of the tomorrow's airports and enabling the way for Heathrow's case. As it touches so many different things, some of them not depending directly on the airport's authority, the number of SDGs that are aligned is bigger than usual, from the 5th to the 17th.

Charles de Gaulle airport

The second airport in Europe also has a sustainability guideline to pursue in the coming years. Nevertheless, this guideline only marks broader points and does not specify actions to take to shift the business way of doing.

The action plan is based in five core items that are described as follows (in brackets, the number of the SDG they are complying):

- People at the core of strategy: giving relevance to the workers and customers to create a safe environment. (3, 5, 8, 10, 11)

- Satisfy customers: Provide customers a safe and pleasant experience in the facilities that enables them to reach their destination. (3, 5, 8, 9, 10)

- Reduce impact: introduce waste management and implement circular economy initiatives. (7, 9, 12, 13)

- Adopt ethical and responsible policies: Fostering the appearance of SAFs with policies that go accordingly and ensure equity inside the airport. (3, 5, 7, 9, 10, 12, 13)

- Foster social commitments on local scale: Proactive role in the wellbeing of neighbour communities. (3, 11)

AENA

When looking at the busiest airports in Europe in 2019, it is seen that the two most important Spanish airport appear one just above the other: Adolfo Suárez Madrid-Barajas and Josep Tarradellas Barcelona-El Prat. As they both have the same regulator (AENA), they apply the same policies. The sustainability agenda, then, it is shared between airports.

The guidelines for all infrastructure under this regulator are the same and are focused on giving answer to the Sustainable Development Agenda of the UN. The network of the regulator carried more than 293,4 million passengers through the 46 Spanish airports (and 2 heliports) and a further 23 more in other countries in 2019 [63], becoming the largest regulator and operator of aviation infrastructure in the world. The two most important facilities are the airports located in Madrid and Barcelona, carrying 61,7 million and 52,7 million in 2019, respectively.

The resolutions taken by AENA are classified in five great items and are described next:

- Protection of the environment, efficient usage of resources and fight climate change. With a 2021-2030 Climate Action Plan [64], the operator intends to tackle the greenhouse gases (to achieve airport carbon neutrality by 2026 and the total net zero carbon by 2040), promote sustainable aviation – including promoting emissions reductions associated with airlines and handling agents, strengthening monitoring capabilities for a better controlling of the plan, and the compliance with the Task Force on Climate-related Financial Disclosures (TCFD) and the Sustainability Accounting Standards Board (SABS) – and improve the sustainability of the environment by collaborating with suppliers, tenants, transport agents and the community.
- Economic sustainable growth. With a range of actions including several academies and proper work conditions, AENA wants to ensure the wellbeing of its workers, to provide career opportunities within the enterprise and retain the talent.

- Diversity and social inclusion. AENA has been the best perceived enterprise in the aerospace sector in Spain to work in with relation to its inclusivity and diversity values [65]. This fosters communication and sharing and improves the customer experience as it is thought in a more holistic manner.

- Guarantee the different types of sustainable consumption. In line of the first item, the impact of the circular economy practises would have an enormous significance on the recycling and reducing single-use products.

- Strengthen alliances for a faster achievement of the SDGs, including sharing best practises and create partnerships to better understand and eliminate the obstacles ahead.

2.3.3 Future infrastructure guidelines complying with the SDGs to consider

Once seen the different recommendations made by the United Nations, how do those apply to the civil and commercial aviation sector and how do some actual enterprises develop them, it is the purpose of this section to create a guideline of our own, and to make sure that the final configuration of the Catalonia's airport infrastructure complies with it.

Even though not all SDGs are within the domain of the civil aviation industry, it has been made clear that it plays a key role in most of them. Therefore, the ultimate airport system should not only consider strictly the aviation industry but also the impact that generates around, economic, social and environmental and acoustic pollution factors. To do so, a summary of main areas of interest when redesigning an airport are as follows:

- Environment. Structured in three main areas, work environment, customer engagement and carbon neutrality. The work environment should focus on equity, giving opportunities of growth to workers and ensure their safety and wellbeing. Customer engagement should maximize the experience of everyone cruising through the facilities and finally the community pilar must. Finally, carbon neutrality should strive to a zero net carbon emission airport to ensure a safe and sustainable infrastructure.

- Technology. The operator of an airport should strive for the encouragement of carbon reducing strategies, including the operation with SAFs. This topic could include tax reduction for environmentally friendly airlines, give facilities to develop new technologies, etc.

- Context. The airport does not end within its physical limits, and it is paramount to understand that. It plays a key role in a whole region and neighbouring community, and it should keep this in mind when expanding/building, etc. Potentiate e-mobility and public transport in and out the facilities, foster safe forums in neighbouring areas to minimize environmental and acoustic pollution with direct and indirect measures, etc. could transform the airport into a cluster of sustainable growth, attracting more interest and thus generating more revenue in the region.

3 TRAFFIC PROGNOSIS

To design the best airport system in Catalonia is necessary to understand the demand generated and the complex process in which the study achieves it. To do so, two main areas of work have been designed. On the one hand, the prognosis of Catalonia's aviation industry has become a detailed procedure in which several methods have been implied in obtaining a feasible, accurate prognosis of how much air traffic is to be expected in the following years to come, considering the pandemic effects on the overall aviation industry. On the other hand, the building of the different scenarios of airport distribution throughout the Catalonian terrain, to then compare the different outcomes based on environmental, economic and social metrics that will finally enable us to decide the best option for Catalonia's airport system.

3.1 Prognosis methodology

To ensure the most accurate prognosis of passengers and operations for the years to come, the methodology used in the prognosis consisted of several models of forecasts that have been treated separately to then compare them and converge all information into one final model. The three different models used are: the CAGR model, the International Organizations Prognosis, and the Macroeconomic model.

3.1.1 CAGR Methodology

The first method used to forecast passengers and operations in the three main airports of Catalonia is achieved using the Compound Annual Growth Rate (CAGR). This variable returns the average annual growth of an infrastructure (in our case, passengers and operations in an airport), and so it gives the ability to forecast the future use of the infrastructure. It is calculated as:

$$CAGR_{OPS} = \left(\frac{OPS\ (year2)}{OPS\ (year1)}\right)^{\left(\frac{1}{year2-year1}\right)} - 1 \qquad (1)$$

$$CAGR_{PAX} = \left(\frac{PAX\ (year2)}{PAX\ (year1)}\right)^{\left(\frac{1}{year2-year1}\right)} - 1 \qquad (2)$$

To tackle the enormous consequences of the pandemic, several scenarios have been made. Ranging from a no covid scenario to a long-term recovery one, the different results have given us the opportunity to have multiple data to best model the actual flow of passengers and operations. A different series of CAGR calculations have been carried out to ensure the reliability of the data:

- The initial CAGR comprises only the years 2014 to 2019. Even though the project collects data from 2011, the real behaviour of the Catalan airports responds better to that timeline, mainly because the previous years the facilities are still facing the 2008 economic crisis, as well as other factors such as the failure of Spanair and the absorption of a vast majority of low-cost carrier's operations by the Barcelona-El Prat airport that were previously held in GRO or REU. This first CAGR also wanted to understand the progression of the facilities before the pandemic, that is why it comes to a halt in 2019.

- Covid CAGR: The second series of data comprises the recovery rate for the Catalan airports during the years 2020 and 2021. Since at the time of delivery of the project statistics from December were still not public, the CAGR comprises the 2020 months until November vs. the 2021 months until November. In 2021 the vaccination has pushed the recovery of the economy further away, with the aviation industry not being oblivious to it. Airports have started to fill and this recovery rate must be studied to better understand future behaviours of the infrastructures.

With this data progressions (Table 5), the first approximation to the final model used using CAGR can be made. An initial hypothesis is made regarding the fact that after the 2019 recovery year (estimated to be 2024 for Europe [66]) all prognoses would then continue to spike with the recovery rate for at least one year more (2025). This hypothesis, nevertheless, lacks credibility, as, for instance, the recovery CAGR for the REU airport stands at a stunning 306,10%. The exponential growth that would mean to stay on the recovery rate for the year 2025 would totally blur the chances of a realistic prognosis.

This recovery rates that the CAGR 2020-2021 presents are only the beginning of the recovery path for the aviation industry. Different estimates [66]–[68] agree to state that further recovery will be achieved in the years 2022 and 2023. For that matter, the final assumption in the CAGR method will use a 2024 year of recovery linear trend, and then use the 2014-2019 CAGR onwards.

		BCN	**GRO**	**REU**
Operations	**CAGR 2014-2019**	3,95%	-2,42%	2,03%
	CAGR 2020- 2021	24,89%	35,50%	16,83%
Passengers	**CAGR 2014-2019**	7,00%	-2,20%	4,23%
	CAGR 2020- 2021	36,22%	74,53%	306,10%

Table 5: CAGR for the Catalan airports, segregated by Covid/No Covid (Source: Own elaboration)

With this calculated CAGR and the assumptions made, the results for the prognosis for the BCN, GRO and REU airports in operations and passengers are shown next:

JT Barcelona-El Prat (BCN) airport

YEAR	OPS	PAX
2019	344563	52688455
2020	122638	12738769
2021	178119	22726191
2022	233601	32713612
2023	289082	42701034
2024	344563	52688455

YEAR	OPS	PAX
2025	358182	56378796
2026	372340	60327611
2027	387058	64553005
2028	402357	69074348
2029	418260	73912370
2030	434793	79089250

YEAR	OPS	PAX
2031	451979	84628724
2032	469844	90556186
2033	488415	96898813
2034	507721	103685682
2035	527789	110947909

Table 6: CAGR prognosis for the BCN airport (2024 year of recovery) (Source: Own elaboration)

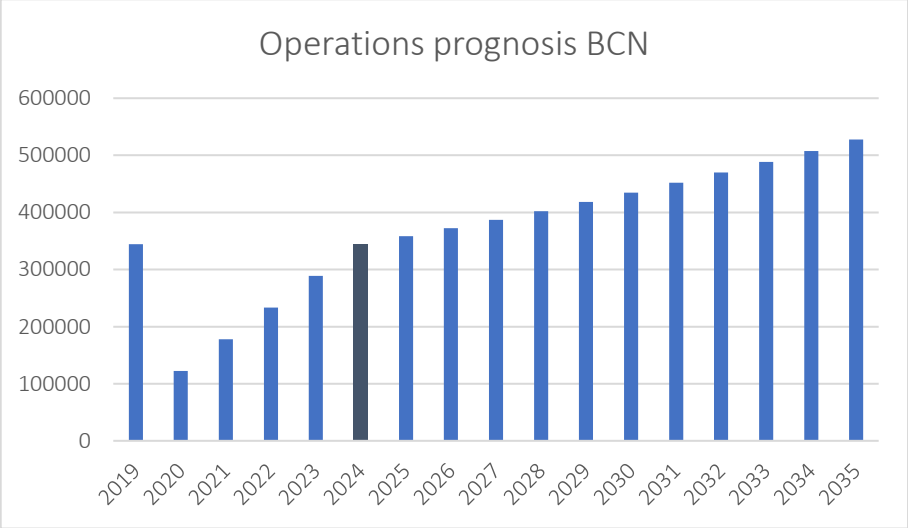


Figure 23: Operations prognosis BCN airport (2024 year of recovery) (Source: Own elaboration)

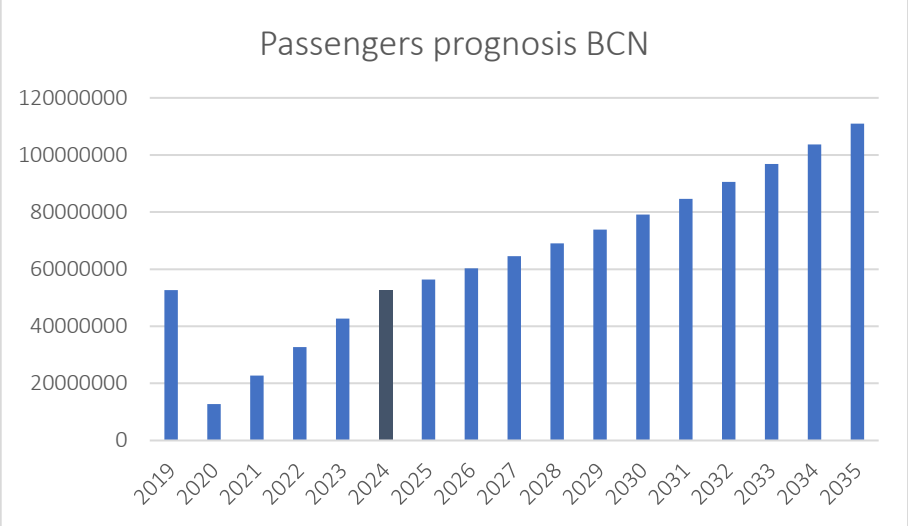


Figure 24: Passenger's prognosis BCN airport (2024 year of recovery) (Source: Own elaboration)

Girona-Costa Brava (GRO) airport

YEAR	OPS	PAX
2019	18253	1933049
2020	9959	172171
2021	12033	612391
2022	14106	1052610
2023	16180	1492830
2024	18253	1933049

YEAR	OPS	PAX
2025	17812	1890474
2026	17381	1848837
2027	16960	1808117
2028	16550	1768293
2029	16150	1729347
2030	15759	1691259

YEAR	OPS	PAX
2031	15378	1654009
2032	15006	1617580
2033	14643	1581953
2034	14289	1547111
2035	13943	1513037

Table 7: CAGR prognosis for the GRO airport (2024 year of recovery) (Source: Own elaboration)

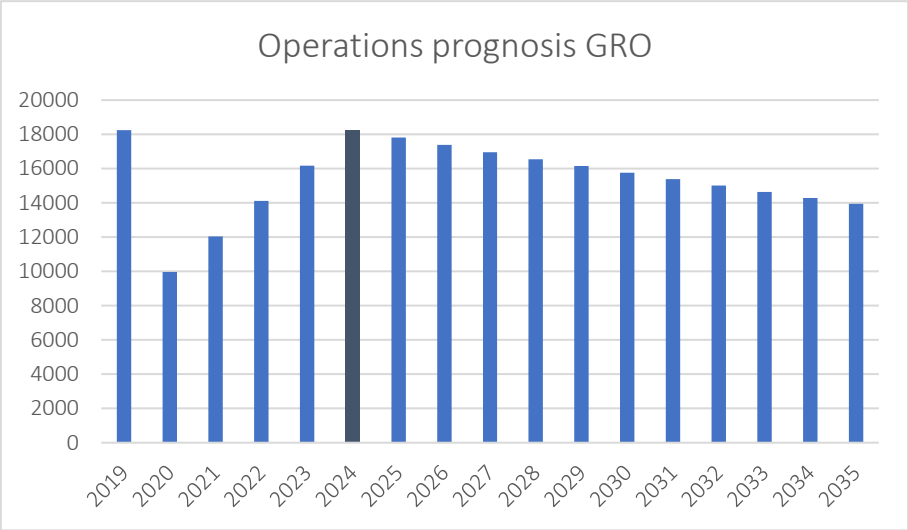


Figure 25: Operations prognosis GRO airport (2024 year of recovery) (Source: Own elaboration)

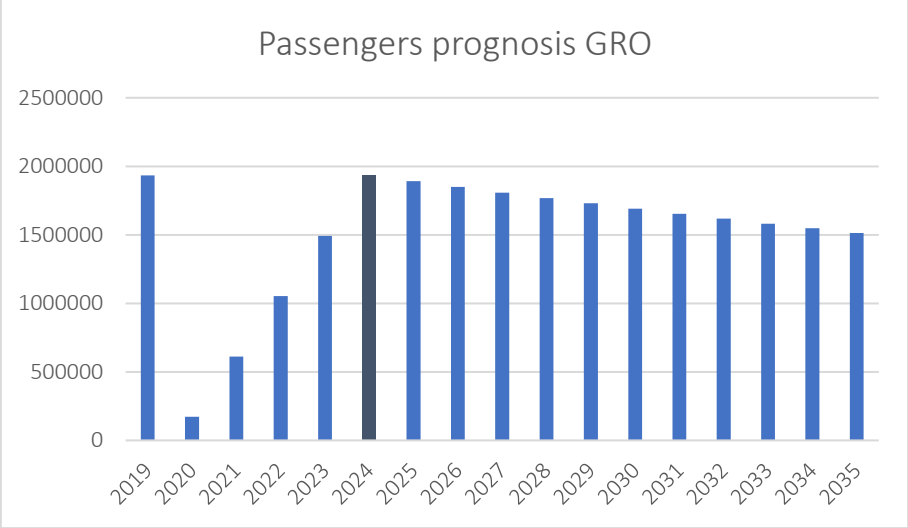


Figure 26: Passenger's prognosis GRO airport (2024 year of recovery) (Source: Own elaboration)

