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An Empirical Analysis of the Aircraft Emissions by Operating from Scheduled Flights within the Domestic Market in Spain

Antonio Martínez Raya *, Alejandro Segura de la Cal and Rafael Eugenio González Díaz

Department of Organizational Engineering, Business Administration and Statistics, Technical University of Madrid—Universidad Politécnica de Madrid (UPM), 28040 Madrid, Spain
* Correspondence: amartinez@cee.uned.es

Abstract: Over the past 20 years, civil aviation has substantially reduced its environmental impact to augment sustainable transportation. In Spain, the domestic market has been habitually characterized by a few enterprises providing air transport services linked to scheduled flights on domestic corridors. Because of geographic diversity and the highly concentrated population characterizing this southern European country, many of them could not be supplied by alternative transport modes in terms of both time and distance by comparison with air transportation. For air quality monitoring from 139 national corridors, this paper aims to study related aviation emissions to conduct an economic analysis in terms of positive or negative externalities. For such purposes, the study focused on these domestic routes served by the five most important Spanish airports, specifically on the number of passengers transported from 2011 to 2020. Up to 10 aircraft types representing no more than 89% of regular operations on these flyways were subsequently identified. In addition, certain engine types also were selected as representatives to evaluate their emissions, depending on the great-circle distance in each route. The research findings, though particularly conditioned by aviation peculiarities of such a domestic market, point decisively to significant dependence upon emissions in connection with the seasonality of the demand and the concentration of flights with low occupancy indices from any one of them. Results suggest that airlines would benefit from operating turboprops instead of turbojets on selected routes, especially when oil prices are high. However, it is not always easy to find a balance between uncompromising economic profitability and effective fleet availability, since nowadays air transport undertakings tend to unify their fleets by using a few aircraft families, mostly powered by jet engines, apart from regional carriers.

Keywords: environment; sustainable transportation; air quality monitoring; aviation emissions; economic analysis; externalities; economic profitability; fleet availability

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1. Introduction

The civil aviation sector is a fundamental part of the planning process for developing sustainable transportation in the European Union (EU), according to one of the Sustainable Development Goals (SDGs), namely Goal 11. The so-called 'European Green Deal' has set up an action plan to combat climate change within the EU. With specific regard to the transportation sector and within the scope of EU's Green Deal's objectives, specifically, the 'Fit for 55' has been included in ambitious proposals to reduce related emissions by up to 55% by 2030 from two transport modes, both maritime and air. For carbon dioxide emissions from aviation, the Emissions Trading System (EU ETS) [1] has increasingly been used since 2005 as the principal instrument for calculating the EU's total emissions through a system based on allowances (EUA) reporting from the European Union Transaction Log (EUTL). Indeed, to entail adjustments to EU climate legislation, the European Commission (hereafter the Commission) has recently amended ETS Directive [2].

Regarding greenhouse gas emissions from the European aviation sector, air transport has been facing both global warming and climate change and is considered a common priority nowadays for the entire industry within the EU framework on ETS. Over the past years, significant efforts have been made to promote the efficient use of airspace by optimizing flight operations and digitizing airline performance. For that purpose, the whole sector (manufacturers, carriers, airport infrastructure managers, and air navigation service providers) has worked towards this as their sole aim for more sustainable aviation. However, initial allocations of emission permits from the implementation of EU ETS should be continually reassessed and the necessary actions defined and revised to avoid the creation of regulatory trade barriers in the aviation sector [3]. Indeed, such a system has often been adapted to respond to the challenges of the European airline industry. More specifically, after the full inclusion of aviation in the EU ETS on 1 January 2012 [4] in accordance with those aviation activities concerned [5], there was a temporary derogation from the greenhouse gas emission allowance scheme [6], namely "Stop the Clock", which gave concerned parties time to overcome the constraints arising from the prompt implementation of ETS-related penalty systems. Then, for 2013–2020, there was an application of the system with a narrow scope allowing airlines, among other special dispensations, to use a simplified methodology to report emissions annually of less than 3000 tons of CO_2 per year on intra-community flights [7]. Lastly, regarding the emissions for the period 2021–2023, airlines concerned, according to EU ETS, must notify of their emissions by flights operated within the European Economic Area (EEA), in addition to those whose destination is any airport located either in the Swiss Confederation (hereafter, Switzerland) or the United Kingdom of Great Britain and Northern Ireland (hereafter, the United Kingdom) for the previous year every 28 February of the year following [8].

Since sprawled environments contribute to climate change directly and indirectly, due to the certain effects of transportation characteristics, among other factors [9], the air industry has often addressed the question of whether full decarbonization of aviation, using alternative energy sources, is actually practicable in the years to come before 2050. Unlike rail transport, the extensive use of aviation fuels for commercial flying based on renewable energy sources is currently not easy to achieve, as a sort of comprehensive technological solution for a partially optimized sustainable fuel is, for the time being, the only remedy available, including those based on Sustainable Aviation Fuel (SAF). In fact, using SAF in commercial airplanes is currently the most workable solution to mitigate aviation emissions by operating existing aircraft. One of the great assets of SAF is that it can be mixed with any fossil jet fuel to reduce emissions. It could even be beneficial for emissions compared to the baseline scenario where airlines only use conventional jet fuel based on simulations made with the Fleet-Level Environmental Evaluation Tool (FLEET) [10]. However, a solution relying entirely on SAF seems to be a temporary arrangement, since there are still unresolved issues regarding their availability problems and production costs. In addition, alternative energy sources, either through electric or hydrogen engines, cannot completely replace carbon-based fuels in the aviation sector. Nevertheless, promoting the research effort in sustainable alternative fuels for aviation is essential, albeit not sufficient. Building on this basis, the challenge now is how to reduce the impact of commercial flights on public transportation by using affordable and sustainable fuels and operating efficient fleets. Without restricting demand, this is unlikely in terms of emission stabilization at levels consistent with risk-averse climate targets [11]. Research in this field has become even more important as time has gone by, since the question is raised as to the feasibility of supplying domestic short-haul air routes that are sensitive to mitigating climate change through real actions towards sustainability. The present paper aims at achieving precisely that objective, thereby contributing to a knowledge of such an important issue and the search for possible solutions. On one hand, there are precisely framed sectorial matters on aviation-related issues. On the other hand, there is a rather vague global technological order on the current dependence on fossil fuels and moving toward complete decarbonization by 2050, or even earlier.

2. Conceptual Research Framework

As pointed out earlier, it has been wondered whether aviation emissions from domestic scheduled flights can be only reduced by operating more effective aircraft or, failing that, whether further types of real actions, either technical or operational, may be necessary for this matter. To that end, the research has been focused on those flights operating from the most representative airports in Spain. Hence, the study was designed under a mixed approach from a conceptual framework created to find answers to the research question. On one hand, the selection of a primary source for data collection to be properly applied to the study is necessary. On the other hand, an empirical analysis with timely and trusted data for the purpose of contributing to a better understanding of the research scope, not only in terms of emissions, but also concerning fuel consumption, thus affecting variable costs of airlines, is also necessary. From a sectorial perspective, promoting lower emissions among carriers creates a sustainable business culture and efficient mobility. At the same time, stakeholders in the air transport system have been facing several uncertainties, casting a shadow on the economic prospects of the aviation sector. Fleet diversification can be a great ally for airlines in dealing with periodical market swings, whether due to seasonal demand (i.e., tourism) or unexpected events (i.e., coronavirus). However, most airlines are subject to leasing contracts limited to a single manufacturer for reasons of efficiency and cost-effectiveness, either due to maintenance or certification. Consequently, as outlined below, there are only a few commercial aircraft types per carrier, which is often only available to one single aircraft family. Thus, during the period under review (2011–2020), and in accordance with usual classification criteria based on the most representative aircraft of European airlines from previous works [12,13], the most utilized commercial airplanes (10) of only single-aisle families, either turboprop or turbojet, in domestic corridors (139) operating in the busiest airports (5) in Spain have been selected for the study. The case of the Spanish domestic market is also a very good approximation as to what occurs in the European aviation sector in terms of emissions, as almost two-thirds of passenger air traffic correspond to France, Germany, Italy, Spain, and the United Kingdom (UK) [14]. With the approach to sustainability regarding the transport of passengers by air over regular routes, specifically focused on the Spanish domestic market, a few earlier papers have handled the issue of aviation emissions with certain routings. For instance, regarding the specific case of the Public Service Obligation (PSO) schema applied in Spain, the emissions, depending on the aircraft type of some domestic routes, such as those serving island territories [15], the EU territories with special status [16], or even intra-regional routes [17] have been discussed. This article brings a comprehensive and consistent view of the sustainability of passenger air transportation by segmenting emissions per distance band and aircraft type to reveal which corridors contribute more to the overall aviation emissions in the Spanish market.

Although the causes of climate global warming are very diverse and highly disturbing, it is widely accepted that the effect of human activities is one thereof, and even a critical one. Using energy based on fossil fuels in transport creates harmful emissions. Regarding the emission analysis of greenhouse gas (GHG), the research has only been focused on carbon dioxide emissions from the aviation sector, since this is the primary driver of global climate change, in line with scarce similar works focusing on sustainable transportation in Spanish domestic market, though without any concern about passenger transportation, but intra-national freight transport instead [18]. Because commercial aircraft emissions are affected by flight-specific variables that change continuously, it becomes necessary to develop average factors to consider the effect of these flight parameters. While these factors cannot entirely be identified from a specific flight basis, the normal methodology considers them for the purpose of developing a more robust estimation of flight emissions. As shown in Figure 1, the empirical analysis carried out in the study has been mainly supported by two primary sources, one for air traffic statistics and the other for the carbon aircraft emissions database, respectively from AENA [19] and International Civil Aviation Organization (ICAO) [20], in line with International Air Transport Association (IATA). Consequently,

Figure 2 summarizes the analysis methodology used in designing the research for the estimation of main climate-related emissions. As a result, the contribution of the paper is intended to evaluate the impact of commercial aviation on carbon dioxide (CO_2) emissions from the analysis of representative domestic flights in such a demanding transportation market as the Spanish route. The research question does arise, therefore, whether regular air passenger services on domestic routes can be always sustainable in terms of excessive pollution by scheduling turbojets, or otherwise deploying turboprops on certain regional corridors where feasible and economical.

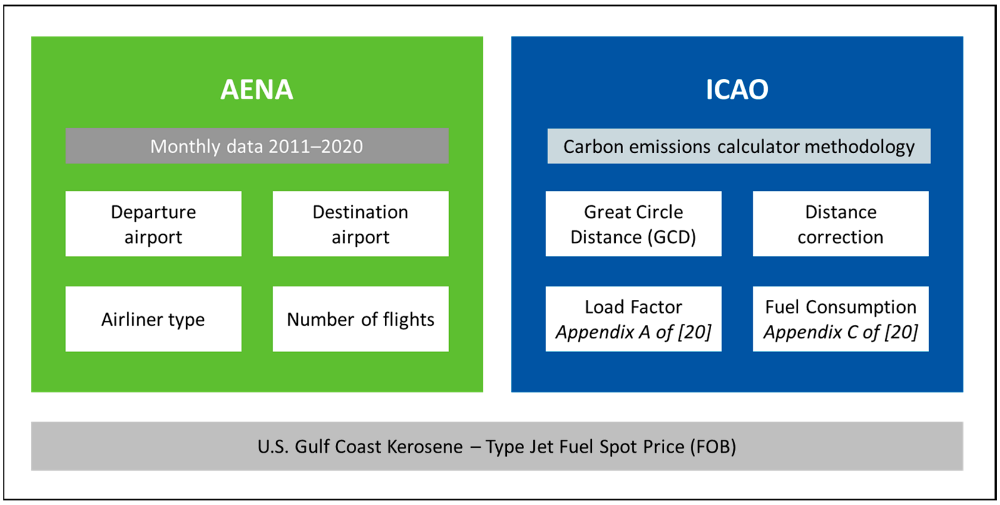


Figure 1. Block diagram for data set collection. Source: own compilation based on research sources according to Appendix A—Load Factors by Route Group from [20] (pp. 12–13), and Appendix C—ICAO Fuel Consumption Table from [20] (pp. 17–23).

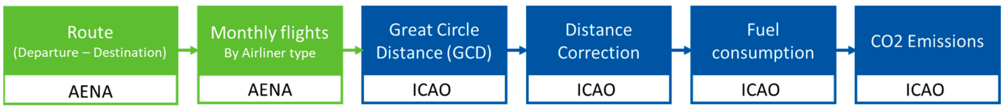


Figure 2. Flow chart research process. Source: own elaboration according to research design.

2.1. Related Considerations in Operating within Airport Network in Spain

Spain has a very dense airport network and an extensive aviation infrastructure. Due to the widespread displacement of the population in certain areas by orography, there are air facilities in almost every Spanish province. Most of them belong to a public business entity, officially named Aena SME, S.A. (hereafter, AENA), specifically 46 airports and 2 heliports. Of these, as shown in Table 1, the five most representative airports according to the number of scheduled passengers boarded by commercial airlines from 2001 to 2020 have been selected for research. Furthermore, as can be seen in Table 2, there are a couple of smaller facilities belonging to other public entities, or even semi-public bodies, at the regional level, which have not been considered in the study due to a slight impact on the research matter. This simplification has no significant influence on the result of the CO_2 emissions from the aviation sector within the Spanish domestic market, since the five airports cover almost the entire domestic network of corridors. In that regard, such consideration is sufficient to support the research approach and hence the validity of their findings, since the routes displayed in Figure 3 represent 62.5% of total aviation-related emissions. Significantly, the following map shows the set of 149 destinations from Table 2 according to 139 routes from Table 3 that have been analyzed when the scheduled passenger transport service occurs in the operative application of domestic flights during the studied ten-year period for each selected airport. Likewise, such a map shows the distribution of those destinations most representative of the study, and specifically whether or not they have a significant impact on the overall emissions. In all of them, the corridor MAD-LPA (hereafter, EC5, as shown in Table 3) makes the greatest impact on the environmental footprint from aviation activity; nine percent to be precise, as explained later in this article.

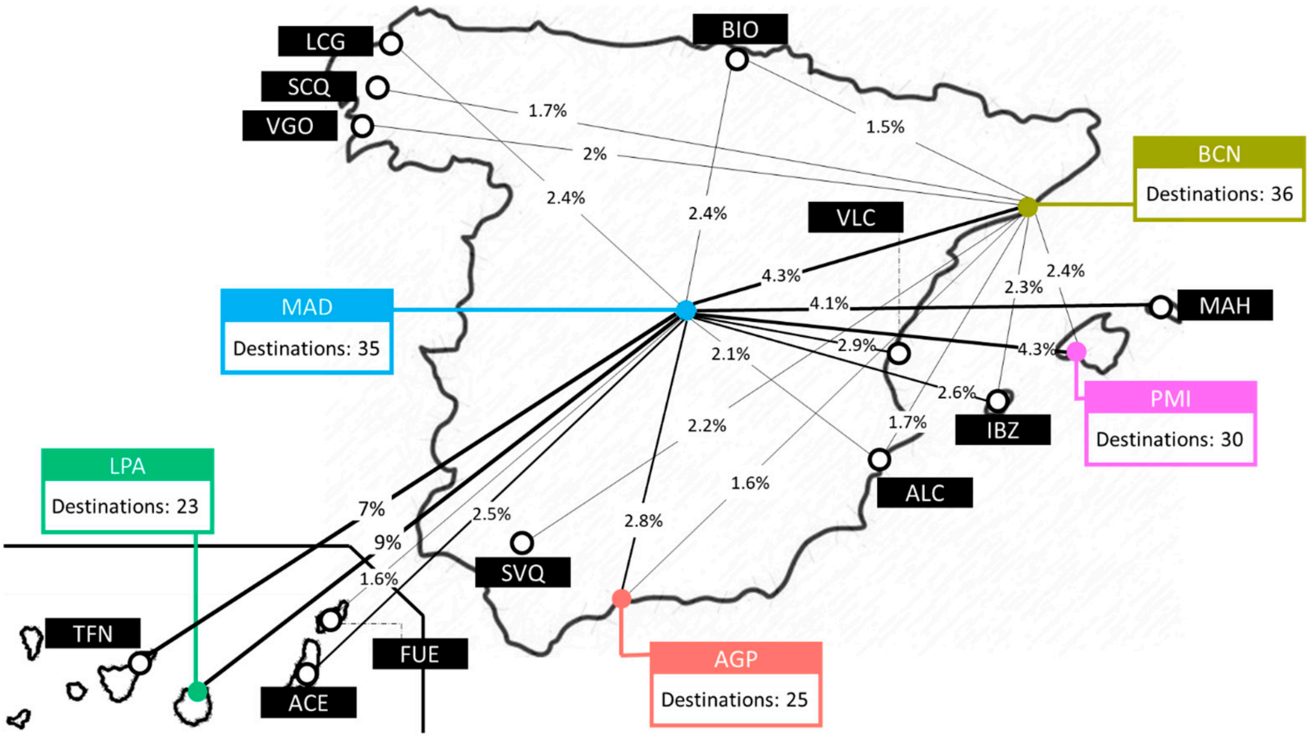


Figure 3. Overview graphic of the routes analyzed in the study whose pollutant emissions have resulted in estimated tons of carbon dioxide equivalent greater than 1.5% with regard to the five airports. Source: own calculations based on data provided from primary sources ([19,20]). Note: the use of color-coded airports, in addition to their IATA designators, has been harmonized throughout the paper, depending on each of them, for a better understanding.

Table 1. Key facts of air passenger traffic at main airports in Spain between 2004 and 2019.

IATA Code	Airport Group [a]	Airport Typology [b]	Airport Category [c]	Average Annual Passenger Traffic [d]	CAGR [e]
MAD	Major	Hub	Level 3	48,414,000	0.7
BCN	Major	Hub	Level 3	36,116,000	1.3
PMI	Major	Touristic	Level 3	23,781,000	0.6
AGP	I	Touristic	Level 3	14,284,000	0.8
LPA	Canary	Touristic	Level 3	10,747,000	0.5

Source: own calculation based on information from Aena database [19]; additional information provided by the Spanish Directorate-General for Civil Aviation (DGAC) upon request. Explanatory notes: [a,b] according to the classification provided by Aena; [c] according to the categorization under Article 3 of [21] and Article 4 of [22], Spanish air facilities have been classified as non-coordinated airports (Level 1), airports with schedules facilitated (Level 2), or coordinated airports (Level 3); [d] total amount, including both arrivals and departures at each airport; [e] Compound Annual Growth Rate (expressed as a decimal figure).

Table 2. Existing civil air facilities in Spain (as of 14 November 2022).