Reus (REU) airport

YEAR	OPS	PAX
2019	17679	1046249
2020	12503	39460
2021	13797	291157
2022	15091	542855
2023	16385	794552
2024	17679	1046249

YEAR	OPS	PAX
2025	18039	1090506
2026	18405	1136635
2027	18780	1184715
2028	19162	1234829
2029	19551	1287063
2030	19949	1341507

YEAR	OPS	PAX
2031	20355	1398253
2032	20769	1457400
2033	21191	1519049
2034	21622	1583305
2035	22062	1650280

Table 8: CAGR prognosis for the REU airport (2024 year of recovery) (Source: Own elaboration)

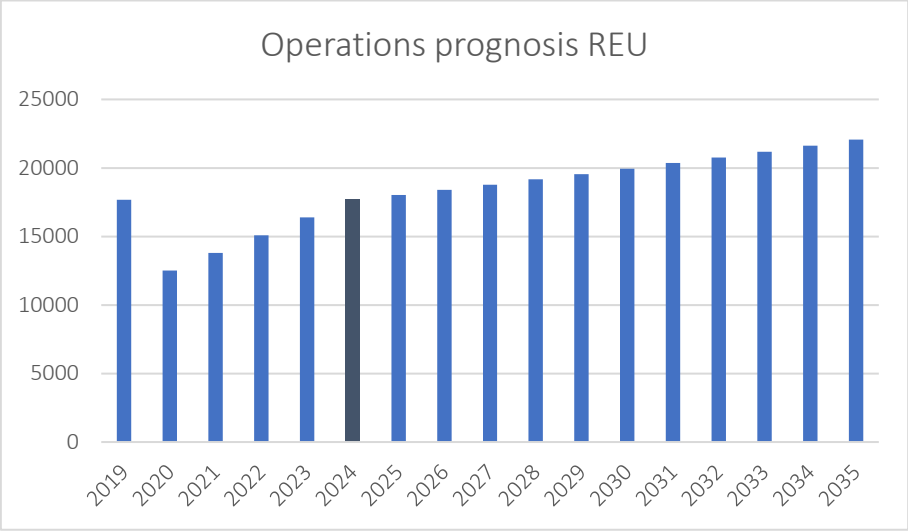


Figure 27: Operations prognosis REU airport (2024 year of recovery) (Source: Own elaboration)

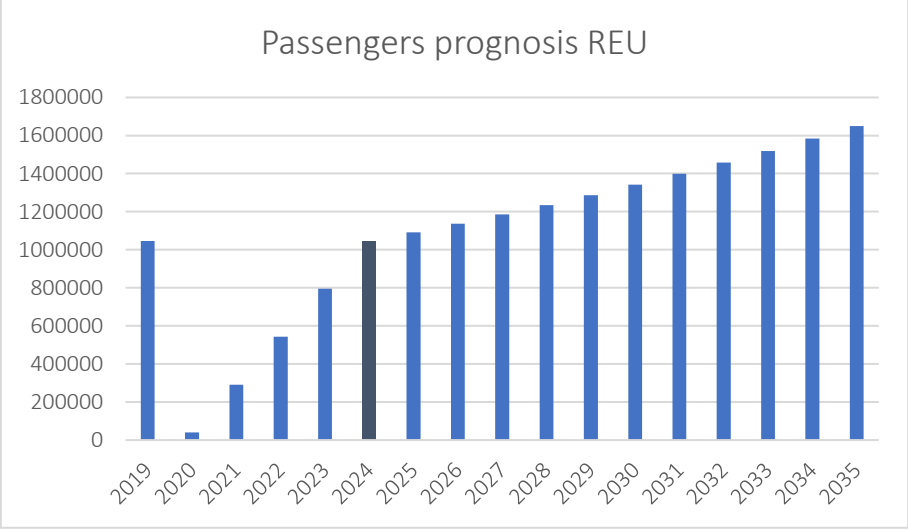


Figure 28: Passenger's prognosis REU airport (2024 year of recovery) (Source: Own elaboration)

As seen in the previous figures from BCN, GRO and REU airport, the linear trend of recovery marks the 2024 as the year of achievement of 2019 records. This linear trend is just a first approximation of the final recovery path that the mentioned infrastructures will endure in the following years, but the little access to data limits the scope and depth of work. Nevertheless, this method gives us a broad vision on where the aviation market of Catalonia is headed.

The trend on the BCN airport goes as high as surpassing the 525.000 operations and 110 million passengers in 2035. On the GRO airport, nevertheless, in the 2014-2019 period a descent of activity is seen due to the relocation of several operations into the more attractive BCN airport. This causes the CAGR to become a negative figure and thus it gives this misleading result of a diminishment of activity until 2035. Although it is true that the airport is ongoing this trend, the different impulses that are to be given to the airport (including acting as a secondary airport for BCN) will relaunch the infrastructure. The low-cost characteristics of such facilities will see again a growth with the increase of tourism. Finally, the REU airport is expected to surpass the 20.000 operations in 2031 and to reach the 1,6 million passengers in 2035. The particularity of REU airport, which still counts with a lot of general aviation activity – even an air training school-, reflects an unusually high number of operations per passenger, as most of the aircrafts operating in the infrastructure tend to do more than one take-off or landing during their flights.

3.1.2 International Organizations prognosis

The main international aviation organizations have done their own studies regarding the recovery of the aviation markets [49], [66], [69]. Even though the results and reports may not be specifically relevant in the local studies, such as the one endured with the Catalonia's main airports, they do give background and understanding on the overall performance of the aviation markets. It is important then, to acknowledge them and to incorporate them into our own previsions. The access to data in which their work is performed will complement the broader vision wanted for this project.

IATA

Being the International Air Transport Association (IATA) the world's leader trade association for airlines, and representing a total of 83% of the worldwide air traffic [70], the relevance of their studies is paramount to the aviation community.

Their latest publication on the matter, a 2019-2040 aviation forecast for the world's air traffic global markets [66], released in November 2021, commented the following:

> "Our scenario analysis indicates that global air passenger growth could plausibly be in the range of 1.5% and 3.8% over the next 20 years"

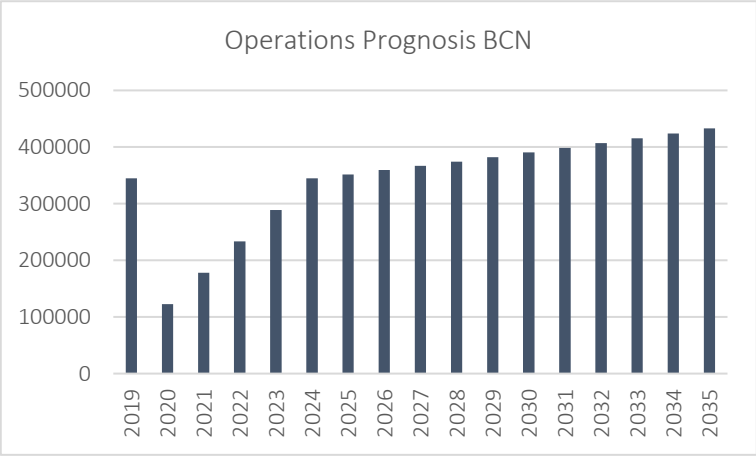
The forecast for the European aviation market from IATA states to reach the levels of activity from 2019 in 2024, and increase with a regional CAGR of 2,1%. The world CAGR is a little bit higher, at 3,3%, due to the impulse of other regions of the world, such as Asia-Pacific, with an estimated growth of 4,5% [66].

The forecast applied to the BCN, GRO and REU infrastructure are presented as follows:

- *BCN airport*

YEAR	2019	2020	2021	2023	2026	2029	2032	2035
OPS	344563	122638	178119	289082	359187	382294	406888	433064
PAX	52688455	12738769	22726191	42701034	54924606	58458030	62218767	66221441

Table 9: IATA prognosis study applied to BCN airport (Source: IATA, Own elaboration)



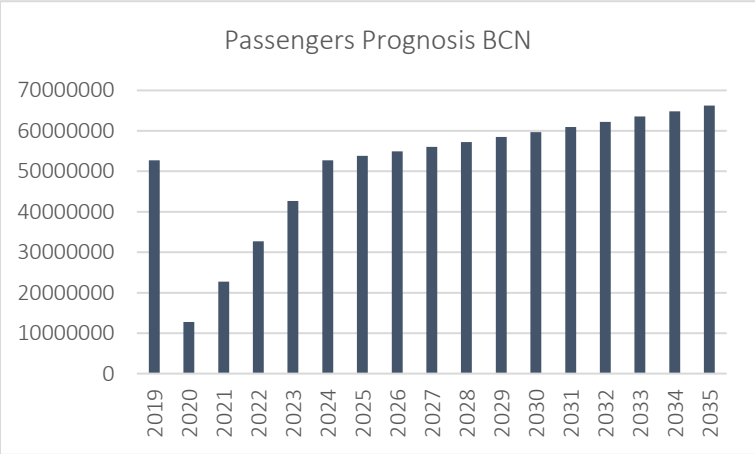
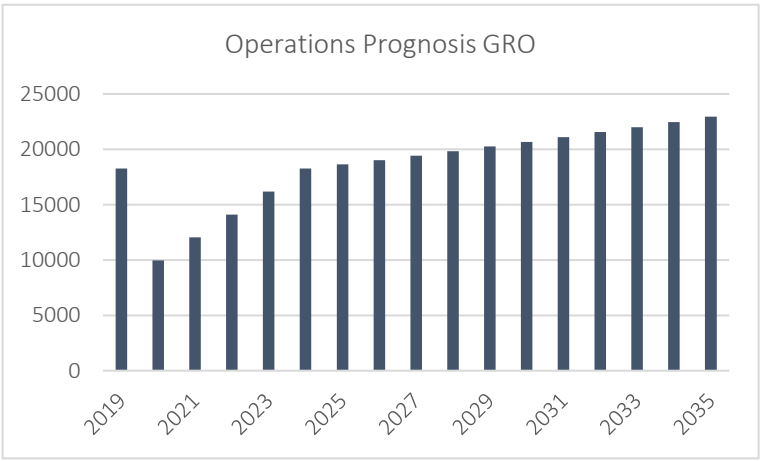


Figure 29 & Figure 30: Graphic of BCN prognosis data extracted from IATA (Source: Own elaboration)

- *GRO airport*

YEAR	2019	2020	2021	2023	2026	2029	2032	2035
OPS	18253	9959	12033	16180	19028	20252	21555	22941
PAX	1933049	172171	612390,5	1492830	2015090	2144725	2282700	2429551

Table 10: IATA prognosis study applied to GRO airport (Source: IATA, Own elaboration)



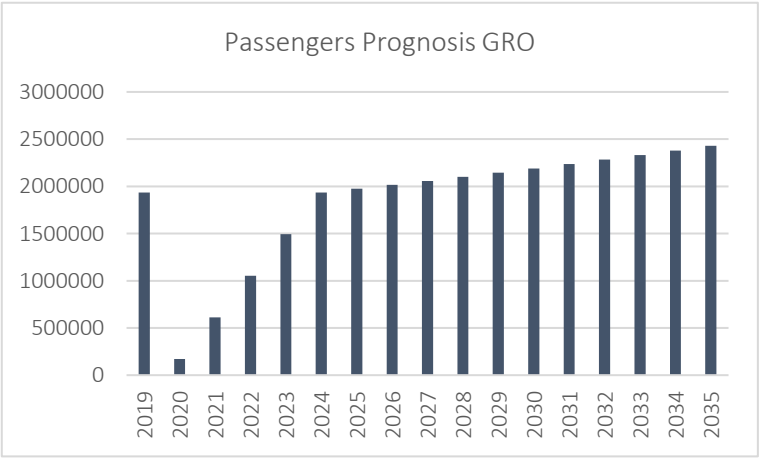
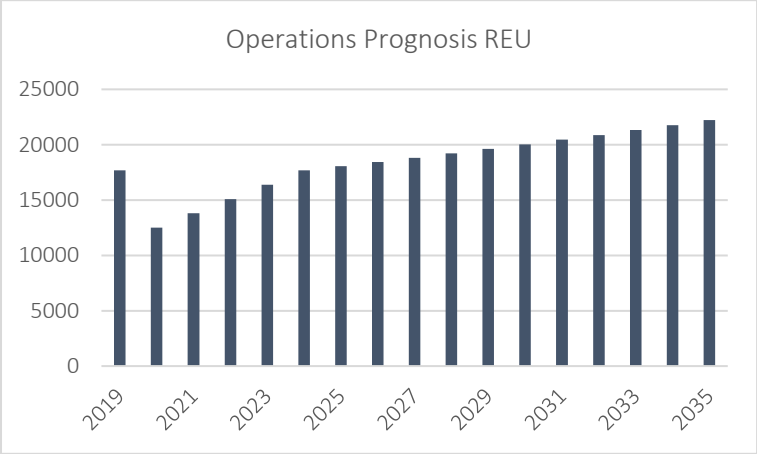


Figure 31 & Figure 32: Graphic of GRO prognosis data extracted from IATA (Source: Own elaboration)

- *REU airport*

YEAR	2019	2020	2021	2023	2026	2029	2032	2035
OPS	17679	12503	13797	16385	18429	19615	20877	22220
PAX	1046249	39460	291157,3	794551,8	1090653	1160817	1235495	1314977

Table 11: IATA prognosis study applied to REU airport (Source: Own elaboration)



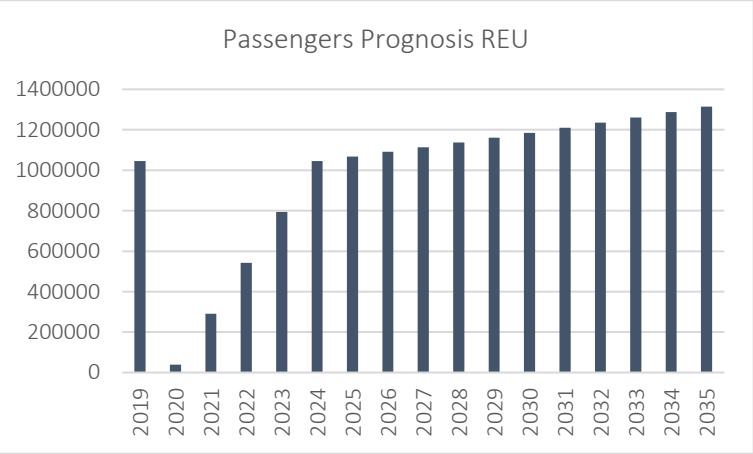


Figure 33 & Figure 34: Graphic of REU prognosis data extracted from IATA (Source: Own elaboration)

EUROCONTROL

The other existing aviation regulator that specifically focuses on the European sky is Eurocontrol. The Support of the European Aviation includes the promulgation of the Single European Sky, and the support in making aviation in Europe safer, more effective and cost-effective and with a minimal environmental impact [71].