Airport Full Name	IATA Designator	ICAO Designator	Airport Operator	Airport Type	Ownership Type
A Coruña	LCG	LECO	Aena	General Interest	Statewide
Adolfo Suárez Madrid-Barajas	MAD	LEMD	Aena	General Interest	Statewide
Albacete	ABC	LEAB	Aena	General Interest	Statewide
Algeciras †	AEI	LEAG	Aena	General Interest	Statewide
Alicante-Elche Miguel Hernández	ALC	LEAL	Aena	General Interest	Statewide
Almería	LEI	LEAM	Aena	General Interest	Statewide
Andorra–La Seu d'Urgell	LEU	LESU	GenCat	Autonomic Interest	Regional
Asturias	OVD	LEAS	Aena	General Interest	Statewide
Badajoz	BJZ	LEBZ	Aena	General Interest	Statewide
Bilbao	BIO	LEBB	Aena	General Interest	Statewide
Burgos	RGS	LEBG	Aena	General Interest	Statewide
Castellón-Costa Azahar	CDT	LECN	Aerocas	General Interest	Statewide
Aeropuerto de Ciudad Real	CQM	LERL	CRIA	Industrial Interest	Private
Ceuta †	JCU	GECE	Aena	General Interest	Statewide
César Manrique-Lanzarote	ACE	GCRR	Aena	General Interest	Statewide
Córdoba	ODB	LEBA	Aena	General Interest	Statewide
El Hierro	VDE	GCHI	Aena	General Interest	Statewide
Federico García Lorca Granada-Jaén	GRX	LEGR	Aena	General Interest	Statewide
Fuerteventura	FUE	GCFV	Aena	General Interest	Statewide
Girona-Costa Brava	GRO	LEGE	Aena	General Interest	Statewide
Gran Canaria	LPA	GCLP	Aena	General Interest	Statewide
Huesca-Pirineos	HSK	LEHC	Aena	General Interest	Statewide
Ibiza	IBZ	LEIB	Aena	General Interest	Statewide
Internacional Región de Murcia *	RMU	LEMI	Aena	General Interest	Statewide
Jerez	XRY	LEJR	Aena	General Interest	Statewide
Josep Tarradellas Barcelona-El Prat	BCN	LEBL	Aena	General Interest	Statewide
La Gomera	GMZ	GCGM	Aena	General Interest	Statewide
La Palma	SPC	GCLA	Aena	General Interest	Statewide
León	LEN	LELN	Aena	General Interest	Statewide
Lleida-Alguaire	ILD	LEDA	GenCat	Autonomic Interest	Regional
Logroño-Agoncillo	RJL	LERJ	Aena	General Interest	Statewide
Madrid-Cuatro Vientos ‡	-	LECU	Aena	General Interest	Statewide
Melilla	MLN	GEML	Aena	General Interest	Statewide
Menorca	MAH	LEMH	Aena	General Interest	Statewide
Málaga-Costa del Sol	AGP	LEMG	Aena	General Interest	Statewide
Palma de Mallorca	PMI	LEPA	Aena	General Interest	Statewide
Pamplona	PNA	LEPP	Aena	General Interest	Statewide
Reus	REU	LERS	Aena	General Interest	Statewide
Sabadell	QSA	LELL	Aena	General Interest	Statewide
Salamanca	SLM	LESA	Aena	General Interest	Statewide
San Sebastián	EAS	LESO	Aena	General Interest	Statewide
Santiago-Rosalía de Castro	SCQ	LEST	Aena	General Interest	Statewide
Seve Ballesteros-Santander	SDR	LEXJ	Aena	General Interest	Statewide
Sevilla	SVQ	LEZL	Aena	General Interest	Statewide
Son Bonet ‡	-	LESB	Aena	General Interest	Statewide
Tenerife Norte-Ciudad de La Laguna	TFN	GCXO	Aena	General Interest	Statewide
Tenerife Sur	TFS	GCTS	Aena	General Interest	Statewide
Teruel	TEV	LETL	Plata	Industrial Interest	Semipublic
Valencia	VLC	LEVC	Aena	General Interest	Statewide
Valladolid	VLL	LEVD	Aena	General Interest	Statewide
Vigo	VGO	LEVX	Aena	General Interest	Statewide
Vitoria	VIT	LEVT	Aena	General Interest	Statewide
Zaragoza	ZAZ	LEZG	Aena	General Interest	Statewide

Source: own elaboration based on IATA and ICAO airport codes. Explanatory note: A dagger "†" denotes a heliport with scheduled flights, while a double dagger "‡" indicates an airport mainly intended for general aviation. (*) The last civil airport belonging to Aena's network, which replaced the former one, named Murcia-San Javier (IATA: MJV, ICAO: LELC), specifically intended for military use so far.

Table 3. Main domestic routes in the Spanish airport network over the study period (2011–2020).

Departure ↓\Arrival →	MAD	LPA	BCN	AGP	PMI
LCG	EC1	EC2	EC3		EC4
MAD	•	EC5	EC6	EC7	EC8
ABC			EC9		
AEI					
ALC	EC10	EC11	EC12	EC13	EC14
LEI	EC15		EC16	EC17	EC18
LEU					
OVD	EC19	EC20	EC21	EC22	EC23
BJZ	EC24		EC25		
BIO	EC26	EC27	EC28	EC29	EC30
RGS	EC31		EC32		
CDT					
CQM	EC33		EC34		
JCU				EC35	
ACE	EC36	EC37	EC38	EC39	
ODB					
VDE		EC40			
GRX	EC41	EC42	EC43	EC44	EC45
FUE	EC46	EC47	EC48	EC49	
GRO	EC50				EC51
LPA	EC5	•	EC52	EC53	EC54
HSK					
IBZ	EC55		EC56	EC57	EC58
RMU/MJV *	EC59		EC60		
XRY	EC61		EC62	EC63	EC64
BCN	EC6	EC52	•	EC65	EC66
GMZ		EC67			
SPC	EC68	EC69	EC70		
LEN	EC71		EC72	EC73	EC74
ILD					EC75
RJL	EC76				EC77
LECU **					
MLN	EC78	EC79	EC80	EC81	EC82
MAH	EC83		EC84	EC85	EC86
AGP	EC7	EC53	EC65	•	EC87
PMI	EC8	EC54	EC66	EC87	•
PNA	EC88		EC89		EC90
REU			EC91		EC92
QSA					
SLM			EC93		EC94
EAS	EC95		EC96		
SCQ	EC97	EC98	EC99	EC100	EC101
SDR	EC102	EC103	EC104	EC105	EC106
SVQ	EC107	EC108	EC109		EC110
LESB **					
TFN	EC111	EC112	EC113	EC114	EC115
TFS	EC116	EC117	EC118	EC119	EC120
TEV					
VLC	EC121	EC122	EC123	EC124	EC125
VLL			EC126	EC127	EC128
VGO	EC129	EC130	EC131		
VIT	EC132		EC133		EC134
ZAZ	EC135	EC136	EC137	EC138	EC139

Source: own codification based on IATA airport codes. Explanatory note: Black circle "•" denotes an airway whose origin and destination are the same, which applies to non-commercial flights, either for training or calibration purposes, while a blank space indicates "not applicable" according to the analysis carried out on national scheduled air transport services in Spain. (*) For the purpose of the analysis carried out within the research period, both airports have been considered as a unit, since the former one (MJV) remained operating until 15 January 2019, and the new one (RMU) has been active since 16 January 2019. (**) In the absence of the IATA code, the ICAO code is shown.

Of all possible routes identified among the air facilities identified below operating from the key airports selected in the study, only 139 corridors fulfilled the criteria for the review. From the air traffic database provided by the related trusted source [19] with regard to possible routes analyzed, properly listed, and adequately codified from Table 3, according to the criteria previously noted, the research has evolved around traffic ancillary data in order to calculate jet fuel consumption and evaluate emissions.

2.2. Related Considerations in Supplying Domestic Air Routes in Spain

On the basis of the above considerations, as summarized in Table 4, jet fuel consumption and carbon dioxide emissions have been calculated according to the most representative carrier and airliner on each corridor selected in the study.

Table 4. Air routes' standard operational and emission facts over the study period (2011–2020).

Air Route Code	Travel Distance (km) [a]	Travel Time (h)	Initial Heading Vector	Block Fuel (kTon) [b,c]	CO_2 Emissions (kTon) [b,c]	Emissions CO_2/PAX (kg) [b,c]	Most Common Airline [d]	Most Common Airliner [d]	Standard Cabin Config.	Share of Airliner [e]
EC1	506	0:54	126° (SE)	3.5	11.1	97.67	IB	319	Y144	0.31
EC2	1818	2:21	202° (SSW)	8.9	28.2	190.28	IB	320	CY180	0.51
EC3	890	1:19	101° (E)	5.3	16.7	113.35	VY	320	CY180	0.61
EC4	1017	1:28	110° (ESE)	5.0	15.9	107.31	IB	32A	CY180	0.59
EC5	1765	2:12	221° (SW)	10.2	32.1	170.70	FR	73H	Y189	0.26
EC6	484	0:52	77° (ENE)	4.0	12.5	81.04	IB	320	CY180	0.44
EC7	432	0:49	191° (S)	2.4	7.7	77.98	I2	320	CY180	0.46
EC8	548	0:55	99° (E)	3.7	11.7	80.39	FR	73H	Y189	0.52
EC9	425	0:50	51° (NE)	1.7	5.3	127.73	YW	CR2	Y50	1.00
EC10	357	0:44	315° (NW)	2.4	7.6	73.45	IB	320	CY180	0.34
EC11	1794	2:22	234° (SW)	6.1	19.1	234.80	YW	CR9	Y90	0.40
EC12	404	0:47	33° (NNE)	3.5	11.2	76.21	VY	320	CY180	0.63
EC13	392	0:53	244° (WSW)	0.9	2.7	n/a	n/a	CNJ	VIP	1.00
EC14	319	0:41	63° (ENE)	2.3	7.1	66.57	VY	320	CY180	0.33
EC15	418	0:49	346° (NNW)	2.3	7.1	95.72	YW	CRK	CY100	0.38
EC16	626	1:02	36° (NE)	3.8	11.9	92.87	VY	320	CY180	0.41
EC17	191	0:40	265° (W)	0.3	0.8	n/a	n/a	BE2	VIP	0.77
EC18	539	0:58	54° (NE)	2.6	8.2	138.74	YW	CR2	Y50	0.40
EC19	396	0:46	148° (SSE)	3.1	9.8	89.98	V7	319	Y144	0.35
EC20	1927	2:22	209° (SSW)	8.0	25.4	182.16	FR	73H	Y189	0.32
EC21	713	1:07	108° (ESE)	4.6	14.5	98.26	VY	320	CY180	0.66
EC22	776	1:17	170° (S)	4.6	14.4	137.67	V7	717	Y125	0.36
EC23	856	1:17	118° (ESE)	4.4	14.7	110.60	V7	320	CY180	0.29
EC24	331	0:43	56° (ENE)	1.3	4.1	113.77	YW	CR2	Y50	0.64
EC25	804	1:15	68° (ENE)	2.5	7.8	137.39	YW	CR9	Y90	0.40
EC26	468	0:51	190° (S)	2.8	8.8	79.11	IB	319	Y144	0.28
EC27	2041	2:35	217° (SW)	9.7	30.7	208.06	VY	320	CY180	0.39
EC28	468	0:51	117° (ESE)	3.7	11.8	80.06	VY	320	CY180	0.56
EC29	748	1:10	191° (S)	4.7	14.9	101.54	VY	320	CY180	0.60
EC30	629	1:02	130° (SE)	4.2	13.4	92.99	VY	320	CY180	0.39
EC31	488	0:54	179° (S)	1.9	6.0	133.43	YW	CR2	Y50	0.75
EC32	619	1:03	102° (ESE)	2.0	6.3	153.28	YW	CR2	Y50	1.00
EC33	185	0:34	11° (N)	0.5	1.6	n/a	n/a	CNJ	VIP	1.00
EC34	583	0:59	60° (ENE)	4.2	13.4	90.29	n/a	320	CY180	1.00
EC35	113	0:30	40° (NE)	0.1	0.3	n/a	n/a	NDE	VIP	1.00
EC36	1574	2:00	33° (NNE)	8.0	25.2	157.27	FR	73H	Y189	0.55
EC37	208	0:44	238° (WSW)	0.6	1.9	31.80	NT	AT7	Y68	0.56
EC38	1974	2:31	42° (NE)	9.8	31.0	181.56	VY	32B	CY232	0.36
EC39	1208	1:40	42° (NE)	6.6	20.8	140.95	VY	320	CY180	0.43
EC40	247	0:49	86° (E)	0.6	1.9	35.13	YW	AT7	Y68	0.63
EC41	367	0:45	3° (N)	2.5	7.9	91.93	YW	CRK	CY100	0.39
EC42	1495	1:59	230° (SW)	8.4	26.5	147.39	VY	32B	CY232	0.60
EC43	681	1:05	46° (NE)	4.6	14.7	96.17	VY	320	CY180	0.56
EC44	86	0:30	229° (SW)	0.1	0.4	n/a	n/a	BE2	VIP	0.59
EC45	627	1:03	63° (ENE)	3.8	12.1	111.62	YW	E95	C12Y108	0.55
EC46	1634	2:04	32° (NNE)	8.2	25.8	161.34	FR	73H	Y189	0.44
EC47	160	0:39	249° (WSW)	0.5	1.5	25.77	NT	AT7	Y68	0.62
EC48	2032	2:29	41° (NE)	9.6	30.2	189.21	FR	73H	Y189	0.54
EC49	1265	1:44	42° (NE)	6.2	19.7	146.16	VY	320	CY180	0.43
EC50	553	0:55	256° (WSW)	4.1	13.0	83.54	FR	73H	Y189	1.00
EC51	261	0:37	180° (S)	2.5	8.0	53.60	UX	73H	Y189	0.98
EC52	2175	2:44	42° (NE)	10.6	33.5	196.04	VY	32B	CY232	0.33

Table 4. *Cont.*

Air Route Code	Travel Distance (km) [a]	Travel Time (h)	Initial Heading Vector	Block Fuel (kTon) [b,c]	CO_2 Emissions (kTon) [b,c]	Emissions CO_2/PAX (kg) [b,c]	Most Common Airline [d]	Most Common Airliner [d]	Standard Cabin Config.	Share of Airliner [e]
EC53	1409	1:54	44° (NE)	7.2	22.9	157.57	VY	320	CY180	0.48
EC54	2110	2:44	48° (NE)	8.4	26.6	249.65	YW	CRK	CY100	0.28
EC55	460	0:49	295° (WNW)	3.0	9.5	75.55	FR	73H	Y189	0.36
EC56	276	0:38	12° (NNE)	2.6	8.2	58.57	YW	320	CY180	0.41
EC57	572	0:56	246° (WSW)	3.4	10.9	84.30	FR	73H	Y189	0.66
EC58	140	0:30	57° (ENE)	0.7	2.3	42.69	YW	CRK	CY100	0.25
EC59	366	0:46	323° (NW)	1.7	5.3	123.50	YW	CR2	Y50	0.79
EC60	476	1:20	31° (NNE)	0.9	2.9	n/a	n/a	CNJ	VIP	1.00
EC61	469	0:51	27° (NNE)	2.9	9.3	95.05	IB	319	Y144	0.36
EC62	867	1:15	52° (NE)	5.1	16.0	104.02	VY	73H	Y189	0.49
EC63	140	0:36	93° (E)	0.1	0.3	n/a	n/a	PA1	VIP	1.00
EC64	831	1:15	65° (ENE)	5.2	16.6	108.36	VY	320	CY180	0.39
EC65	766	1:11	230° (SW)	4.8	15.0	102.83	VY	320	CY180	0.45
EC66	202	0:33	164° (SSE)	1.9	6.1	43.04	FR	73H	Y189	0.40
EC67	180	0:41	93° (E)	0.6	2.0	51.60	NT	AT7	Y68	0.45
EC68	1847	2:23	41° (NE)	9.3	29.5	192.50	I2/IB	320	CY180	0.66
EC69	245	0:49	108° (ESE)	0.7	2.2	36.28	YW	AT7	Y68	0.60
EC70	2283	2:52	47° (NE)	10.6	33.6	227.04	VY	320	CY180	0.60
EC71	291	0:40	143° (SE)	1.3	4.2	101.43	YW	CR2	Y50	1.00
EC72	657	1:06	100° (E)	2.4	7.6	154.96	YW	CR2	Y50	0.45
EC73	664	1:06	171° (S)	2.0	6.4	156.14	YW	CR2	Y50	1.00
EC74	782	1:15	113° (ESE)	2.2	7.1	169.14	YW	CR2	Y50	0.65
EC75	305	0:41	142° (SE)	1.4	4.4	103.84	YW	CR2	Y50	0.44
EC76	242	0:37	206° (SSW)	1.1	3.6	87.00	YW	CR2	Y50	1.00
EC77	534	0:57	126° (SE)	2.0	6.4	156.52	YW	CR2	Y50	1.00
EC78	581	1:28	335° (N)	1.2	3.9	70.57	YW	AT7	Y68	0.97
EC79	1432	3:09	239° (WSW)	2.5	7.9	140.98	YW	AT7	Y68	1.00
EC80	800	1:54	319° (NW)	1.5	4.9	87.24	YW	AT7	Y68	1.00
EC81	208	0:45	138° (SE)	0.6	1.7	31.80	YW	AT7	Y68	0.82
EC82	692	1:41	45° (NE)	0.6	1.8	31.80	YW	AT7	Y68	1.00
EC83	667	1:39	279° (W)	3.5	10.9	117.65	YW	CRK	CY100	0.32
EC84	241	0:48	312° (NW)	2.1	6.7	52.41	VY	320	CY180	0.50
EC85	840	1:59	248° (WSW)	5.1	16.2	109.31	VY	320	CY180	1.00
EC86	132	0:35	255° (WSW)	0.7	2.1	42.72	YW	CR9	Y90	0.28
EC87	710	1:05	61° (ENE)	4.5	14.2	91.91	UX	73H	Y189	0.41
EC88	299	0:40	213° (SSW)	1.8	5.6	78.74	YW	CRK	CY100	0.44
EC89	349	0:44	117° (ESE)	1.7	5.3	118.58	YW	CR2	Y50	0.79
EC90	513	0:56	133° (SE)	1.4	4.5	80.83	YW	AT7	Y68	1.00
EC91	78	0:25	77° (ENE)	0.7	2.2	22.70	n/a	320	CY180	0.78
EC92	222	0:34	143° (SE)	2.3	7.2	46.38	FR	73H	Y189	0.97
EC93	638	1:05	84° (E)	2.0	6.2	153.58	YW	CR2	Y50	0.98
EC94	718	1:10	100° (E)	1.7	5.5	161.71	YW	CR2	Y50	1.00
EC95	350	1:01	205° (SSW)	1.1	3.6	50.13	YW	AT7	Y68	0.55
EC96	392	0:46	124° (SE)	2.6	8.4	89.48	VY	319	Y144	0.77
EC97	484	0:52	122° (ESE)	3.7	11.6	81.04	IB	320	CY180	0.44
EC98	1775	2:13	203° (SSW)	7.9	24.9	171.54	FR	73H	Y189	0.86
EC99	885	1:16	98° (E)	5.2	16.5	105.33	FR	73H	Y189	0.42
EC100	768	1:09	153° (SSE)	4.8	15.1	96.49	FR	73H	Y189	0.54
EC101	1005	1:24	108° (ESE)	5.3	16.8	114.58	FR	73H	Y189	0.47
EC102	327	0:43	176° (S)	2.0	6.4	112.26	YW	CR2	Y50	0.28
EC103	2008	2:27	215° (SW)	9.0	28.3	187.93	FR	73H	Y189	0.97
EC104	540	0:54	114° (ESE)	3.5	11.1	79.95	FR	73H	Y189	0.51
EC105	752	1:08	185° (S)	4.6	14.7	95.39	FR	73H	Y189	1.00
EC106	696	1:04	126° (SE)	4.3	13.7	91.14	FR	73H	Y189	0.71
EC107	396	0:46	30° (NNE)	2.8	8.9	75.72	I2	320	CY180	0.62
EC108	1377	1:51	223° (SW)	7.1	22.6	154.92	I2	320	CY180	0.42
EC109	810	1:14	55° (NE)	5.0	15.7	106.55	I2	320	CY180	0.48
EC110	789	1:10	70° (ENE)	4.9	15.4	97.96	FR	73H	Y189	0.53
EC111	1771	2:12	38° (NE)	10.5	33.2	171.06	UX	73H	Y189	0.27
EC112	112	0:33	123° (ESE)	0.5	1.5	19.61	NT	AT7	Y68	0.45
EC113	2195	2:39	45° (NE)	10.5	33.1	200.74	FR	73H	Y189	0.40
EC114	1434	1:51	48° (NE)	7.4	23.3	147.14	UX	73H	Y189	0.44
EC115	2140	2:46	50° (NE)	7.0	22.0	252.24	YW	CRK	CY100	0.67
EC116	1824	2:16	37° (NE)	8.9	28.3	174.78	FR	73H	Y189	0.39
EC117	117	0:34	96° (E)	0.5	1.5	20.22	NT	AT7	Y68	0.28