Eurocontrol also made a forecast for the years 2020-2027, stressing the recovery rates of air traffic in three different scenarios, depending on the evolution of the pandemic. This regional approach enables for more accurate predictions, given that Eurocontrol is also in possession of all data regarding European flights. The curves are shown as follows:

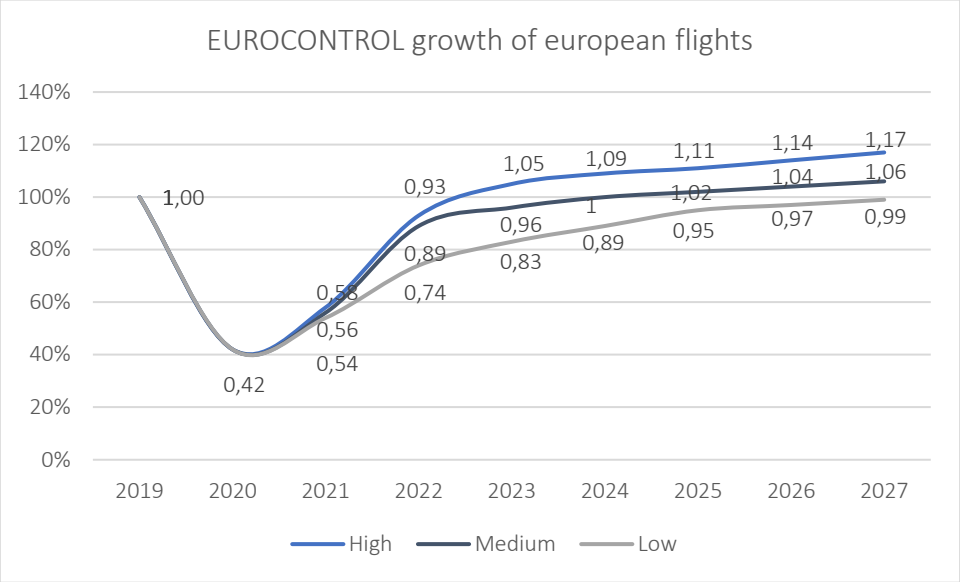


Figure 35: Recovery scenarios for European Airports (Source: Eurocontrol)

The recovery year in this case varies from scenario to scenario: the High one recovers in 2023, the medium eventuality is expected to reach 2019 levels in 2024 and the low forecast is not expected to recover until 2027.

When comparing these predictions with the results obtained in 2020 and 2021, it is seen that the actual drop in Catalan airports was rather bigger than expected by EC, and that the recovery path in 2021 is still behind as the one planed on the three scenarios. Nevertheless, the Catalonian resilient infrastructure is expected to endure a huge recovery process in the years 2022 and 2023.

Rather than the exact quantity of passengers and operation per year that this model gives (See Annex B), it is more important to focus on the qualitative aspect of it. The forms of the different scenarios-data give us an important idea of how the industry is believed to recover, and will prove useful for correcting and comparing with other methodologies.

3.1.3 Macroeconomics methodology

Economics, and mainly the macroeconomic factors, are constantly shaping the aviation industry markets [72]–[77]. Therefore, the idea to create a macroeconomic model that could forecast passengers and operations in the three airports, given a certain macroeconomic data, lies within the scope of the project. To do so, choosing the right and useful variables for the data moulding is paramount. It ought to be considered that all chosen macroeconomic data should have a prediction for the following years, as the intended model will work with current data for current year. The following table aims to explain which of them were chosen and why:

Constant-price GDP	GPD is believed to be the main -even not only- macroeconomic variable by default [78]. Accounting for the economic activity developed in a specific region in a certain time (usually a year), it gives the ability to understand a broad view of the economics of a region. It is calculated at constant prices to avoid the effects of the inflation processes through the years (See Inflation), and thus making it easier to compare with other GDP in the studied timeline.

	For reliability reasons, the variable appears in a logarithmic scale $ln(GDP)$. The data has been extracted from Idescat [1], [79]–[81].
Inflation rate (%)	The inflation rate is the percentage increase in prices over a twelve-month period [82, p. 114]. The inflation, boldly, changes the value of money (devaluing it), and it is important to acknowledge it to understand its effects on the purchasing power. Data extracted from CEE, Banco de España, INE, IMF [67], [78], [79], [83]–[85].
Public Debt (%)	Accounting for the national debt of a country or territory for which the state is ultimately responsible [82]. In this case, the major correlation was achieved when studying the Spanish public debt, rather than the Catalan. This can be explained because a large part of Catalonia's debt is assumed by the Central Government, and thus aligning more with the actual state of the economy. It is presented as the part of the total GDP of the region. Data from Banco de España, IMF [78], [80], [85].
Unemployment rate (%)	The percentage of people that are currently out of jobs out of the overall people eligible for one, in a certain territory. It complements the other factors in assessing a background for the economic activity of a region, with several long-term estimates that make this a reliable variable. As there were little prognosis of Catalan data, the Spanish rate has been chosen. Data from CEE, IMF [79], [84], [85].

Table 12: Variables used in the macroeconomic study (Source: Own elaboration)

All four macroeconomic variables present high reliability and long-term forecasts, for it is fundamental to build a sustainable macroeconomic model.

Once the variables are understood, the model can now assemble. It consists of an Ordinary Least Squares regression model such as the next one:

$$y_{i,j} = \varepsilon_i + \sum_{k=1}^{k=n} \alpha_{i,k} \cdot A_{k,j} \quad (3)$$

Where:

$$y = number\ of\ OPS\ or\ PAX \mid \ln of\ number\ of\ OPS\ or\ PAX\ ^{2}$$

$$i = airport\ \{1 = BCN, 2 = GRO, 3 = REU\}$$

$$j = number\ of\ year\ of\ study$$

$$k = number\ of\ macroeconomic\ variables$$

$$\alpha = macroeconomic\ coefficient\ (matrix) for\ each\ airport(i) and\ variable(k)$$

$$A = macroeconomic\ variable\ value\ (matrix) for\ each\ variable\ (k) and\ year\ (j)$$

$$\varepsilon = Independent\ coefficient\ for\ each\ airport\ (i)$$

[2] Each airport presents different best correlations as they behave differently, and so each case has been studied thoroughly for itself. That is the reason why in some airports the "y" represents the number of OPS (BCN) or PAX (BCN, GRO) itself, and in some other airports shows them on a Napierian logarithm scale (GRO's and REU's operations; REU's passengers).

Therefore, applying all the changes to the number of variables chosen for the project (through Granger causality test [86]) in Table 12 ($k = 4$) the linear model becomes:

$$y_{\{OPS\}_{i,j}} = \varepsilon_i + \alpha_{i,1} \cdot A_{1,j} + \alpha_{i,2} \cdot A_{2,j} + \alpha_{i,3} \cdot A_{3,j} + \alpha_{i,4} \cdot A_{4,j} \quad (4)$$

$$y_{\{PAX\}_{i,j}} = \delta_i + \beta_{i,1} \cdot A_{1,j} + \beta_{i,2} \cdot A_{2,j} + \beta_{i,3} \cdot A_{3,j} + \beta_{i,4} \cdot A_{4,j} \quad (5)$$

Through a numerical linear correlation process from historic data for the three airports and the 2011-2020 records ($i = \{1,2,3\}; j = \{1, \dots, 10\}$), the model is assembled by establishing the matrices and coefficients $\varepsilon, \alpha, A, \delta, \beta$ to find the better match between the function and the real passengers and operations of those years. The results are shown next:

$$\varepsilon = \begin{bmatrix} -22775273 \\ -38{,}267706 \\ -0{,}2419555 \end{bmatrix}$$

$$\alpha = \begin{bmatrix} 1853473{,}6 & 1716553{,}8 & -297486{,}88 & 2766414{,}52 \\ 3{,}8359044 & 9{,}2220638 & -1{,}0788389 & 9{,}82522385 \\ 0{,}8556712 & 3{,}8646145 & -0{,}8373629 & 0{,}85411174 \end{bmatrix}$$

$$A = \begin{bmatrix} 12{,}214 & 12{,}190 & 12{,}200 & 12{,}232 & 12{,}278 & 12{,}311 & 12{,}336 & 12{,}378 & 12{,}422 & 12{,}323 \\ 3{,}20 & 2{,}45 & 1{,}41 & -0{,}15 & -0{,}50 & 0{,}20 & 1{,}96 & 1{,}68 & 0{,}70 & -0{,}32 \\ 69{,}5 & 85{,}7 & 95{,}5 & 100{,}4 & 99{,}3 & 99{,}2 & 98{,}6 & 97{,}5 & 95{,}5 & 119{,}9 \\ 21{,}4 & 24{,}8 & 26{,}1 & 24{,}4 & 22{,}1 & 19{,}6 & 17{,}2 & 15{,}3 & 14{,}1 & 15{,}5 \end{bmatrix}$$

$$\delta = \begin{bmatrix} -4{,}748 \cdot 10^9 \\ -133702272 \\ -313{,}72214 \end{bmatrix}$$

$$\beta = \begin{bmatrix} 383142589 & 338956963 & -35334451 & 543261485 \\ 10831693 & 30792760 & -2862275{,}9 & 25186784{,}9 \\ 26{,}25012 & 28{,}473978 & -5{,}0057927 & 45{,}4642995 \end{bmatrix}$$

To understand the matrices α, A, β the following comments are made - ε (for operations) and δ (for passengers) are merely independent coefficients for each airport: first row is BCN, 2nd GRO and 3rd REU-.

The three rows of α & β matrices correspond again to the three studied airports (1-BCN, 2-GRO, 3-REU). The four columns, then, represent the coefficients that go with each variable, that is: the first column presents the coefficients for each airport in relation to the GDP, the second column holds the same relation to the inflation rate, the third column with respect to the public debt and the fourth and last one for the unemployment rate.

It is seen that in both operations and passengers in all airports there is an inverse proportionality with the public debt, but the weights for each variable change from airport to airport. In BCN the most relevant variable for operations and passengers is the unemployment rate, but in the GRO airport this position it is held by the inflation rate, whereas in the REU airport the leading one is the inflation rate for operations but the unemployment rate for passengers.

Finally, the A matrix contains the historic data for the 10 years of span of the study – First row is the Napierian logarithm of the GDP of Catalonia at constant prices, second row is the inflation rate, third row is the public debt of Spain and last row presents the unemployment rate.

With this data, the macroeconomic model is completed and ready to start the prognosis, with the final formulation (See Annex B for further procedure):

$$OPS(BCN) = 1853473{,}65 \cdot \ln(\text{GDP}) + 1716553{,}77 \cdot \text{Inflation\_rate} - 297486{,}879 \cdot \text{Public\_debt} + 543261485{,}2 \cdot \text{Unemployment\_rate} - 22775272{,}7$$

$$PAX(BCN) = 383142589 \cdot \ln(\text{GDP}) + 338956963 \cdot \text{Inflation\_rate} - 35334450{,}6 \cdot \text{Public\_debt} + \cdot \text{Unemployment\_rate} - 4747808908$$

$$\ln(OPS(GRO)) = 3{,}83590438 \cdot \ln(\text{GDP}) + 9{,}22206384 \cdot \text{Inflation\_rate} - 1{,}0788389 \cdot \text{Public\_debt} + 9{,}825223853 \cdot \text{Unemployment\_rate} - 38{,}2677061$$

$$PAX(GRO) = 10831693{,}2 \cdot \ln(\text{GDP}) + 30792760{,}5 \cdot \text{Inflation}_{\text{rate}} - 2862275{,}87 \cdot \text{Public}_{\text{debt}} + 25186784{,}87 \cdot \text{Unemployment\_rate} - 133702272$$

$$\ln(OPS(REU)) = 0{,}85567115 \cdot \ln(\text{GDP}) + 3{,}86461446 \cdot \text{Inflation\_rate} - 0{,}83736293 \cdot \text{Public\_debt} + 0{,}854111738 \cdot \text{Unemployment\_rate} - 0{,}24195552$$

$$\ln(PAX(REU)) = 26{,}2501201 \cdot \ln(\text{GDP}) + 28{,}473978 \cdot \text{Inflation\_rate} - 5{,}0057927 \cdot \text{Public\_debt} + 45{,}46429955 \cdot \text{Unemployment\_rate} - 313{,}722139$$

For reliability purposes, the next table states the correlation between the model operations and passengers and the real operations and passengers:

	R_OPS (correlation factor for operations)	R_PAX (correlation factor for passengers)
BCN	0,94860619	0,94673581
GRO	0,99805776	0,98910163
REU	0,81784355	0,95807475

Table 13: Correlation factors for operations and passengers macroeconomic forecast (Source: Own Elaboration)

With this high correlation factors, it is proven that the macroeconomic model is valid for prognosis purposes, and so the prognosis is shown next:

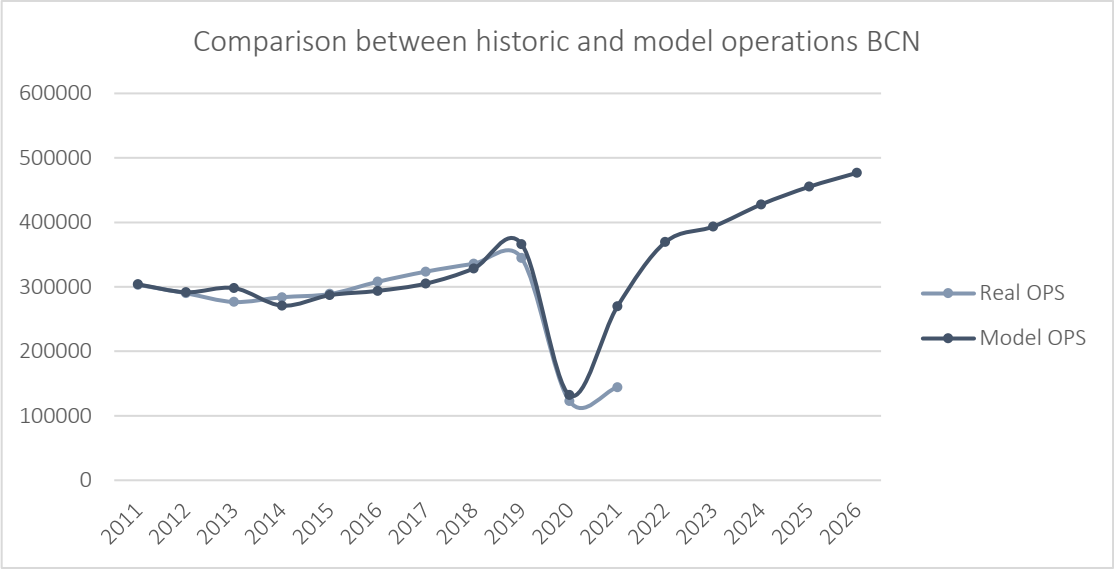


Figure 36: Comparison between historic and model operations BCN (Source: Own elaboration)

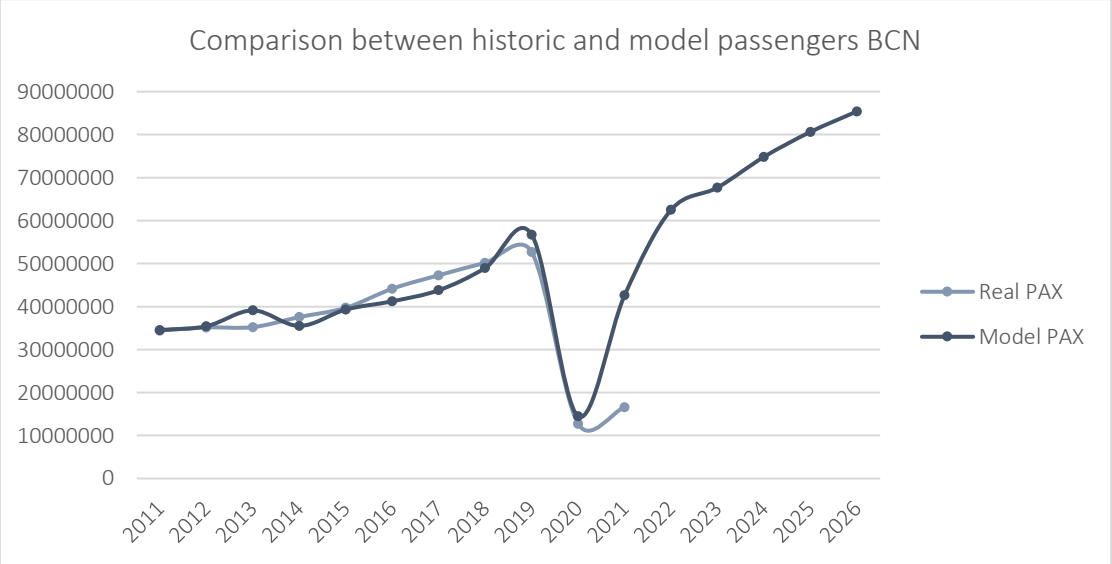


Figure 37: Comparison between historic and model passengers BCN (Source: Own elaboration)

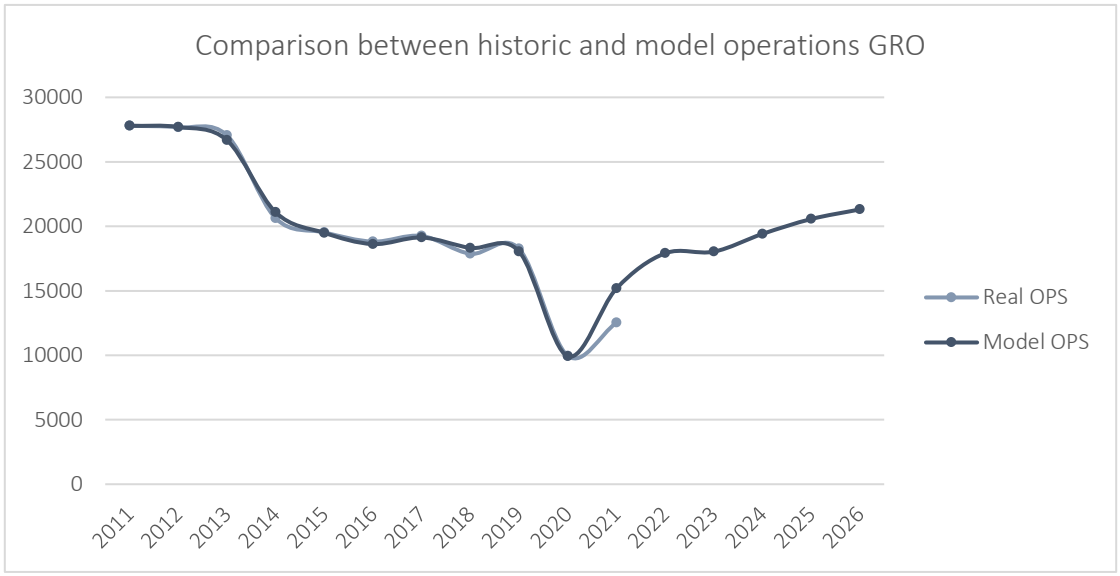


Figure 38: Comparison between historic and model operations GRO (Source: Own elaboration)

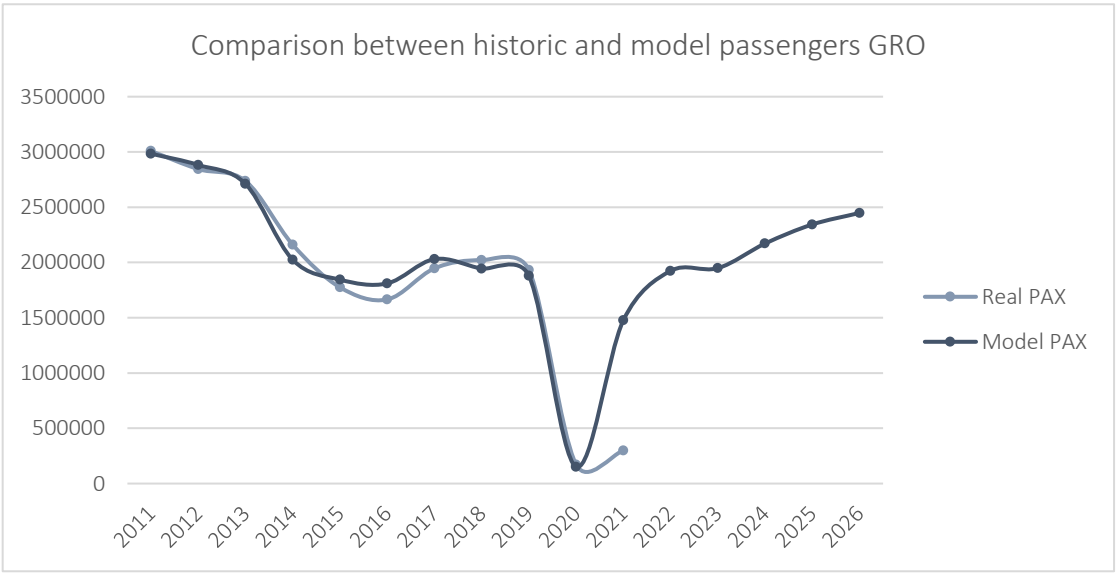


Figure 39: Comparison between historic and model passengers GRO (Source: Own elaboration)

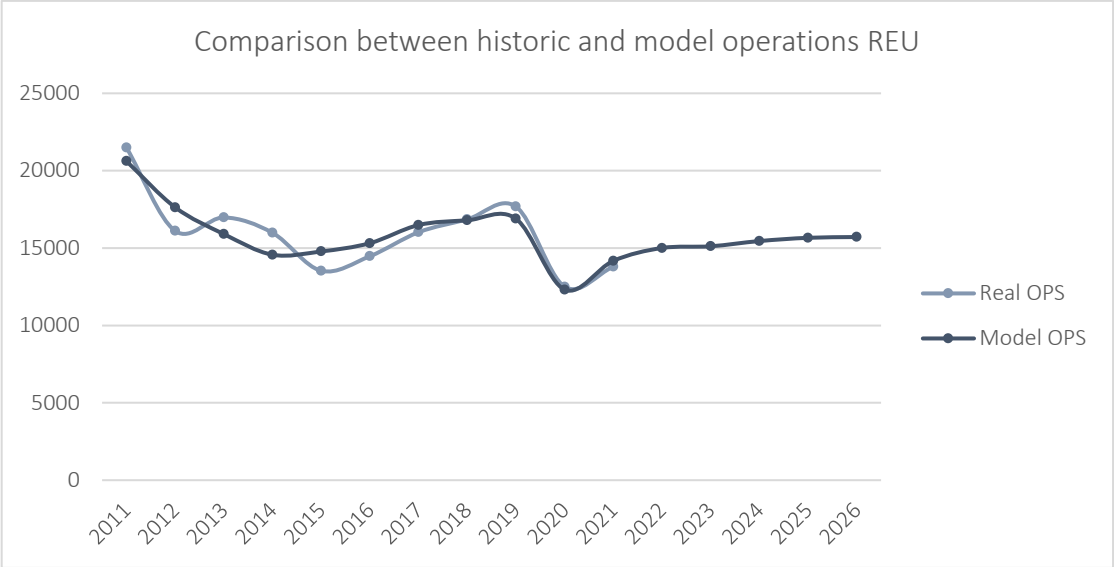


Figure 40: Comparison between historic and model operations REU (Source: Own elaboration)

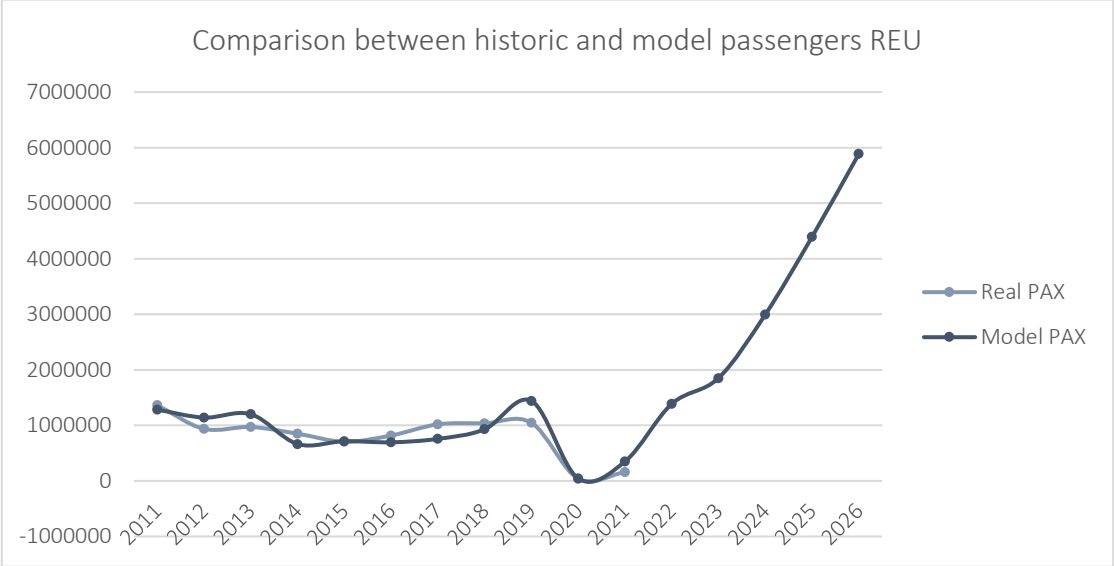


Figure 41: Comparison between historic and model passengers REU (Source: Own elaboration)

The results from the analysis present a coherent relation, with an obvious miss in the passenger's graph of REU airport -due to the high weight that the unemployment rate has-. All model results seem to be more optimistic than real life when recovering from the pandemic crisis, with faster recovery rates especially in BCN and GRO passengers. The model, then, is expected to be less reliable during the pandemic as the different indicators start to align again towards a truthful recovery.

In 2026, the model expects 476.864 ops and 85.408.025 pax in BCN, 21.308 ops and 2.447.996 pax in GRO and finally 15.713 ops and a misleading number of passengers of 5.885.968 pax.

3.2 Assembling the final prognosis

3.2.1 Prognosis comparison

The different approaches that the data sets have given us are meant to follow the same direction. With the availability achieved it is now necessary to converge the different models in one result. Not only it is interesting to compare trends and methodologies, but also to understand how the actual market is behaving to the recuperation rates forecasted, and which one is more realistic. For that sake the year 2021 will incorporate the real data.

The different prognoses compared for each airport are presented next.

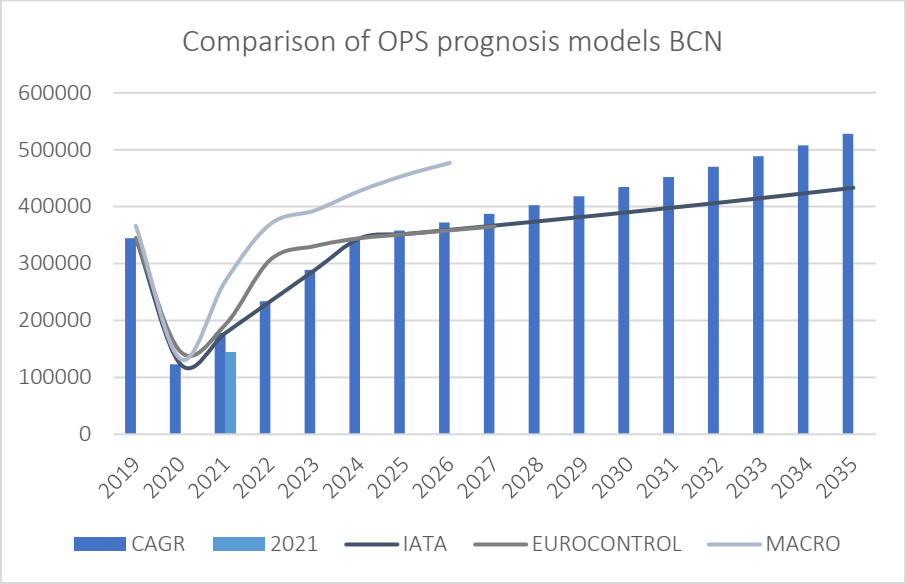


Figure 42: Comparison of operations prognosis models for BCN (Source: Own elaboration)

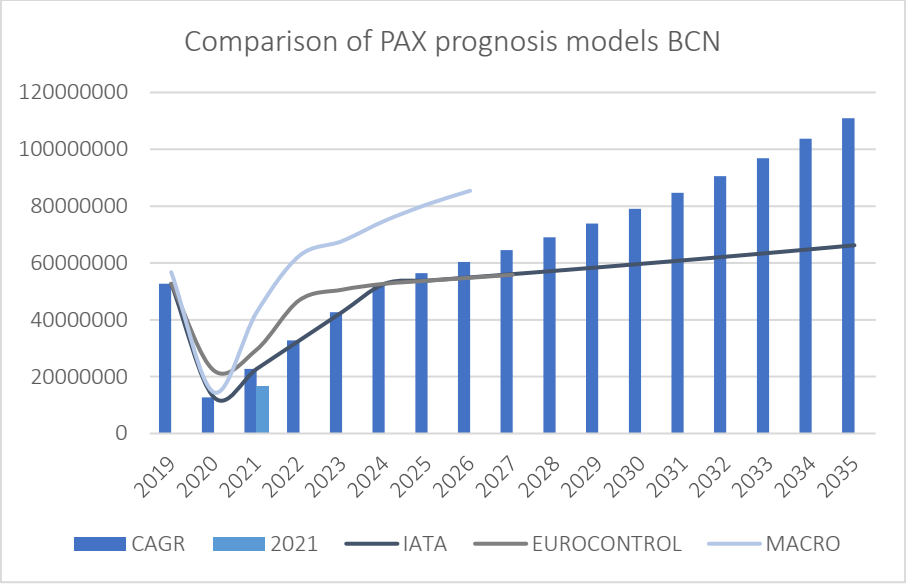


Figure 43: Comparison of passenger's prognosis models for BCN (Source: Own elaboration)

The Barcelona comparison of forecasts for operations and passengers show us a tendency that will become familiar in the next airports as well. The macroeconomic model tends to be more optimistic than the other models, reaching the levels of 2019 in 2022. Nevertheless, in 2023 the macroeconomic model expects the recuperation rates to slow down and to become almost flat. On the other side, the CAGR model presents the most pessimistic scenario. The real data from 2021 reached less than expected for all models (pending December as data has not yet surfaced), with a greater gap in passengers.