Table 4. *Cont.*

Air Route Code	Travel Distance (km) [a]	Travel Time (h)	Initial Heading Vector	Block Fuel (kTon) [b,c]	CO_2 Emissions (kTon) [b,c]	Emissions CO_2/PAX (kg) [b,c]	Most Common Airline [d]	Most Common Airliner [d]	Standard Cabin Config.	Share of Airliner [e]
EC118	2246	2:42	44° (NE)	10.0	31.6	204.26	FR	73H	Y189	0.62
EC119	1483	1:54	47° (NE)	7.3	23.0	150.69	FR	73H	Y189	0.71
EC120	2189	2:45	49° (NE)	10.5	33.1	223.69	VY	320	CY180	1.00
EC121	286	0:40	294° (WNW)	1.5	4.8	75.57	YW	CRK	CY100	0.37
EC122	1880	2:19	231° (SW)	7.4	23.3	178.80	FR	73H	Y189	0.59
EC123	296	0:41	46° (NE)	3.2	10.1	n/a	n/a	763	C18Y246	0.25
EC124	471	0:50	230° (SW)	1.8	5.6	76.26	FR	73H	Y189	0.33
EC125	277	0:38	88° (E)	2.0	6.4	56.06	FR	73H	Y189	0.28
EC126	580	0:57	92° (E)	3.5	10.9	84.74	FR	73H	Y189	0.60
EC127	559	0:55	177° (S)	4.1	13.0	83.82	FR	73H	Y189	1.00
EC128	685	1:03	108° (ESE)	2.9	9.3	83.82	FR	73H	Y189	0.66
EC129	465	0:52	113° (ESE)	3.3	10.4	96.00	UX	E95	C12Y108	0.37
EC130	1701	2:16	203° (SSW)	5.6	17.5	213.49	YW	CRK	CY100	0.51
EC131	896	1:19	93° (E)	5.3	16.8	113.79	VY	320	CY180	0.53
EC132	274	0:37	195° (SSW)	2.9	9.0	n/a	n/a	752	Y216	0.40
EC133	435	0:48	112° (ESE)	3.2	10.1	n/a	n/a	73Y	FREIGHT	0.39
EC134	589	0:57	127° (SE)	4.5	14.3	91.82	UX	73H	Y189	1.00
EC135	249	0:41	239° (WSW)	0.6	2.0	n/a	n/a	CNJ	VIP	1.00
EC136	2005	2:27	225° (SW)	9.2	29.2	187.58	UX	73H	Y189	1.00
EC137	264	0:37	98° (E)	2.4	7.6	n/a	n/a	734	Y150	0.63
EC138	629	1:00	209° (SSW)	3.3	10.3	87.78	UX	73H	Y189	0.80
EC139	397	0:47	125° (SE)	3.0	9.6	90.90	UX	E95	C12Y108	0.46

Source: own calculation based on information provided by ICAO [20]. Explanatory note: [a] an orthodromic distance on cruise flight; [b] standard assumptions: Jet A1 density as of 0.804 kg/L, CO_2 emissions as of 3.16 kg of CO_2 per kg of Jet A1; [c] on route assumptions: maximum payload, no wind, one aircraft per leg under technical specifications by International Standard Atmosphere (ISA), Joint Aviation Requirements (JAR), EU Aviation Safety Agency (EASA), passengers (PAX); [d] IATA designator; [e] Emissions share per aircraft of each route regarding total routes thereof (expressed as a decimal figure). Not applicable (n/a) when scheduled flights (i.e., general aviation) have not been identified through analysis based on related air traffic data.

3. Results

As pointed out previously, the research analysis has been focused on the empirical evaluation of partial greenhouse gas emissions from the aviation sector in Spain by estimating fuel consumption due to commercial domestic corridors for scheduled passenger air transport services according to the distribution from Table 5. Therefore, significant analysis work has been carried out to evaluate carbon dioxide emissions from commercial aviation activities on major national routes. To that end, after gathering information sourced from the trusted database [19], primary screening of data records was made by identifying relevant passenger flights within the Spanish domestic market, thereby rejecting air services likely operated by charter carriers, as well as those with little significance when compared with the total number of 25,000 flights covered by the preliminary analysis. For instance, those origin-destination-aircraft combinations below 10 flights in the 10-year period studied were removed from the analysis. This has thus made it possible to simplify the subsequent calculation up to 2500 flights. Then, based on the five major airports introduced earlier and the corresponding 139 routes finally identified for the study, the following considerations have been considered throughout the 10-year analysis period. Firstly, the Passenger Load Factor (PLF) is estimated at 82.3% [20] (p. 12). Secondly, as shown in Table 6, the label 'Distance Segment' is designed to break down the total of 'corridors', and any subtotals, in an attempt to identify the existing different distance segments to said emissions relating to the research matter. While aviation routes are typically categorized by flight time, short-haul flights (0–3 h in duration), medium-haul flights (3–6 h in duration), and long-haul flights (6–12 h in duration), the research has identified three types of segments for classifying the corridors from Table 4, as ranked in Table 6. Thirdly, most representative airplanes (see Appendix A Table A1) have been identified from the corridors previously selected for the emissions analysis. Similarly, as the fourth point, most representative airlines (see Appendix A Table A2) have been identified for the study. Fifthly, similar to above, most representative engine families have been cleared for the study (see Appendix A Table A3). Sixthly, and finally, only narrow-body airplanes have been considered for the analysis of 139 routes, since only intra-country passenger transport services, without distinction for engine families, have been analyzed.

Table 5. Air corridor distribution on the travel distance [1].

Distance Segment (km)	Percentage (%)	Emission Share (%)	Average (km)
Short Route: $d \leq 500$	67.31	39.36	296
Medium Route: $501 \leq d \leq 1000$	19.96	24.57	680
Long Route: $d \geq 1001$	12.73	36.07	1799
Average Distance Traveled (km)			564

Source: own calculation in connection with the 2500 routes previously defined for the study. [1] Considered as orthodromic distance on cruise flight.

Table 6. Air corridor distribution on route type [1].

Route Type	Number of Routes	Percentage
Short	58	41.73%
Medium	47	33.81%
Long	34	24.46%

Source: own calculation in connection with the 139 routes previously defined for the study. [1] According to the classification provided in Table 5.

In addition to the aforementioned considerations, the emissions estimation has been subjected to calculation methodology provided by ICAO [20] that is affected by flight-specific variables, which in turn change continuously. According to such guidelines, it has been necessary to develop average factors to consider the effect of various flight parameters. While the factors cannot be captured on a specific flight basis, the methodology considers them to develop a more robust estimation of flight emissions.

Each aircraft has been mapped with one of the 312 equivalent airplane types to calculate fuel consumption per trip based on the driving distance between the airports involved in the routes selected. Based on the traffic and operational data collected by ICAO over several past years, this methodology has been applied according to both PLF and the corresponding weight ratio of freight and passengers, better known as a pax-to-freight factor (PFF), for estimating the total fuel (TF) burned for the passengers carried on each route selected. Then, the average fuel consumption for the journey, weighted by the departure frequency of each equivalent aircraft type, was calculated by dividing the total number of equivalent economy class passengers (Y-seats). This calculates, therefore, an average fuel consumption per such class passenger. Lastly, the result must be multiplied by 3.16 to obtain the carbon dioxide footprint attributed to passengers on each route selected.

Hence, the equation for calculating the CO_2 emissions per passenger (E_p):

$$E_p = 3.16 * (TF * PFF)/(\text{Y-seats} * PLF), \quad (1)$$

where variables are as follows according to ICAO [20] (p. 6):

- TF = Weighted average fuel consumed on all flights between the departure airport and arrival airport. The weighting factor is thus the ratio between the number of departures for each equivalent aircraft type and the total number of departures;
- PPF = Ratio calculated from the ICAO statistical database based on the number of passengers and the tonnage of mail and cargo transported on particular routes;
- Y-seats = Total number of economy class equivalent seats available on all flights serving the given pair of airports;
- PLF = Ratio calculated from the ICAO statistical database based on the number of passengers transported and the number of seats available on particular routes;

- 3.16 = Constant representing the number of tons of CO_2 produced by burning one ton of aviation fuel.