For the Girona-Costa Brava airport the comparison looks as follows:

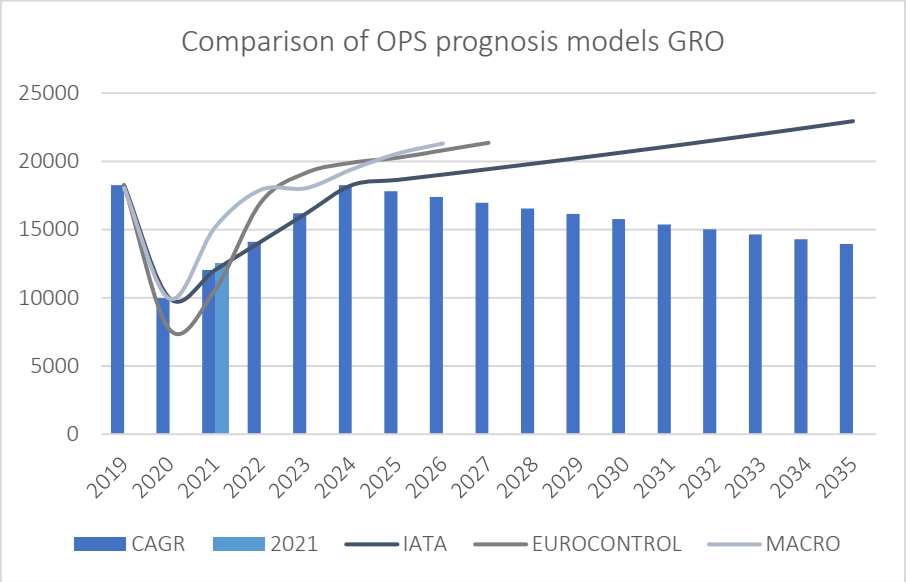


Figure 44: Comparison of operations prognosis models for GRO (Source: Own elaboration)

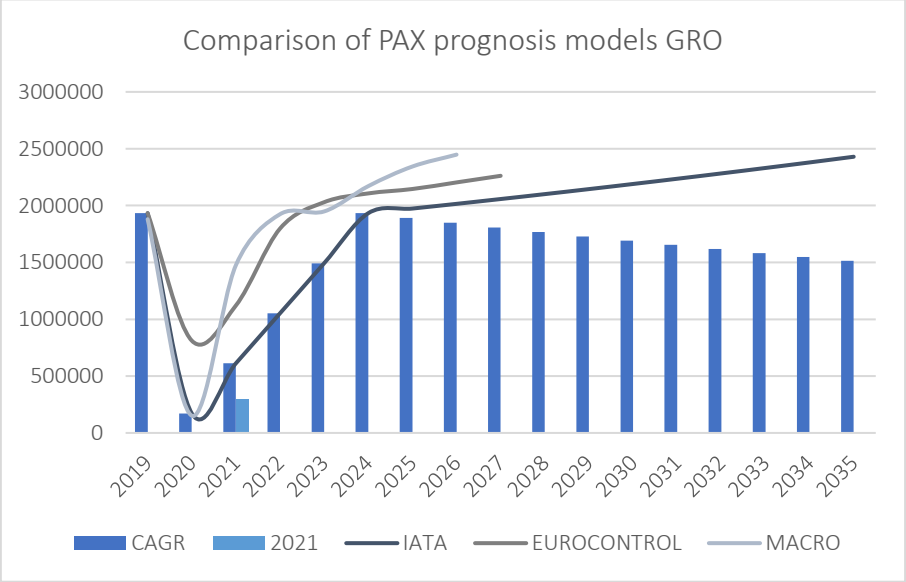


Figure 45: Comparison of passenger's prognosis models for GRO (Source: Own elaboration)

The GRO airport sees a similar situation to the BCN one. The macroeconomic model appoints to a very accurate level the diminishment of activity due to the covid pandemic, and even though it appears a little bit optimistic on the recuperation path, enables a setback in 2023. The Eurocontrol forecast fails to predict the behaviour of the airport in 2020/2021, as it falls behind in the actual impact on operations and seems far too optimistic for the passenger's one. The CAGR singularity predicts a misleading loss of activity in the airport that does not meet the interest on the area and the potential of the infrastructure, giving a wrong impression of decline. The 2021 data shows that the actual recovery rate surpasses the CAGR and IATA predictions for operations, and falls behind all predictions for passengers, with a great gap in between.

Lastly, the Reus airport presents the following data:

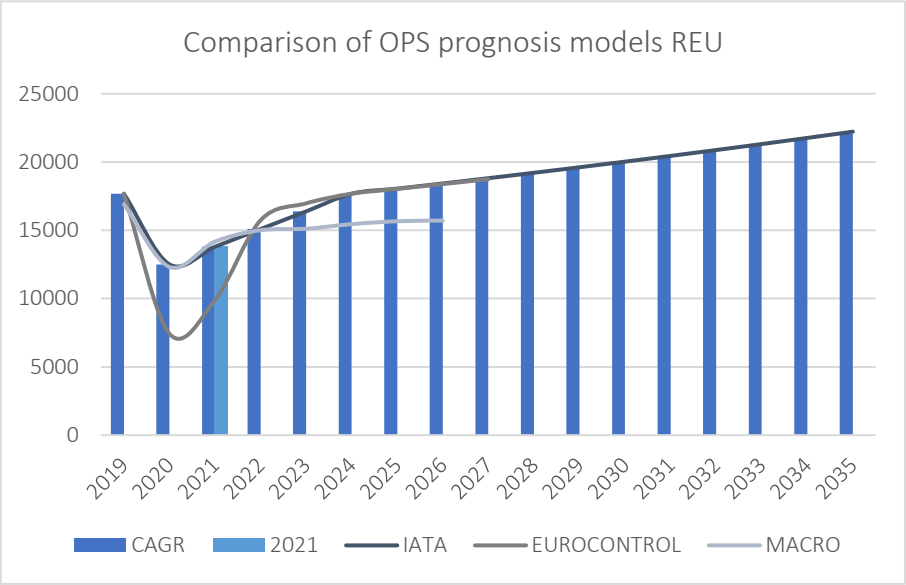


Figure 46: Comparison of operations prognosis models for REU (Source: Own elaboration)

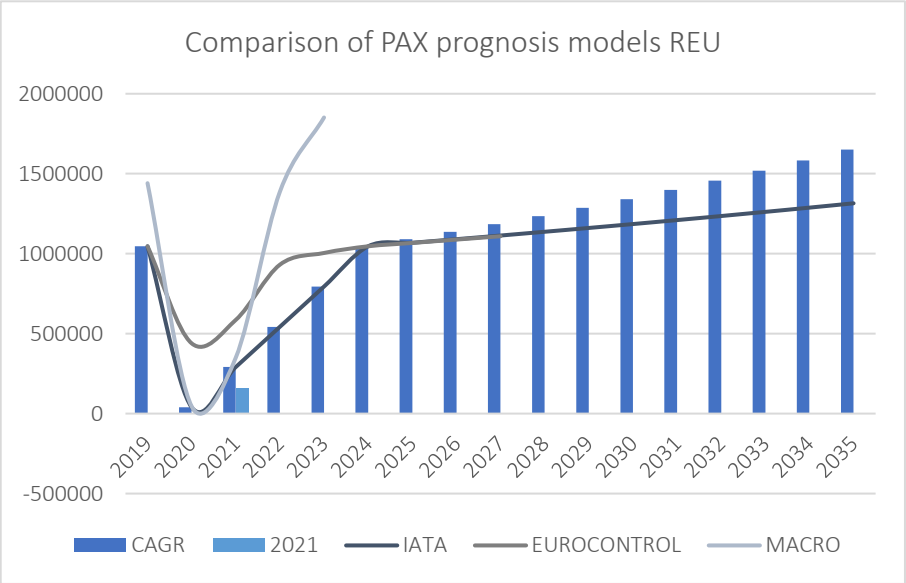


Figure 47: Comparison of passenger's prognosis models for REU (Source: Own elaboration)

The REU airport presents some particularities when comparing all methodologies in one graphic. The CAGR, IATA and Macroeconomic forecasts present high accuracy when comparing the actual data from 2021 with the predictions made for operations. It is necessary to point out that the macroeconomic model previews a stabilization of operations around the 15.000 and little growth, whereas the other prognosis converge into the same increase pattern. In the passenger's one, however, the macroeconomic model presents unreliable data, that is the reason why the forecast is put to a halt in 2024. The other methodologies overestimate the impact (Eurocontrol) and recuperation (Eurocontrol, IATA, CAGR) of the airport, as the real data from 2021 show little improvement from the previous year.

The comparison of the different methodologies for the three airports studied gives a wider view of how to tackle the recuperation and growth of the infrastructures in the coming years, and presents us with different possibilities that are needed to converge to create the different scenarios in which the thesis is going to work on. This convergence needs to understand the different motives behind every forecast and become assertive when choosing one data over the other, to create the most accurate scenario with different inputs from different methods. That is mainly the reason why this project is undergoing several ways to forecast the airport's activity. In the next chapter the final prognosis is finally revealed. The results for the methodology are finally applied to achieve the goals proposed in the beginning.

3.2.2 Prognosis results

As mentioned before, the starting point of the results is the presentation of the final prognosis for the Barcelona-El Prat airport, the Girona-Costa Brava airport and the Reus airport.

	OPS	PAX
2019	344563	52688455
2020	122638	12738769
2021	192955	22948902
2022	303189	39803168
2023	329740	46640975
2024	339190	52688455
2025	353502	55086854
2026	364044	57626108
2027	362538	60315514
2028	388394	63165004
2029	400277	66185200
2030	412558	69387449
2031	425249	72783885
2032	438366	76387477
2033	451924	80212087
2034	465939	84272538
2035	480427	88584675

Table 14: Final prognosis study of the BCN airport (Source: Own elaboration)

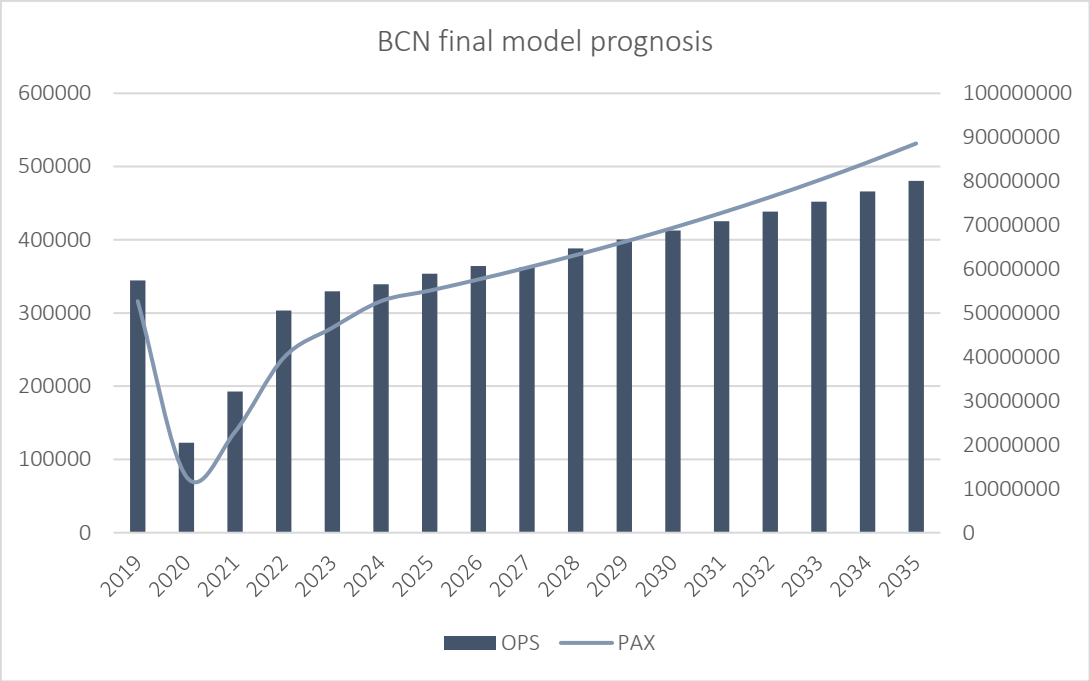


Figure 48: Final prognosis study of the BCN airport (Source: Own elaboration)

The prognosis results of the BCN airport consider all the different inputs taken prom the different prognosis methods. The final result estimates nearly 90million passengers and 500.000 operations yearly in the facilities.

For the Girona airport, the prognosis stands as follows:

	OPS	PAX
2019	18253	1933049
2020	9959	172171
2021	13603	455486
2022	16086	832500
2023	17245	1674278
2024	18639	1933049
2025	19272	1972677
2026	19773	1993400
2027	19388	2014558
2028	19835	2100612
2029	20252	2144725
2030	20677	2189764
2031	21111	2235749
2032	21555	2282700
2033	22007	2330636
2034	22469	2379580
2035	22941	2429551

Table 15: Final prognosis study of the GRO airport (Source: Own elaboration)

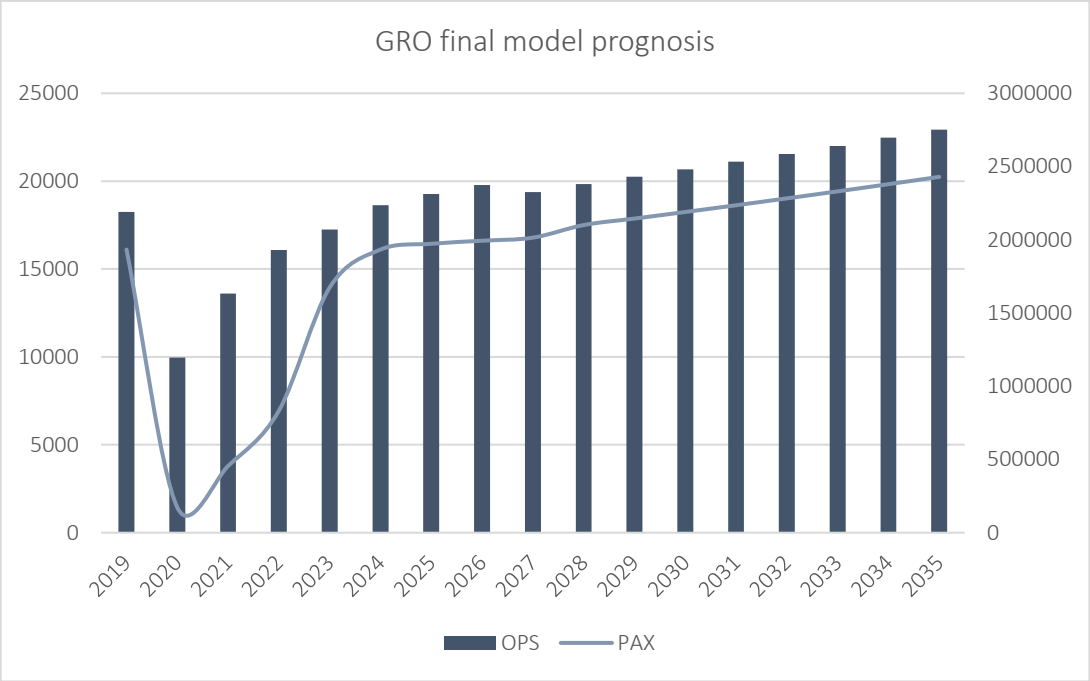


Figure 49: Final prognosis study of the GRO airport (Source: Own elaboration)

The prognosis results of the GRO airport amount to almost 2,5 million passengers and more than 22.500 operations in 2035.

Finally, for the Reus airport, the prognosis is:

	OPS	PAX
2019	17679	1046249
2020	12503	39460
2021	14175	254207
2022	15006	672290
2023	16157	864501
2024	16701	1046249
2025	16895	1079363
2026	17038	1113644
2027	18779	1149136
2028	19187	1185885
2029	19583	1223940
2030	19988	1263350
2031	20401	1304168
2032	20823	1346448
2033	21253	1390245
2034	21692	1435618
2035	22141	1482629

Table 16: Final prognosis study of the REU airport (Source: Own elaboration)

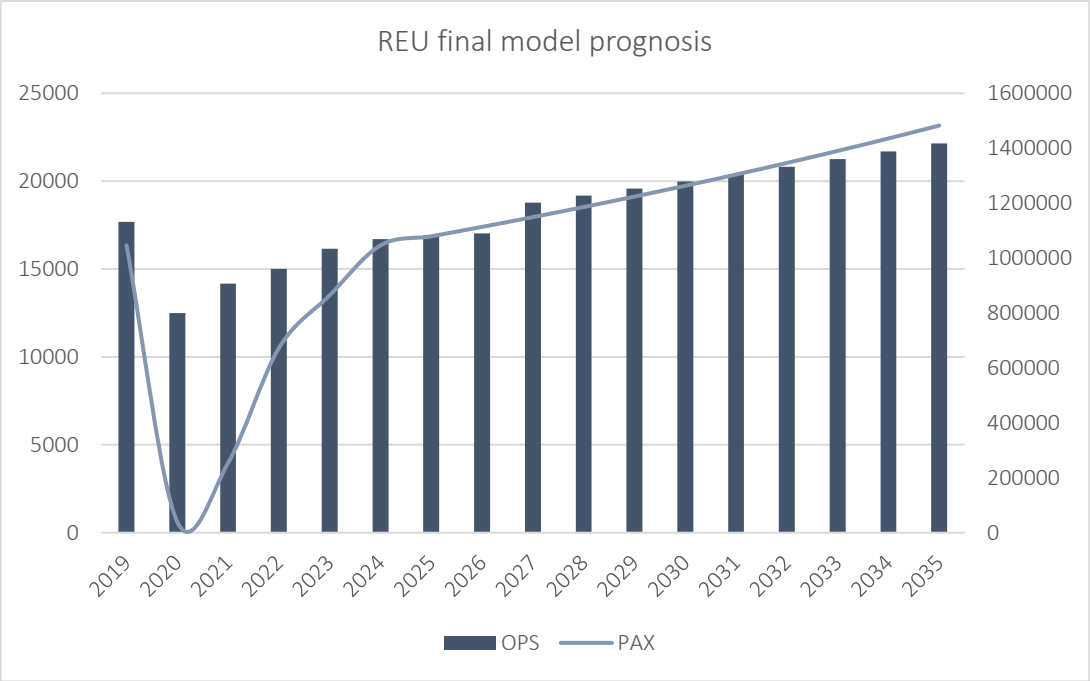


Figure 50: Final prognosis study of the REU airport (Source: Own elaboration)

The Reus airport is estimated to end 2035 with almost 1,5 million passengers and more than 22.000 operations. It is the most irregular pattern of all three airports, as general aviation still has an important weight on the infrastructure.

With these results, the design parameters can be set for the study. In the case of all three airports, the little access to reliable data on hourly distribution of flights complicates the task of design day and hour. Nevertheless, AENA facilitates in their 2019 technical documents ([22], [26], [27]) the average operations and passengers per week in every airport. It is with this data that the design parameters study is carried. To adjust the average day and hour capacity and use to the most realistic scenario, a standard 7 weekdays is settled and an operable timeline average of 2/3 of the day's hours (where most of flights are concentrated) for BCN and ½ for GRO and REU airports is fixed. With these adjustments, the aim is to prevent an even distribution throughout the day. The reality is that flights are usually concentrated in peak hours, and to replicate this phenomenon it has been considered to segregate the operable hours of the infrastructure in snooze hours (23.00-05.59 for BCN and 20.00-7.59 for GRO and REU) and active hours (06.00-22.59 for BCN and 8.00-19.59 for GRO and REU).

With this data and considerations, the following table explains the increase rate (CAGR) for the final prognosis in all studied airports:

	BCN	**GRO**	**REU**
Final forecast operations CAGR	2,099	1,439	1,417
Final forecast passengers CAGR	3,301	1,439	2,203
Airports' active hours	66,6% (16h)	50% (12h)	50% (12h)

Table 17: Increase rate for the final prognosis and active hours (Source: Own elaboration)

Considering 2035 the year of design, the extrapolation of average (design) operation and passengers per hour can be achieved using the previously mentioned increase rate for all three airports. Therefore, the design parameters for the studied Catalonia's infrastructure are shown next:

BCN	2019		2035 (DESIGN YEAR)	
	ops	pax	ops	pax
Average parameters per week (2019)[3]	6626 ops/week	1,0 Mpax/week		
Average parameters per hour[4]	60 ops/h	8929 pax/h	84 ops/h	15.014 pax/h
Peak parameters per hour[5]	70 ops/h	10.505 pax/h	99 ops/h	17.664 pax/h

Table 18: Design parameters for the Barcelona-El Prat airport in 2035 (Source: Own elaboration)

GRO	2019		2035 (DESIGN YEAR)	
	ops	pax	ops	pax
Average parameters per week (2019)[6]	351 ops/week	37,2 Kpax/week		
Average parameters per hour[7]	5 ops/h	443 pax/h	7 ops/h	557 pax/h
Peak parameters per hour[8]	6 ops/h	522 pax/h	9 ops/h	656pax/h

Table 19: Design parameters for the Girona-Costa Brava airport in 2035 (Source: Own elaboration)

[3] Extracted from [22].
[4] Using specified conditions and boundaries (Active hours).
[5] Peak parameters are 15% higher than design (average) parameters.
[6] Extracted from [27].
[7] Using specified conditions and boundaries (Active hours).
[8] Peak parameters are 15% higher than design (average) parameters.

REU	2019		2035 (DESIGN YEAR)	
	ops	pax	ops	pax
Average parameters per week (2019)[9]	340 ops/week	20,1 Kpax/week		
Average parameters per hour[10]	4 ops/h	240 pax/h	5 ops/h	341 pax/h
Peak parameters per hour[11]	5 ops/h	282 pax/h	6 ops/h	401 pax/h

Table 20: Design parameters for the Reus airport in 2035 (Source: Own elaboration)

The results show us the forecasted operations and passengers for the infrastructures in 2035. It is with these results that the scenarios for the different configuration of the airports are carried.

[9] Extracted from [26].
[10] Using specified conditions and boundaries (Active hours).
[11] Peak parameters are 15% higher than design (average) parameters.

4 DEFINITION OF THE DESIGNED SCENARIOS

Once the prognosis is finally assembled and converged, it is time now to present the scenarios of the Catalonia's infrastructure that aim to cover the demand generated in the three main existing airports, and how is the growth going to be absorbed by them.

The main factor deciding the distribution will be played by the major contributor to the demand, that is, the Barcelona-El Prat airport. This airport has attracted operations and passengers since its beginnings, and it has now the potential to serve as a big hub connecting different flights and parts of the world. The only setback preventing the infrastructure from becoming this aimed hub is the facilities' structural boundary and environmental limitations (explained in section 2.1.1) that reduce the maximum operability to 78 operations/hour – being 90ops/h the minimum operation rate to function as a hub-. The airport can achieve such rate, but the acoustic limitations that derived into a segregated usage of the runways reduced their maximum capacity.

Considering the increase of passengers and operations expected for 2035, the infrastructure needs to think ahead and create a plan to accommodate the mentioned growth. It is then that the creation of different scenarios takes place, to answer the demand generated and to maximize the compliance with the nowadays' regulations. These scenarios will then have an impact in the other Catalan airports (Girona-Costa Brava and Reus), that will see their actions and plans interfered. The three main eventualities are:

4.1 Scenario 1: Change the regime of the BCN airport runways

This first scenario does not imply further construction. When built in 2004, the runways allowed for 90 operations a day. But in 2006[12] the neighbouring cities pushed to change the independent configuration of the runways (in which take-offs and landings take place indistinctly in both runways) to segregated runways (where the 07L/25R is used for landings and the 07R/25L is used for take-offs only). This change of configuration minimized the acoustic impact on Gavà and Castelldefels, as no aircrafts flew at low altitudes through there and take-offs could be easily diverted into the sea, but also diminished the maximum operability terms of the configuration of runways.

Being the 2035s' average activity 84 operations/hour, with a peak use of 99 operations per hour, the change on the runways configuration would suffice to attend the demand growth. The acoustic impact for the surrounding citizens would increase dramatically and new approaches on acoustic pollution diminishment ought to be taken. Howbeit, when comparing the potentially affected population with other European airports, it is seen that most of them still present higher affected populated areas. Moreover, the aviation technology has been continuously developing more silent aircraft, and with other measures (most of them already applied in the airport) the acoustic harmful effects could be minimized. The use of Continuous Descent Operations is proven to have reduced the noise levels and the fuel consumption when landing, with a stunning 50kg of CO_2 reduction per each flight.

Other measures that could be adopted to further increase the operability of the airport include the reduction of the minimum separation between aircrafts from 3 nautical miles to 2,5 in HIRO conditions (only applicable in daytime operations), the optimization of the segregation for turbulent wake (forecasted to increase 1 or 2 ops/h), the reduction between arrivals from 8NM to 6NM when the landing runway is stopped for an exceptional wide-body

[12] See section 2.1.1.

take-off (with an environmental consequences on the natural regions) and the optimization of air traffic management with new techniques based on satellite navigation [24].

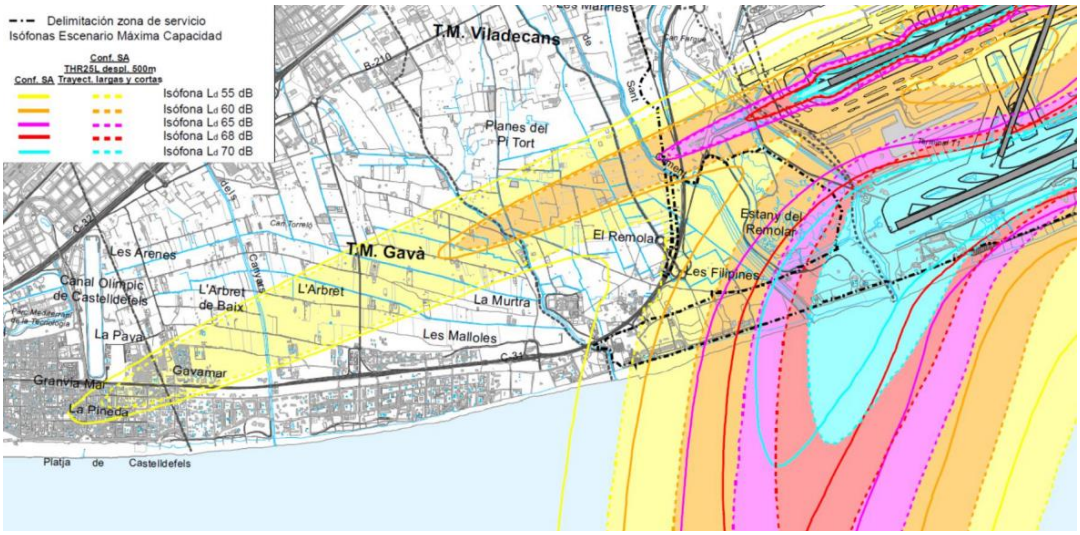


Figure 51: Acoustic isophones of the daytime operations in the BCN airport (Source: AENA)

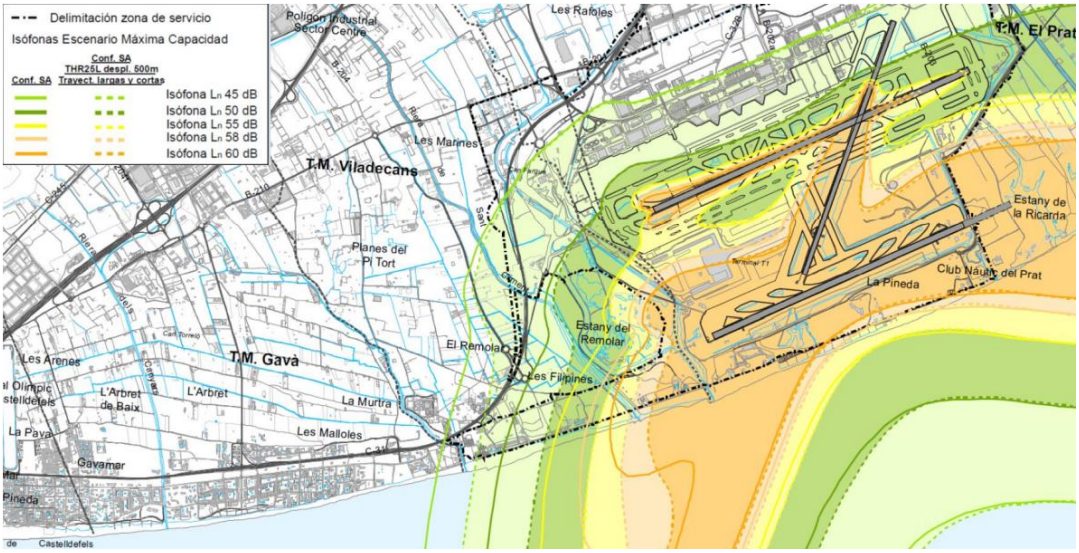


Figure 52: Acoustic isophones of the night-time operations in the BCN airport (Source: AENA)

The GRO and REU airport would embrace their respective growth without the need for any change, as the operability standards are still far above from the potential activity of the facilities. This scenario, then, has the potential to become the most economic (no further work and construction is considered) and the most aligned with environmental protection. It has, anyhow, a considerable setback when it comes to the quality of life of the surrounding neighbours.

4.2 Scenario 2: Expand the BCN 07R/25L runway

This is the initial proposal from the operator of the studied airports (AENA). The enlargement of the third runway one of the sides (the 25L heading) would also allow the infrastructure to regain the 90 operations per hour, in this case without having to sacrifice the segregation of the runways, and thus, respecting the collaboration between the airport and the nearby communities in acoustic pollution terms.

This expansion would allow for widebodies to take off as well from the sea runway, and therefore, leaving the whole 07L/25R one for landings exclusively, eliminating the existing need for some big aircrafts to take-off through the initially thought as landing runway (Non-Preferred Take-offs), as the sea runway is too short for some aircrafts. Were the expansion not to be done, the expected increasing trend of transatlantic routes by 2035 will otherwise further disrupt the runway's capacity, as more wide bodies will need to take off from the landing runway, diminishing in the long term the operability of the airport.

Figure 53: Proposed expansion of BCN-El Prat airport (Source: Google Maps, Own Elaboration)

The said runway should comply with the Annex 14 of the ICAO [87], and considering the A380-800 as the critical aircraft when designing the runway, with an $L_{A380} = 2.900\,m$, and reference characteristics specified in Table 2 for correction purposes, the overall runway should have a length of 3.308,7m.

$L_{A380\text{-}800}$	2.900m
Temperature correction (29ºC)	406m
Altitude correction (4m)	2,7m
Slope correction (0º)	0m
TOTAL	3308,7m (3400)

Table 21: Runway length specifications for BCN airport expansion (Source: Annex 14 ICAO; Own Elaboration)

The current 07R/25L runway has a length of 2660m, so the expansion needed should be of about 740m. AENA estimates consider only a 500m expansion, but the difference it can be due to different factors, such as the fact that the first 240m could already be expanded within the actual limits of the airport.

This expansion, nonetheless, generated a political quarrel, as the elongation would need to happen over a natural protected environment, La Ricarda. The compensations that AENA projected included the protection of 25,2% more of land using autochthon plants and recreating ecosystems for endangered species [17]. The fact that the runway had to destroy protected habitats did not convince the local and regional authorities, that claimed that the loss of habitat and species would be certain and that the emissions generated would increase. The debate over the model of airport that Barcelona-El Prat aspires to be is still on the table, and this instability disabled the regional government to reach an agreement with the Spanish one, and finally in September 2021 the project of expansion was dismissed [88].

The operator estimated the whole cost for the ampliation of the airport to add up to a staggering 1.704M€, accounting for the construction of a new satellite terminal (681M€), the connection between terminals (378M€), the reconfiguration of the existing T1 (152M€), new parking facilities (192M€) and an improvement of the airfield operative efficiency (39M€) – including a new by-pass through the 25R heading that would potentially increase resiliency and efficiency of the infrastructure (and reduce unnecessary emissions). All these actuations amount

From the acoustic point of view this configuration stands out as the most sustainable one, lowering the impact on the nearby areas and enhancing the quality of life of the neighbourhood. Nevertheless, the high environmental and economic requirements difficult the readiness of the plan and its normal development, with high opposition on the streets.

Figure 54: Potential map of the BCN airport with the satellite terminal (Source: GTD Systems)

4.3 Scenario 3: Hinder the expansion of BCN and expand GRO

The third scenario that aims to cover the demand generated by the 2035 prognosis is the most deviant from the already mentioned ones. In the awe of the realistic scenario that Barcelona halts all expansion plans, the generated demand in 2035 will need to relocate to other European destinations and other infrastructures on the zone. With the current ceiling of 55 million passengers and 78 operations per hour, all excess airport activity would necessarily move to other facilities. In this scenario, we are considering the transfer of those passengers and operations to the GRO airport. This last airport is not encapsulated in between protected areas and a possible expansion would not have such harmful effects on the environment. Nowadays, it holds a maximum of 18 ops/hour and 7,2 million passengers a year. With a slight increase of operations prognosed for 2035 up to 7 ops/h and 4,88 million yearly passengers, the surplus of demand generated by the BCN airport won't be able to fit in with the current infrastructure.