3.1. Technical and Operational Issues

In addition to the equation above (1), the estimation of carbon dioxide emissions in serving the routes concerned for the analysis period had to consider elements relating to aircraft performance and operating limitations, even though this problem is sometimes exacerbated by a lack of open access databases with full flight records. Looking at air operation when airplanes fly between two points, the pathway used is the distance runs on the great-circle distance (GCD). However, due to temporary limitations of air traffic flow management on certain air routes, as well as temporal and spatial variation of air space and possible restrictions (e.g., night flying restrictions), the performance of both airports and aircraft involved in operating every one of the flights on routes selected for the research could have been deviated from the optimal route to fly, better known as 'business trajectory', which is indeed a function of the required time of arrival at the airport. Delayed flights, mainly due to air traffic jams, increase the time of flight and fuel consumption. Airport congestion during the approach to landing is a further cause of leaving airplanes in a holding pattern, which can even result in a total diversion, resulting in significant unnecessary emissions. To confront these uncertainties of calculating emissions, specific considerations relating to technique as well as operation on the 139 routes have been adopted. At the technical level, based on the most common aircraft per route, differentiating between turboprop and turbojet, emissions have been calculated considering the standard engines of each representative aircraft, as expressed in ICAO [20] (p. 9). Regarding operational aspects, the travel distance of each route has been considered without take-off and the landing cycle, while a GCD correction factor (+50 km, +100 km, +125 km) has been made according to guidelines provided by ICAO [20] (pp. 7–8). As shown below, results vary based on the specific airplane model and seasonal pattern, including thus, if relevant, the impact of both technical and operational factors in the emissions calculated.

3.1.1. Aircraft Performance

In line with each representative aircraft, Figure 4 is a graphical view of performances on all the routes selected, showing how they relate to various distance trips identified.

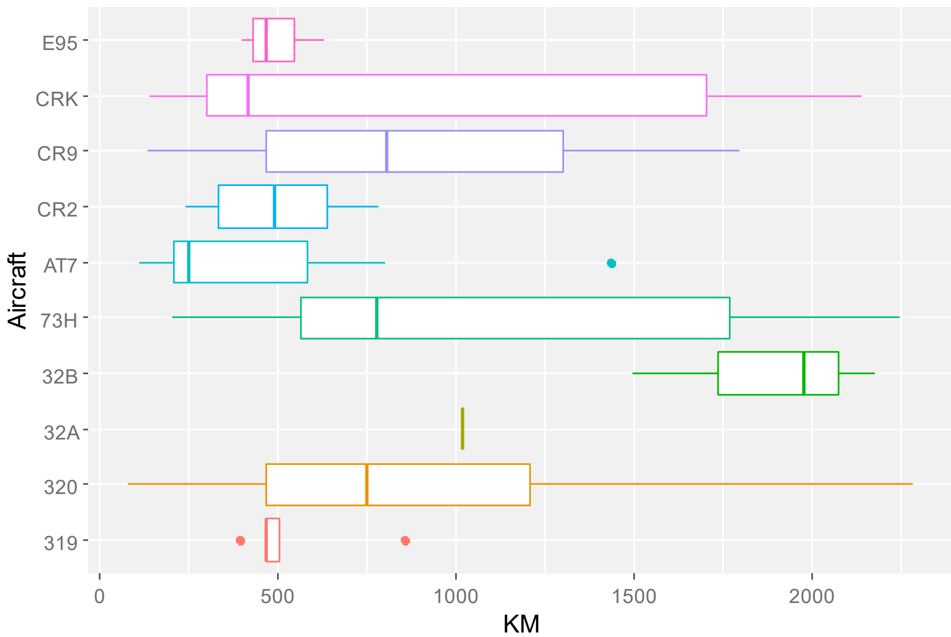


Figure 4. Overall fleet performance. Source: own elaboration from data published by [19].

3.1.2. Airport Performance

As shown in Figure 5, an analysis of the scheduled seasons of air transport services operating in the five airports has been provided to identify the seasonal trends of regular flights performed on 139 domestic routes, thus calculating their respective emissions.

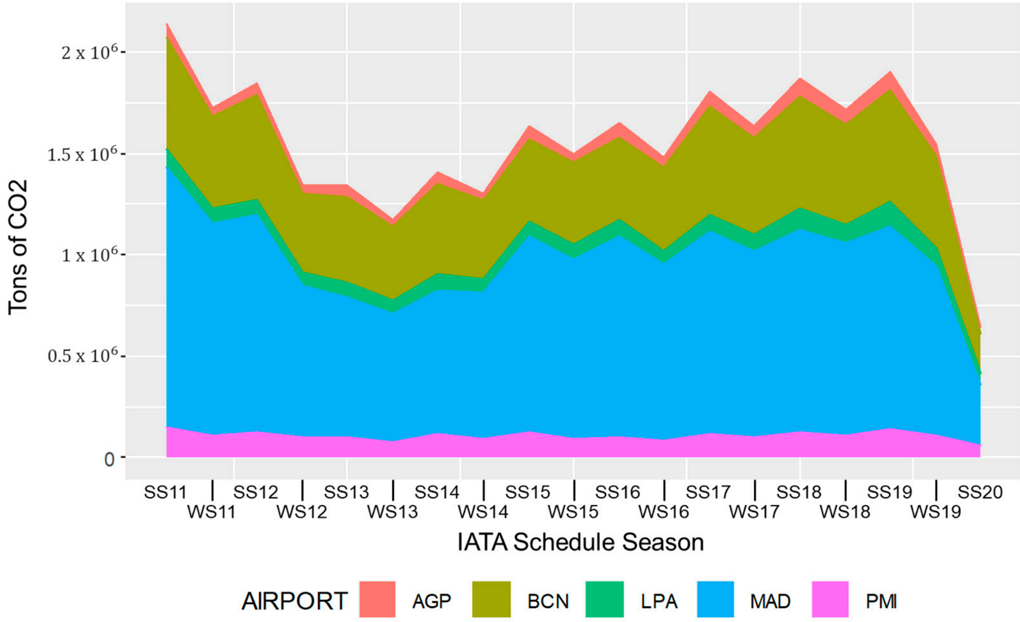


Figure 5. Cumulative carbon dioxide emissions in tons (T) of carbon dioxide equivalent associated with scheduled seasons between 2001 and 2020. Source: own calculation based on data published by [19] according to guidelines provided by [20]. Note: although the IATA Summer schedule begins on the last Sunday of March and ends on the last Saturday of October, and the IATA Winter schedule begins on the last Sunday of October and ends on the last Saturday of March, the calculation has been made by considering the same semester period in every year for simplification purposes.

3.2. Emissions Analysis Disaggregated by Airport Concerned

In order to analyze carbon dioxide emissions over the years under the set of 139 routes operating in the airport network identified as representative of the domestic market in Spain, collected flight data has been compiled to explain its monthly evolution, as summarized in Figure 6. These indicate emissions have been estimated on the basis of charging the quantity of fuel consumed monthly per route to the departure airport instead of the destination airport, as with the results shown in Figure 5. In other words, where emissions are associated with a certain corridor whose flights have been operating between two airports (e.g., A and B), the calculation is obliged to count each flight up to two legs, that is, from A to B, and then B to A. However, in this example, to simplify the approach for calculating emissions, the estimation is allocated to airport A. Under this scenario, as can be seen in Figure 6, aside from the effect of travel restrictions due to Coronavirus disease 2019 (hereafter, COVID-19) on mobility, and hence on aviation activity, there is apparently a pronounced relationship between what national demand dropped and what supply has shrunk (see, for example, the period 2013–2014).