The first step, is then, to study the caption of the Barcelona's network. Given the airport's nature, the most realistic option is that the Girona-Costa Brava targets the low-cost market. The catchment area of the airport and GDP of the region will play here a major role in deciding which part of the market is relocated to GRO and which is distributed to other European destinations (and thus, out of scope of the work). The following table explains the relation between the BCN and GRO in terms of catchment area and the convergence between both markets:

Catchment Area	BCN	GRO	Relation
30mins	4,4 Mpax	667 Kpax	15,16%
60mins	6,2 Mpax	5,7Mpax	91,94%
120mins	7,6 Mpax	7,1 Mpax	93,42%

Table 22: Catchment area for the BCN and GRO airport (Source: Own Elaboration)

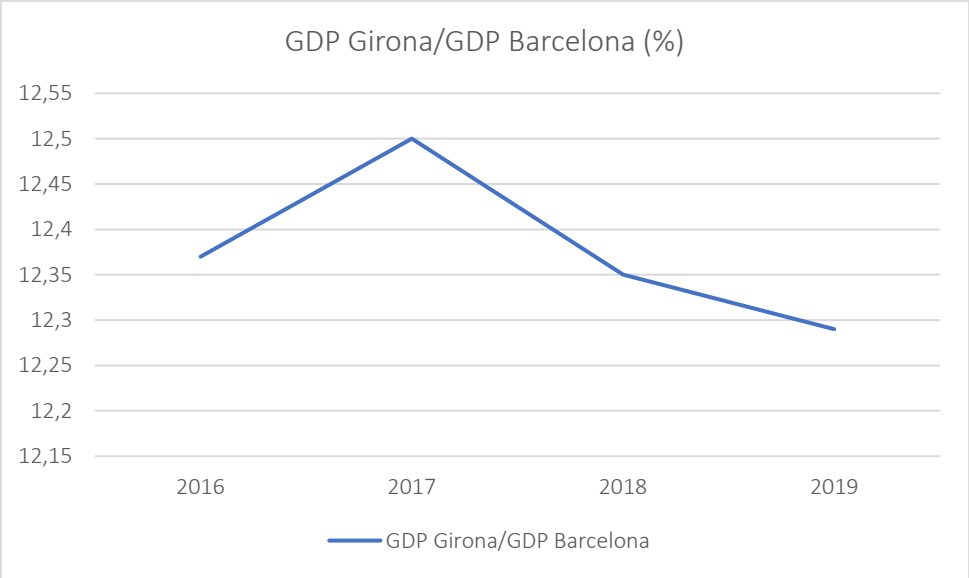


Figure 55: Relation of GDP distribution in Girona and Barcelona (Source: Idescat, Own Elaboration)

The relation between GDP in the Barcelona and Girona province also can shed a light on how the distribution of flights will take place. The relation between provinces escalates up to 12,29% in 2019 [13]. This means that the total GDP of the Girona region equals the 12,29% of the Barcelona one. The fluctuation over the last years is presented in Figure 55.

Considering the 60-minute catchment area as the standard number, and considering the implications of the GDP comparison, the rate of flights expected to shift over to the Girona airport is around the 52% of the total expected excess of operations and passengers for the Barcelona airport. The following table presents the results of the activity shift to GRO as well as the overall activity for the airport:

	GRO catchment from BCN[14]	GRO forecasted	TOTAL
Operations	67.614	22.942	90.556
Passengers	17.464.031	2.429.551	19.893.582

16ops/h	**3407 pax/h**

Table 23: Catchment and overall passengers of GRO airport in 2035 and design parameters (Source: Own Elaboration)

The catchment passengers from BCN amount to 19,71% of the total BCN passengers in 2035. This decongestion should help both infrastructures specialize in different markets (low-cost for GRO, long-range for BCN). The economic cost of such transformation is budgeted to be 332,43M€.

This scenario would solve with the environmental issue with La Ricarda, as no new expansion would have to take place in the BCN airport, and the GRO would then improve exponentially on capacity and operations. The transfer of operations is not elastic (48% of operations would be lost to other European destinations), but the distribution of the environmental damage on different locations would promote a more sustainable approach to the aviation infrastructure. Moreover, the economic growth that the GRO airport would experience would also improve the better distribution of wealth in Catalonia.

The targeted market for the GRO would not harm the connectivity on the BCN airports as low-cost present point-to-point operations. The decongestion of short and mid haul LCC would give BCN the opportunity to become a functional hub with long-range operations and high connectivity rates with mid-haul routes.

4.4 Scenario 4: Hinder the expansion of BCN and expand REU

There is a fourth hidden scenario. If the BCN expansion is hindered, the excess could opt for the Reus airport rather than the GRO one. This option, nevertheless, is not actually feasible. With connecting times far higher than the Girona ones, and with less experience in dealing with commercial civil aviation, the airport would struggle enormously to maintain the aviation activity in their facilities.

[13] Data extracted from Idescat [1]
[14] Considering a 52% of retention rate of the overall excess of activity in BCN airport

5 COMPARISON OF THE DESIGNED SCENARIOS

This section aims to compare the previous scenarios to see which is the most efficient for planning of Catalonia's airport system. This decision should be in full alignment with the specified requirements[15] and should consider different criteria.

5.1 Selection of criteria

For the present comparison between scenarios, the need for empirical criteria is paramount to ensure a full scientific decision when electing the final case. Reflecting on the thesis so far, the main stress of the report is to ensure economic success, and sustainability (*per se* not empirically demonstrable, but it has several indicators to show it, being the main ones the acoustic pollution, environmental pollution and social distribution). It is with these ideas that we set the following table, clarifying what do we understand with those terms:

Cost	This first criterion will tackle the cost for the operability of the desired configuration. The monetary investment plays a key role in deciding the final proposal. As said in the requirements section, the total cost should not be over the estimates 1,7 billion € for the AENA's proposed expansion plan.
Economic success	We understand economic success as the monetary impact that every scenario will have on the territory. It won't focus on how the growth is distributed, but rather how much is generated. There are different ways to record this criterion, from actual monetary impact (effect on GDP) to number of jobs created[16].
Acoustic compliance	The main concern in this criterion is to make sure that the neighbouring populated areas do not endure a reduction of quality of life due to the excessive noise levels- proven to be harmful on the health of neighbours [89]. The isophones of the airports should minimize and avoid contact with populated areas. Measured in dB, if the L_{AMAX} surpassed standard levels[17] restrictions ought to be made.
Environmental compliance	The item treated has a dual application. On the one hand, environmental compliance entails the particle pollution due to the airport's activity (mainly produced by the commute to the airport and the APUs of the airplanes), and on the other hand the preservation of protected and natural areas.
Context consciousness	The final proposed configuration should keep in mind the responsibility and the context in which is going to operate. To obtain an empiric value of this criterion can be difficult and confusing if it is not properly assessed. In this case, the way to calculate the compliance will use the UN SDGs. As said in the requirements, the resulting configuration should comply at least with two of them.

Table 24: Criterion definition and specifications (Source: Own Elaboration)

[15] See section 1.3
[16] InterVISTAR Economic Impact of European Airport (2015) [90].
[17] L_{AMAX}: Maximum sound level. This is the maximum instantaneous sound level occurring during the measurement period.

5.2 Scenario evaluation

To carry the comparison, it is necessary first to understand how every configuration aligns with the selected criteria. Next are the specifications of each configuration in each field.

5.2.1 Scenario 1: Change the regime of the BCN airport runways

Cost	There is no cost in changing the operation of the runways from segregated to independent. Secondary actuations in BCN (such as the construction of a by-pass in the 25L heading or the reduction of distances between aircrafts in some conditions) would have a minimum impact on the cost. Total cost forecasted: 39M€ (further cost on REU and GRO airports for maintenance operations is not considered).
Economic success	The economic impact of the proposed change is the following [90]: As it is acting in an airport with more than 10M traffic units, for every 1000 increase of traffic units, 0,854 jobs are estimated to be created, and for every 1% of increase of passengers, 0,0375% of increase in GDP per capita is expected to happen. Considering the increase of the total Catalonia's infrastructure traffic units for the 2019-2035 to be 35.896.220 for BCN, 496.502 for GRO and 436.380 for REU, an expected of 30.656, 422 and 371 jobs (direct and indirect) are to be created (BCN, GRO and REU, respectively). The GDP per capita upheaval will be 1,52% in BCN, 0,76% in GRO and 1,10% in REU.
Acoustic compliance	The main setback on implementing this solution is, without a doubt, the acoustic impact on the nearby areas. The independent use of runways implies the low-altitude flights in Gavà, Castelldefelds and El Prat. The isophones show a 55dB threshold in most of the populated area of Gavà, including in the night operative (Ln=45dB).
Environmental compliance	The pollutants on the area are expected to increase for the growth in operations expected. Being the road connections the main responsible for the air pollution, more operations would implicitly mean more passengers and more road traffic concentrated in one point. No natural or protected areas will be harmed in this airport's configuration.
Context consciousness	The proposal complies with several SDG, including the creation of decent work and economic growth, resilient infrastructure, and the protection of life on land, but exaggerates inequalities between citizens of Catalonia and diminish the well-being of those living near the BCN airport. Furthermore, it fails to tackle climate action and create sustainable communities. (Other SDGs not applicable) COMPLYING:  NOT COMPLYING: 

5.2.2 Scenario 2: Expand the BCN 07R/25L runway

Cost	There cost of the expansion of the 07R/25L runway, plus the construction of the satellite terminal and its adjustments (connection between terminals, reconfiguration of existing terminal, parking facilities, and airfield operative efficiency) add up to 1.704M€, the estimated cost that AENA forecasted for the conversion of Barcelona into a hub. Further cost of maintaining the GRO and REU infrastructure is also to be considered.
Economic success	Following the same methodology as in the previous case [90]: Considering the increase of the total Catalonia's infrastructure traffic units for the 2019-2035 to be 35.896.220 for BCN, 496.502 for GRO and 436.380 for REU, an expected of 30.656, 422 and 371 jobs (direct and indirect) are to be created (BCN, GRO and REU, respectively). The GDP per capita upheaval will be 1,52% in BCN, 0,76% in GRO and 1,10% in REU.
Acoustic compliance	The expansion of the 07R/25L runway will enable the airport to achieve the 90 operations per hour without compromising the segregation of the runways. This way for take-offs the deviation to the sea can be done before and thus affecting less to the nearby population. The configuration will also allow for far less noise during night-time operations.
Environmental compliance	As in the previous case, the pollutants on the area are expected to increase for the growth in operations expected with road traffic being the main catalyst The main setback of this proposal is that to achieve the necessary length construction must go over a protected area, La Ricarda. Even though there are compensations in place that rise the protected area up to a 25% more, the destruction of the habitat is certain and sudden changes could set back what's achieved until now.
Context consciousness	The expansion of the runway is aligned with the construction of resilient infrastructure, with the economic growth and wellbeing of communities and neighbours (low decibels). Nevertheless, it fails to protect natural areas, to reduce inequalities over Catalonia and to take climate action. COMPLYING:  NOT COMPLYING: 

5.2.3 Scenario 3: Hinder the expansion of BCN and expand GRO

Cost	The shift of strategy presented in this scenario changes the stress of the previous cases. The transfer of operations and passengers to the GRO airport demands the rehabilitation of the airport to accommodate the expected growth, including different constructions such as a new terminal building, new taxiing aprons, a rapid exit on the runway, the adaptation of the airfield to comply with the different regulations (EU, national and regional) and the access to the high-speed rail system, adding up to a total of 332,43M€. Further cost of maintaining the BCN and REU infrastructure is also to be considered.
Economic success	For this scenario, the 2019-2035 growth is expected to be 5.311.545 pax for BCN, 17.960.803 for GRO and 436.380 for REU, and so an expected of 4.536, 15.339 and 371 jobs (direct and indirect) are to be created (BCN, GRO and REU, respectively). The GDP per capita upheaval will be 0,34% in BCN, 3,39% in GRO and 1,10% in REU.
Acoustic compliance	The transfer of airport activity to the GRO airport will decongest the BCN airport. The segregated runways will still be able to work and thus protecting the neighbouring areas from the acoustic harmful effects. The reduction of activity in the airport will also contribute to the lowering of decibels.
Environmental compliance	The pollution derived from the airport activity will soften in the BCN airport and will exponentially increase in the GRO one. As the GRO airport is away from big, populated areas, the distribution of the pollution due to the aviation activity in the Catalan territory will be more evenly dispersed. The lowering effect that it will have on the BCN facilities will help decongest an area where the pollution particle levels are an all-time high, contributing to the improvement of the quality of life of all the surroundings (including the capital city of Barcelona). The proposal, also, won't have to deal with any expansion of the Barcelona airport, leaving the protected areas as they are right now. In Girona, as the single runway will be capable to absorb the forecasted activity, no big constructions that could potentially affect the environment ought to be made.
Context consciousness	The distribution of the airport infrastructure power throughout the region will allow for the creation of resilient and inclusive infrastructure, with an economic growth and job creation that will be distributed more evenly, as so will the pollution, caring for the well-being of the citizens and their communities. Nevertheless, it fails to maximize the economic potential of the BCN airport (that is why SDG 8 is shown twice). natural areas, to reduce inequalities over Catalonia and to take climate action, and further climate action could be done to lessen the harmful effects of aviation emissions and its related economic activity. . COMPLYING:  NOT COMPLYING: 

5.3 Scenario comparison

Now that all proposals have submitted their pros and cons with the related topics, it is time now to face them and decide which configuration is the more economically viable and sustainable to become the proposed Catalonia's Airport System.

5.3.1 Cost

In terms of cost, the most feasible option is without a doubt the reconfiguration of the runway use. The change from segregated runways to independent runways present little economic effort, with a total of 39M€, regarding minor operations to improve the operations flow. All other scenarios present a cost that surpasses the 300M€. The transfer of operations to the Girona-Costa Brava airport needs building a new terminal capable of giving service to all passengers and operations forecasted, with a total budget of 332,43M€. And the most expensive option, scenario 2 (expanding the runway at the Barcelona-El Prat airport), accounts for the construction of a satellite terminal, the connections necessary to link the satellite with the existing T1 terminal, the rehabilitation of spaces to accommodate the new demand, the reorganization of the airfield and, of course, of the construction of the expansion of the runway, with more that 1.700 million € budgeted.

5.3.2 Economic success

The economic success item has more controversy when comparing the three plausible scenarios. The option that creates more jobs is the extension of the Barcelona's 07R/25L runway and the change of the runway configuration, tied at the same number – a total of 31.449 jobs, 30.656 of which will be created only in the BCN airport-. This job creation foster's the economic upheaval but it resents the sustainable and inclusive distribution of work. The most evenly distributed scenario is the GRO expansion one, with 4.536 jobs in BCN, 15.339 in GRO and 371 in REU.

A similar situation happens with the expected impact on the economy. The option that has the potential to generate more wealth is scenario 1 and 2 (as the third scenario -GRO expansion- losses competitivity by letting go operations and passengers lost in the transfer of activity). However, the distribution of the wealth in the first two cases are very concentrated in the same area, with little redistribution of wealth that could potentially create bigger circular economy loops that generated more wealth. This is also seen when comparing the GDP per capita increase for each scenario. The Reus airport contribution to the regions GDP stays the same throughout all scenarios, but the chance to potentiate the region with less GDP per capita of the studied ones (Girona, [91]) should be taken as an opportunity.

5.3.3 Acoustic compliance

It is in this matter that things start to become clear. While the change of configuration of the use of the BCN runways (scenario 1) may prove to be the cheapest and most economically successful operation, it has a very big setback: it diminishes drastically the quality of life, health and well-being of the surrounding neighbourhoods, that amount to a population of almost 1,0 million people concentrated in the nearby areas.

The excess of decibels from the aviation activity are proved to have harmful effects on the health of people, as several studies have proven [89], [92], [93]. Scenarios 2 and 3 prevent that from happening: In the BCN expansion scenario the deviation of flights to the sea can be done more efficiently, avoiding populated areas. In the scenario 3, the operations are directly held away from the Barcelona and done in the GRO airport, with little acoustic pollution problems due to the distance from populated areas.

5.3.4 Environmental pollution

The environmental considerations play a major role in this thesis. IT is what disabled the governments to reach an agreement and it is where most of the political quarrel has been held. The first scenario – changing the runway use – presents an increase of air pollution in the surroundings of the airport, as the new configuration would allow for more operations and thus more fuel consumption and emissions and more road traffic into and from the airport (the main pollutant factor). On the other hand, this scenario preserves the protected areas that are located around the airport.