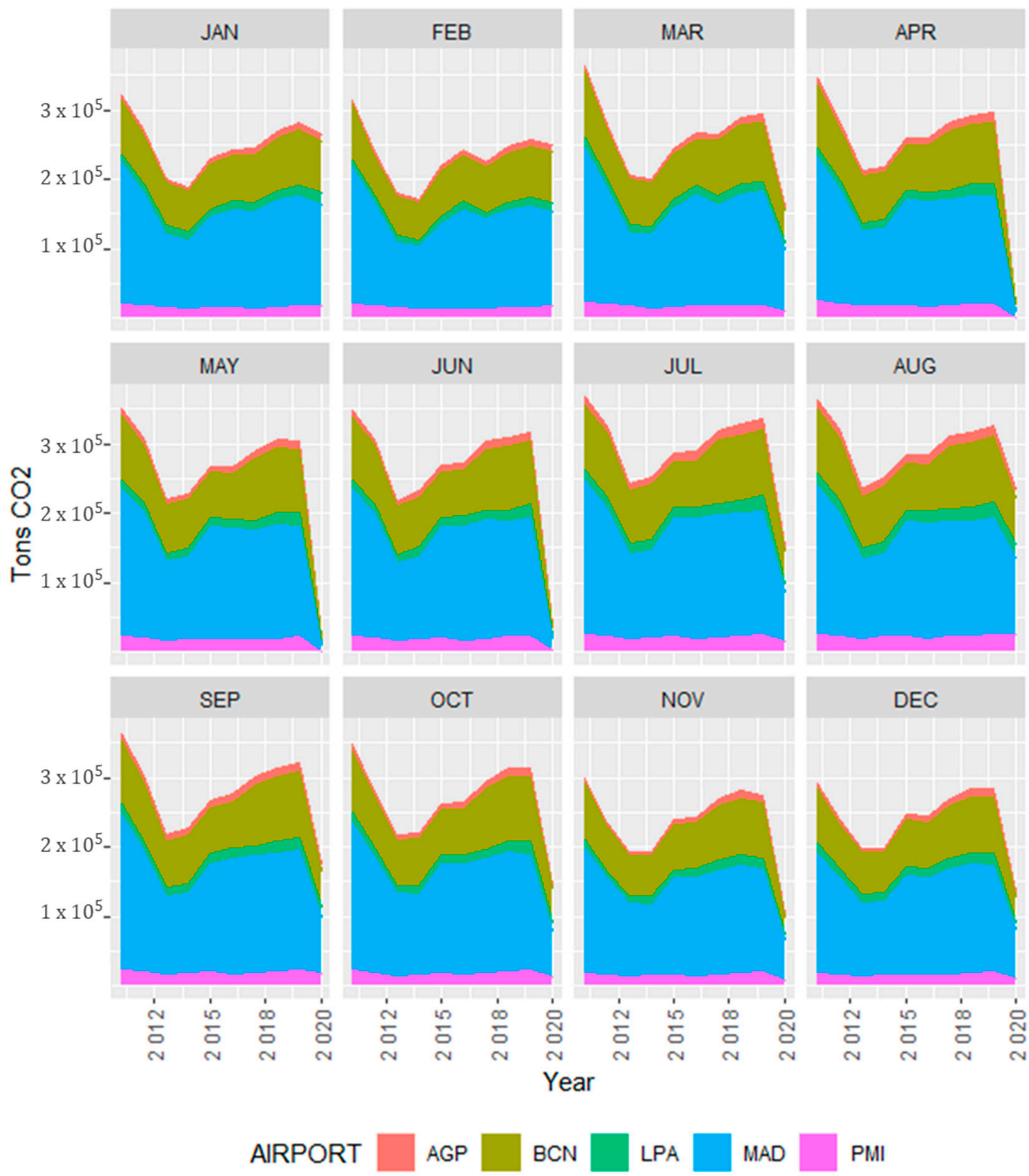
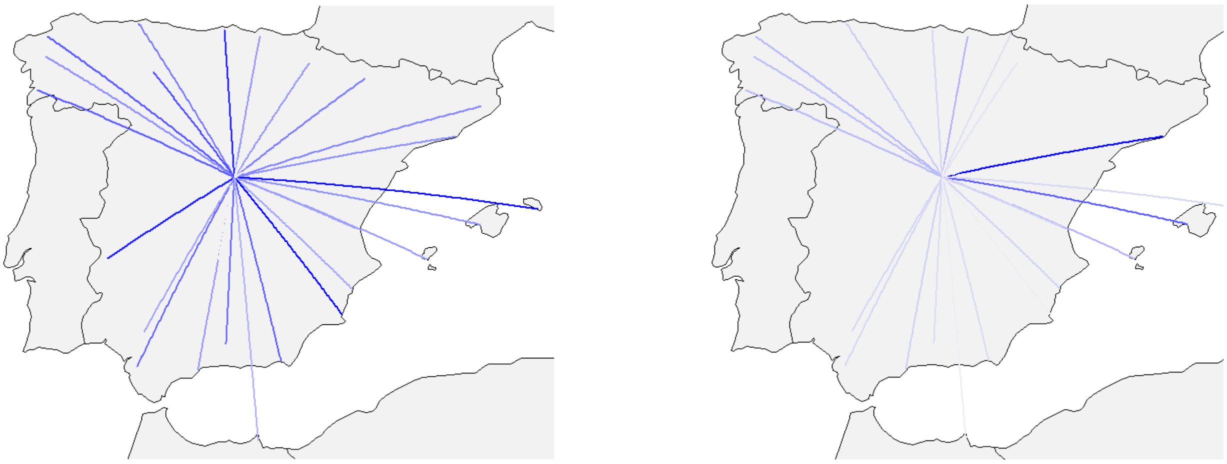


Figure 6. Monthly carbon dioxide emissions (disaggregated by each airport) between 2001 and 2020. Source: own calculation based on data published by [19] according to guidelines provided by [20].

3.2.1. Related Aspects Concerning Domestic Routes Operating in the MAD Airport

As noted earlier in Table 1, the Adolfo Suárez Madrid-Barajas airport (IATA: MAD, ICAO: LEMD) concentrates most of the regular flights in the Spanish domestic market. As can be seen in Figure 7a, there are some routes, such as EC83, EC102, and EC24, with very high fuel consumption per passenger, and thus a larger impact on specific emissions. Where total consumption is concerned, though, these routes will have scarcely any effect in terms of emissions from flights operated at such an airport. Indeed, as shown in Figure 7b, only two routes, EC6 and EC8, are significant to the total emissions chargeable to the airport in the specified analysis period. Besides no long-distance segment of both routes (484 and 548 km, respectively), two main factors have a direct impact on emission levels thereof. Both aspects are not connected, but they are weakening the capabilities for reducing emissions per passenger from domestic flights, in comparison with other related corridors, even shorter routes (e.g., EC24). On one hand, the intensive use of turbojets instead of turboprops on paths up to 550 km range, such as EC6 and EC8, and on the other hand, the overall capacity in terms of supplied seats has been especially intense on both routes because they have had a robust demand over the last 10 years analyzed, even after taking account of unfavorable seasonality. Specifically, the EC6 is the legendary air shuttle in Spain, which has been habitually operated by Iberia (IATA: IB, ICAO: IBE), whose offer of flights is primarily targeted at frequent travelers, and mainly for business reasons. Furthermore, other airlines have been operating on the route, such as Vueling (IATA: VY, ICAO: VLG) and Air Europa (IATA: UX, ICAO: AEA). All of them are usually operated using single-aisle jets, either Airbus A320 family or Boeing B737-800 series, which have recently been upgraded by retrofitting scimitar winglets on existing aircraft to cut fuel, or even renewed with A320neo family and B737 MAX series, respectively, and offer enhanced performance in terms of fuel consumption thanks to the improved design of both engines and aerodynamic shapes. Additionally, it should be noted that, within the potential market in Spain of domestic corridors, there are about 30 million passengers in the internal market of air transport services, of which about 2.5 million are concentrated on the EC6, according to the figures of 2019, i.e., over 200,000 passengers carried on such a route monthly before people went into the lockdown in March 2020 because of the COVID-19 outbreak. That and, above all, the importance of this corridor in the overall aviation emissions of domestic flights in Spain is shown.

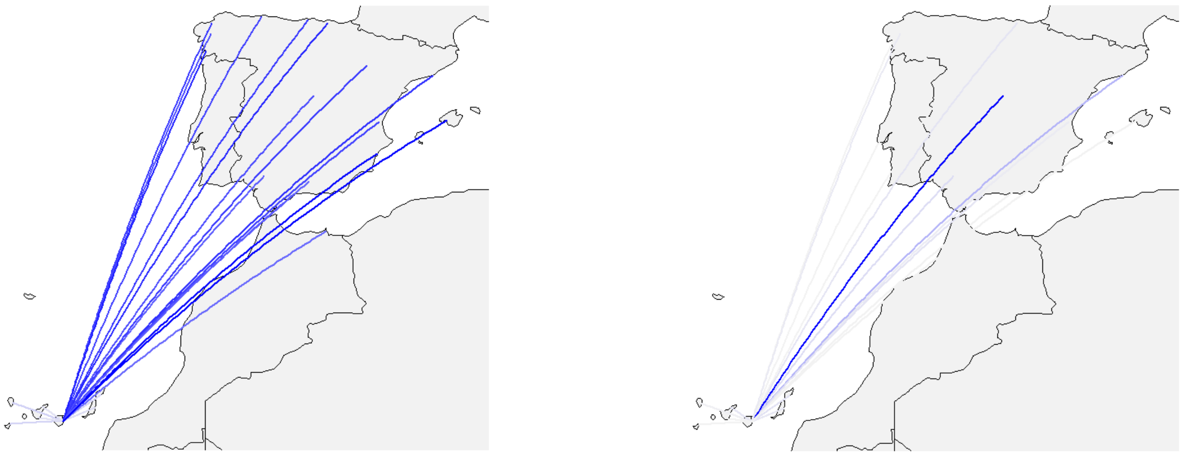


(**a**) (**b**)

Figure 7. Carbon dioxide emissions from main domestic corridors operating in MAD airport, where a rough sketch means more emissions than the thinner one as follows: (**a**) Partial emission per passenger and per route (arithmetic average: 72.58, standard deviation: 13.76); (**b**) Total emission of routes concerned. Source: own elaboration from the data provided by [19,20].

3.2.2. Related Aspects Concerning Domestic Routes Operating in the LPA Airport

The Gran Canaria Airport (IATA: LPA, ICAO: GCLP), as can be seen in Table 1, has habitually held the fifth position in terms of passengers carried within the Spanish domestic market of regular air transport services. Moreover, the airport has a two-fold role: on the one hand, the major destination for flights from the Spanish mainland are always operated with turbojets, either narrow-body or wide-body aircraft; and on the other hand, this airport is headquarters to the main regional airline operating in the Canary Islands, named Binter Canarias (IATA: NT, ICAO: IBB), whose fleet has traditionally been comprised of short-haul regional airliners, mainly turbofans, such as the ATR 72 (IATA: AT7, ICAO: AT72), and more recently of medium-range jet airliners, the newest Embraer E2 (IATA: 295, ICAO: E295). Furthermore, both aircraft types have been designed with tight specifications that are tuned for reduced emissions per passenger carried, even with low levels of PLF. As a result, while the related flights into the Spanish mainland present a high carbon dioxide emission level, inter-island flights in such Spanish archipelago have proved to be the lowest level of the whole study in the specific years examined. Further to be noted is the seasonal character of the demand for air services such as from the main airport of the Canary Islands to mainland Spain, whereas the related inter-island air traffic market in the period being analyzed has become more stable than the supply of flights out of the archipelago, partly owing to generated extra demand for regional routes from subsidizing air transport and Public Service Obligation (PSO) implementation [23]. Moreover, six of the 23 routes so far imposed in Spain as essential transportation services under such EU schema have been linked to LPA, and two of them have been often operating as a type 3 PSO, that is, a closed route with both exclusivity and compensation [24]. Nevertheless, the existence of affordable regular flights from the Canary Islands, belonging to the EU's outermost regions group, helps to ensure the mobility of their inhabitants. Indeed, the specific matter resulting from such a geographical situation must not be misunderstood. As noted in the pooled results shown below, respectively Figure 8a,b, the highest emissions per passenger carried appear in those corridors to mainland destinations, and concerning absolute values for all of the corridors selected, the EC5 has been intensively operated by twin-engine turbojets, some of them even wide-body, such as the A330 family (IATA: 330, ICAO: A330) due to a greater haul capacity for cargo and mail.