The scenario 2 presents an increase of air pollution following the same reasons as scenario 1, but moreover it presents a huge disruption of the natural protected area. Even though the plan conceives the creation of more natural wetlands in the surroundings of the airport, the ecosystem disruption and the human interference could alter seriously the biodiversity of the area even before the zones could be relocated. The current protected areas hold threatened species, and the biodiversity loss could prove fatal for the delta of the river Llobregat.

However, the third scenario can shed a light in this matter. The deviation of the operations and passengers to the Girona-Costa Brava airport would decongest the airport, lowering the emissions and air pollution on the area – and thus improving the quality of life of the neighbouring areas –, to an all-time minimum. Moreover, this scenario does not contempt to construct in the surroundings of the existing Barcelona or Girona airport, and thus not further environmental damage must be done.

5.3.5 Context consciousness

For the full immersion on the thesis, it is necessary to understand the role that an infrastructure like an airport can play in a region. Not only is a node of transport, but it also fosters opportunities, connections, and can be a tool for enhancing the community and region. For all of this it is necessary to ask whether the project proposed is aligned with some of these ideas, summarized in the 17 goals for the sustainable development (SDGs) from the UN. The scenario that complies most with these criteria is without a doubt the third one, the expansion of the Girona infrastructure, with 6 out of 8 approvals. This case fosters the equal distribution of wealth in the Catalan territory, it fosters collaboration between regions, and potentiates infrastructures that could otherwise struggle to find their position in the ever-changing civil aviation industry.

This evenly split of wealth can become a motor for the region, using the circular economy principles, and boost the region's performance to create synergies with the surrounding provinces as well.

5.4 Scenario decision

Once having compared all scenarios, it is finally time to decide and further develop the final airport configuration for Catalonia. Considering all criteria, and with the mentioned point in the previous section, the following table aims to answer the punctuations of every scenario regarding the criteria. To do so, a number ranking the position (being 1 the highest mark and 3 the lowest) will appear next to each scenario and criteria. Therefore, the scenario with less punctuation is the most suitable to develop the Catalonia's airport system.

	Cost	**Economic Success**	**Acoustic compliance**	**Environmental pollution**	**Context consciousness**
Scenario 1: Change the regime of the BCN airport runways	1	2	3	2	3
Scenario 2: Expand the BCN 07R/25L runway	3	1	1	3	2
Scenario 3: Hinder the expansion of BCN and expand GRO	2	3	2	1	1

Table 25: Comparison punctuation between scenarios (Source: Own Elaboration)

	TOTAL PUNCTUATION
Scenario 1: Change the regime of the BCN airport runways	11
Scenario 2: Expand the BCN 07R/25L runway	10
Scenario 3: Hinder the expansion of BCN and expand GRO	9

Table 26: Total marks for each scenario (Source: Own Elaboration)

Therefore, the configuration that adjusts the most to the desired solution for the requirements stated in the beginning of the project is the **SCENARIO 3: To hinder the expansion of BCN and expand GRO**. With this decision we achieve an economically viable configuration, with an acceptable cost, compliant with the acoustic and environmental regulation and responsible with the role it plays in within the community.

It is important to stress that this configuration aims to expand its area of influence towards the Barcelona metropolitan area to offer a competitive service to a bigger catchment area, despite the BCN airport interference. The difference in their targeted market will complement and better the offer. The scenario does not contemplate to unify both infrastructures under a same name, as perhaps it can be understood with the misleading effect of calling the GRO airport "the 4th runway of BCN".

6 CHARACTERIZATION OF THE CHOSEN SCENARIO

The expansion of the Girona-Costa Brava airport (with the consequence halt in the expansion programs of the BCN airport) presents some particularities. The characterization and initial development of the plan it is aimed in this section, to provide further data on how this expansion is expected.

6.1 Traffic characterization

As mentioned in section *Scenario 3: Hinder the expansion of BCN and expand GRO* not all excess from the forecasted activity for the BCN airport will transfer to the GRO infrastructure. When studying the catchment area and the GDP relation between regions we observe that the economic and structural relation converges around the 52%. That means that almost the half of the prognosed operations and passengers will be lost to other European airports. To win back the activity it will be necessary to build resilient and effective infrastructure and management. The design parameters for 2035 is again represented in the following table:

	GRO catchment from BCN[18]	GRO forecasted	TOTAL
Operations	67.614	22.942	90.556
Passengers	17.464.031	2.429.551	19.893.582

16ops/h	**3407 pax/h**

Table 27: Catchment and overall passengers of GRO airport in 2035 and design parameters (Source: Own Elaboration)

The GRO catchment share from BCN amount to 19,71% of total Barcelona-El Prat airport.

On the other hand, the Girona airport was built as a low-cost targeted market infrastructure. Therefore, the capacity that is forecasted to hold by 2035 should entitle LCC from the BCN airport. For the adjustment to the market share calculated, the airlines designed to fill the Girona's facilities are Ryanair, Wizz and EasyJet. The three airlines amount to approximately 20% of the total operations of the Barcelona-El Prat airport.

These airlines are known to operate one single type of aircraft for all their operations, as the scale economy is proven to be far more efficient and economical for the airline (B737-800 for Ryanair and A320 for EasyJet and Wizz, all code C aircrafts). As the existing runway already surpasses the 1.800m, the airport, then, is expected to have a 4C category.

Regarding the role of the other airports of Catalonia, the 20% reduction of market share in the Barcelona-El Prat will allow for a great decongestion of the infrastructure, to then focus on intercontinental flights and connectivity nodes. The IAG principal airlines will have the ability to use it as an operations hub for the airlines Vueling and LEVEL.

[18] Considering a 52% of retention rate of the overall excess of activity in BCN airport

6.2 Infrastructure enhancement: A first approach

With such results, the airport should undergo several actuations to accommodate the expected operations and passengers. Even though the scope of the work does not require to forecast the technical specifications of the chosen scenario, the current section will overgo a first and very initial approach on the work's construction and readiness of the existing airport to accommodate the expected demand by 2035.

The main components of the airport, along with their transformations that should endure (or not) are explained next: The existing runway has capacity for 18ops/h, so there wouldn't be a need for building a secondary one, as also there wouldn't be need for an expansion of the existing runway. The effort should be directed, then, into gaining efficiency, by building a rapid exit taxiway on the runway for a 4C airdrome (in the 20 heading, 1.700m into the runway), and more taxi spots for the design and critical aircraft and other smaller aircraft sizes. On the other hand, the terminal building would have to be expanded to accommodate the nearly 20 million passengers expected to go through in 2035.

6.2.1 Rapid exit taxiway initial specifications for the GRO airport

Distance to runway centreline	158m
Distance to objects	26m
Distance to other taxiway centreline	44m
Curvature radius	550m
Entry amplitude	27m
Angle with the runway centreline	30º

Table 28: General distances of the projected GRO rapid exit taxiway from the runway (Source: Annex 14, ICAO [87]*; Own Elaboration)*

Figure 56: Rapid exit taxiway diagram with beaconing and distances (Source: WED X-Plane developer, Own elaboration)

6.2.2 Taxiing aprons initial specifications for the GRO airport

Terminal (Fingers)	4	Type VI (code C aircraft)	11
Close Remote	8	Type VII (code C aircraft)	11
Far Remote	15	Type VIII (A & B code aircraft)	5

Table 29: Distribution and dimensioning of the aprons (Source: Annex 14, ICAO; Own Elaboration)

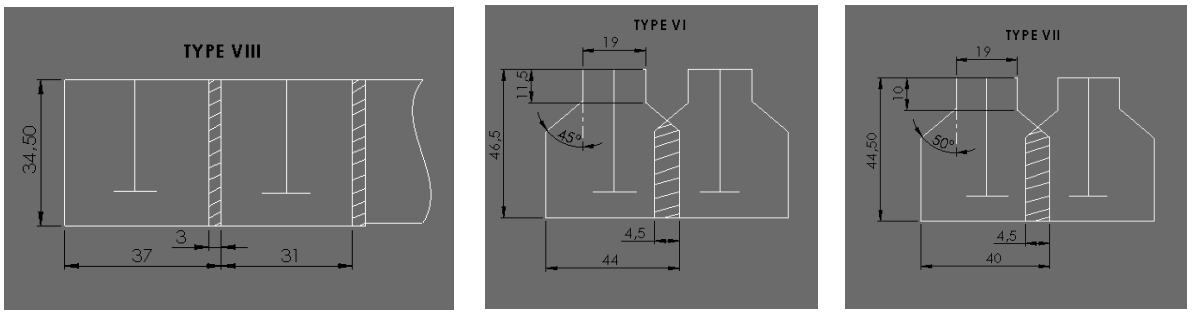


Figure 57: Apron dimensioning and shape (Source: SolidWorks, Own elaboration)

6.2.3 High-speed connection for the GRO airport

Furthermore, to increase productivity and efficiency, there airport should also be connected to some sort of quick transfer to Barcelona. The high-speed rail, few meters away from the current airport, becomes the most feasible option. By reducing transfer times to 38 minutes (standard Girona-Barcelona high-speed commuting times), the competitiveness of the airport would increase exponentially, as the catchment area would increase as well. When comparing the transfer times with other similar target European airports, we obtain the following table:

AIRPORT	TRANSFER TIME
London Gatwick (LGW)	30mins
Paris-Orly (ORY)	35mins
London Stansted (STN)	35mins
Girona-Costa Brava (GRO)	**38mins**
Bergamo Orio al Serio (BGY)	56mins

Table 30: Transfer times for secondary airports in similar European cities (Source: Own elaboration)

6.2.4 Enhancements in BCN and REU airports

To enhance the operations performance of the BCN airport, the 39M€ reorganization of the airfield can be conducted, including a by-pass through the 07L heading, enabling aircrafts taxiing in the T2 terminal to cross the 07L/25R runway without affecting ongoing operations on the runway. Other existing manoeuvres such as the reduction of distances in specific conditions could also improve the airport's capacity.

Regarding the Reus airport, the existing infrastructure allow for an increase of both operations and passengers without having to build more infrastructure.

6.3 Budget briefing: A first approach

This section aims to answer the economic support needed for developing the expansion of the GRO airport and the improvement of several aspects in the REU and BCN airports. To do so a summary of the construction and rehabilitations procedures will take place, along with the prognosticated cost.

For the Girona-Costa Brava airport, the needed actions and constructions with their respective budgets are the following[19]:

Items GRO	**Investment (€)**
Land-side actions	**292.000.000**
- Remodelling and ampliation of current terminal building	225.000.000
- New parking facilities	10.000.000
- Connection with the high-speed rail network (AVE)	55.000.000
Air-side actions	**29.450.000**
- Rapid exit taxiway	2.200.000
- New terminal aviation platform	15.000.000
- Relocation of hangars	5.250.000
- Relocation of control tower	7.000.000
Airfield adequation	**24.868.000**
- Relocation of support services (Energy generators, etc.)	4.140.000
- Compliance with European regulations (nº 139/2014)	20.728.000
Terrain acquisitions	**20.000.000**
Maintenance	**50.000.000**

[19] Data for forecasted costs of constructions and remodelling extracted from [11], [94].

TOTAL GRO	**414,32 M€**

Table 31: Budget record of actions to take in GRO airport (Source: AENA, Own Elaboration)

For the other infrastructure, the budget is:

Item Other	Investment (€)
Air-side actions BCN	**39.000.000**
- Creation of by-pass taxiway around 07L heading and complete enhancing capacity operations	39.000.000
Maintenance BCN	**100.000.000**
Maintenance REU	**15.000.000**
TOTAL Other	**154,0 M€**

Table 32: Budget record of actions to take in the other airports (Source: AENA, Own Elaboration)

The final budget for the implementation of the project is, then, summarized in the following table. This investment will procure and enable the growth of the GRO airport in consonance with the other existing infrastructure, and will empower all the Catalan system by enhancing long-haul connectivity in BCN and low-cost short and mid-haul flights in GRO and REU.

TOTAL BUDGET	568,32 M€

6.4 Analysis of environmental and social implications

The environmental impact of the proposed scenario includes the increase of air pollution in the nearby areas of the GRO airport, because of the transfer of activity from the BCN airport, which at the same time it would see an important reduction of emissions in its surroundings. Whereas the GRO airport does not have any populated areas nearby (and no natural protected areas), and the actual impact of the increase of emissions would have little impact on the well-being of neighbouring areas, the reduction of emissions in the BCN airport would have an enormous impact on the quality of the air in one of the most stressed regions of all Catalonia when it comes to air pollution. This improvement is one of the reasons this scenario has been chosen.

On the social implication's topic, the fact that a great share of aviation economic activity moves to the Girona province implies the better distribution of wealth and contributes to the inclusive economic growth of Catalonia. From its four existing provinces, Girona is the one that presents the lowest GDP per capita. The economic impulse that a functional operating airport would mean for the region could create synergies with the other regions and create circular economy loops to further boost the economy of the overall territory. The fight against inequalities and poverty is greatly diminished with accessibility, and an airport can offer so.

7 CONCLUSIONS

The civil and commercial aviation, being the most catalyst industry for economic growth in a region, has had to endure the greatest crisis of all times. The spread of the COVID put to a halt the steady growth of the industry of the last 50 years. Nevertheless, 2021 has shed a light in recuperating the 2019 activity levels. The resilient characterization of the aviation industry has triggered the beginning of the recuperation.

European- and therefore also Catalan- aviation infrastructures are not oblivious to this phenomenon, and since the strike of the first wave of the pandemic they have seen an increase of activity within the facilities. The intrinsic characteristics of the Catalan airport situation – where saturation levels before the pandemic in the major BCN airport were almost reached – has pushed several capacity enhancement plans for this airport and the other main ones (over 500.000 passengers), Girona-Costa Brava (GRO) and Reus (REU). The aim of the thesis was, then, to find the most economically, environmentally, and socially sustainable system that procured the needs and satisfied the demand generated in the region, to enhance and thrive economically whilst meeting the SDG (Sustainable Development Goals) for the UN 2030 Agenda.

To do so, it was necessary first to understand the demand generated by the design year of 2035. It is necessary to point out the little access to public data to generate such demand models, that has complicated the data obtention and treatment. During the span of the study, the results have pointed to the conclusion that the Catalan infrastructure is in a strong position to continue embracing the industry activity, with an increase of the demand. The different methodologies used for the prognosis of operations and passengers converged in an increase of aviation activity in the region (except for the CAGR predictions for the GRO airport). The use of macroeconomic factors to forecast has had a positive impact on the overall results, with correlations as high as $R\_ops(GRO) = 0{,}998$ for the operations in the Girona airport. The convergence of all different prognosis has allowed for a feasible final prevision in which to work the different capacity enhancement options.

These scenarios had to comply with several items listed in the requirements, such as a feasible cost, a positive economic impact, ensure the sustainability of the infrastructure and be reliable to hold the expected growth for 2035. A total of 3 scenarios have been designed:

- A change in the operation of the BCN runways towards an independent regime (with no further construction to be endured, but with huge consequences for the acoustic pollution in the neighbouring populated areas),

- The expansion of the 07R/25L runway in BCN to maintain the segregated regime of runways in that airport (with a polemic increase of the sea runway towards a naturally protected area), and

- The halt to expansion plans for the BCN airport and the encouraging of the GRO expansion (with the subsequent loss of economic power for the BCN airport).

When comparing the different characteristics for the criteria selected it has been observed that the one with the best performance in most of the items described at the beginning of the paragraph was the redistribution of the industry with the GRO airport as the new leading airport in LCC operations.

This scenario allows for a better distribution of the wealth generated and the environmental pollution of the airport activity, working towards and inclusive economic growth and alleviating the high pollution pressure on Barcelona and its surroundings (including the BCN airport). This redistribution of powers enables the BCN airport to fully focus on connectivity

and long-haul flights, attracting qualitative and not quantitative assets. The GA component in the REU airport could be directed to a knowledge hub for General Aviation. For all this reasons the chosen configuration for the Catalan airport system is concluded to be the most economically viable and sustainable option.

Finally, a first high-level approach has been undergone to set the foundations for the chosen scenario. Further work should consider a thorough study on the specifics of the project to ensure the desired operability of the infrastructures, as well as the inclusion of the smaller airports in Catalonia, to complete a wider view on how to act for further enhancing the Catalan system.

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