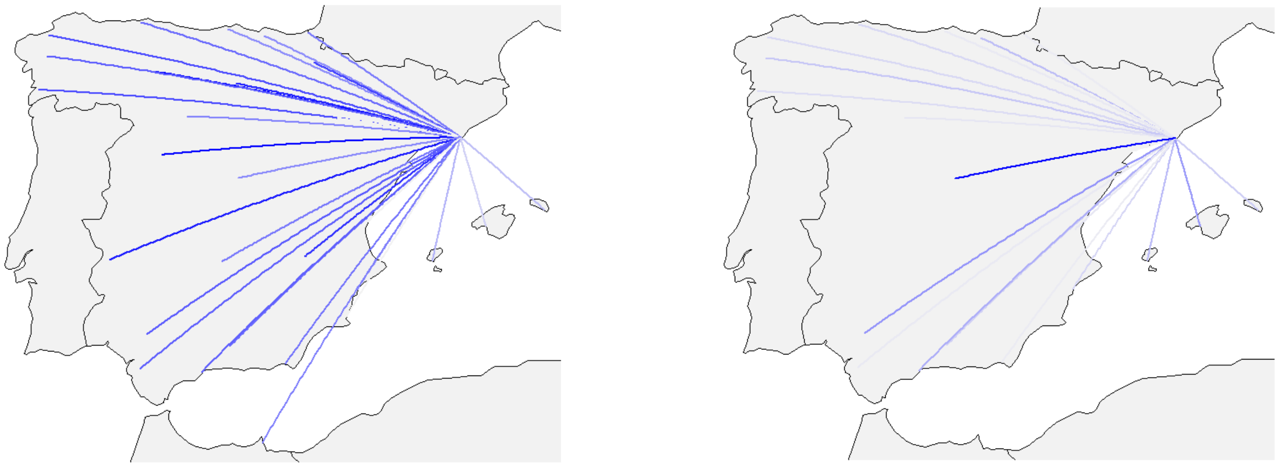


(**a**) (**b**)

Figure 8. Carbon dioxide emissions from main domestic corridors operating in LPA airport, where a rough sketch means more emissions than the thinner one as follows: (**a**) Partial emission per passenger and route (arithmetic average: 112.43, standard deviation: 65.99); (**b**) Total emission of routes concerned. Source: own elaboration from the data provided by [19,20].

3.2.3. Related Aspects Concerning Domestic Routes Operating in the BCN Airport

As can be seen from Table 1 above, the Josep Tarradellas Barcelona-El Prat Airport (IATA: BCN, ICAO: LEBL) is the second facility belonging to Aena's network in terms of passenger traffic and aircraft operations. The analysis of domestic flights operated from BCN over the period under study has been summarized in Figure 9. As with the case of MAD, it shows that related routes linking to BCN have had a high impact on the total aviation emissions of the Spanish aviation market, despite comparatively little supply in comparison with the total operations, the majority of which were medium-haul flights to travel destinations in other European countries, and in a few cases, even long-haul flights over the Atlantic Ocean. Interestingly, though being operated at almost full load on national corridors, some of them with a trip distance up to 500 km, carriers still mostly operated turbojets, possibly indicating the limited availability of regional turboprop airliners based especially to such an airport, even because of the absence of eco-friendly planes for regional routes in related airlines' fleets. For instance, scheduling on short routes, such as EC9, EC12, EC16, and EC25, an AT7 can be used instead of operating small turbojets, such as CJR200 (IATA: CR2, ICAO: CRJ2) and CRJ900 (IATA: CR9, ICAO: CRJ9), which can lead to a reduction of up to 50% less carbon dioxide emissions in similar circumstances [15]. In contrast, regional turbofans in scheduled air carriers are very scarce in Spain and limited to a few airlines. In the absence of any aircraft model of Bombardier Q Series, for example, the DHC-8-400 (IATA: DH4, ICAO: DH8D), the turboprops existing in Spain for commercial purposes belong to the ATR aircraft family, and the vast majority of them are AT7s, habitually operated by Air Nostrum (IATA: YW, ICAO: ANE) in addition to those operated on the Canary Islands' market mainly by NT, and to a much lesser extent, by Canaryfly (IATA: PM, ICAO: CNF). Nonetheless, in the case at hand, because of increased requirements of payload, a small aircraft operated on short-haul routes has sometimes been replaced by a large aircraft. It is also worth noting the fact of considering fleet availability as a key factor for airlines when scheduling their offer of flights. In such a context, Figure 9a shows a similar impact of specific emissions on each route selected, while Figure 9b highlights significant emissions on domestic routes with high demand, particularly those linking to three major cities in Spain, such as EC6, EC65, and EC109.

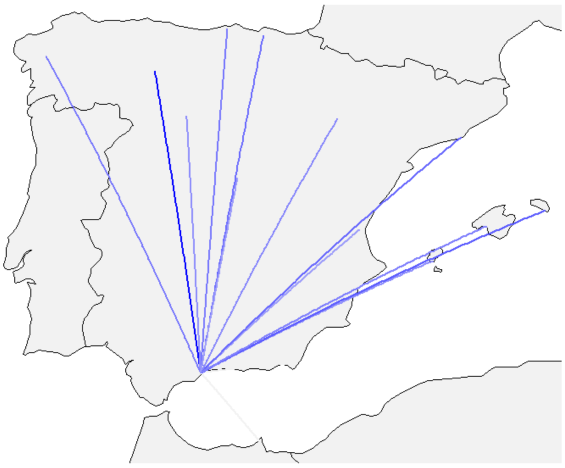


(**a**) (**b**)

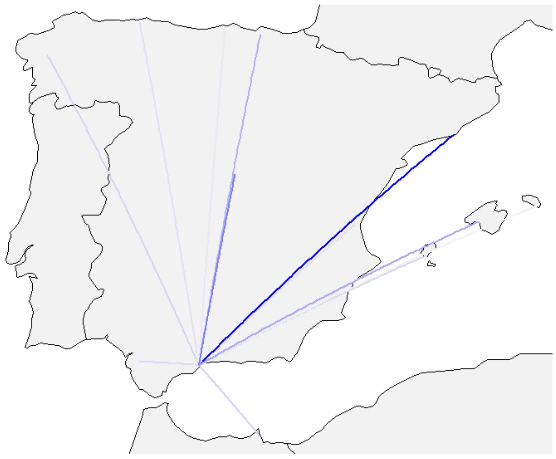
Figure 9. Carbon dioxide emissions from main domestic corridors operating in BCN airport, where a rough sketch means more emissions than the thinner one as follows: (**a**) Partial emission per passenger and route (arithmetic average: 79.39, standard deviation: 25.64); (**b**) Total emission of routes concerned. Source: own elaboration from the data provided by [19,20].

3.2.4. Related Aspects Concerning Domestic Routes Operating in the AGP Airport

The Málaga-Costa del Sol airport (IATA: AGP, ICAO: LEMG), as noted in Table 1, is the most important air transport infrastructure situated in Southern Spain, linking to several destinations (mostly European) whose flights have habitually been scheduled by low-cost carriers instead of legacy airlines, that has an enormous presence of international travelers. The airport has witnessed a substantial year-on-year increase in demand as a direct result of recent facility expansion through both terminal building and runway, contributing towards the 6% and 18% increase in traffic according to the growth rate estimation, respectively [25]. The significant improvement of such infrastructure has led to a remarkable increase in airport capacity, not just in terms of passengers, but also in terms of freight carried. Regarding related domestic routes, as can be seen in Figure 10, involves identifying what impacts the overall emissions have and how to explain them. In that sense, Figure 10a shows significant specific emissions per passenger on some air corridors into Northern Spain and Central Spain, such as EC22, EC29, EC73, and EC105. By contrast, despite the EC07 playing the role of a feeder route for both the UX and IB hubs in MAD, the route does not have significant specific emissions since carriers have been flying some of their various regional aircraft just 432 km to MAD for shuttle services according to demand, in particular by using aircraft with extremely low engine emissions figures, such as AT7 and Embraer E195LR (IATA: E95, ICAO: E195). It should also be noted that unit emissions for EC85 lead to a high rate in comparison with the rest of the routes selected in the study. At the same time, the calculated emissions for EC65, in absolute terms, have been revealed to be of critical importance within the overall estimation of emissions with regard to those domestic flights departing from AGP, as shown in Figure 10b. Commercial airlines operating such a corridor have not only operated twinjets, but also all flights under consideration were scheduled by six-abreast cabins belonging both to VY and Ryanair (IATA: FR, ICAO: RYR). In fact, these carriers today operate solely narrow-body aircraft on short-haul routes within Europe (and therefore includes domestic routes in Spain), specifically the Airbus A320 family in VY and Boeing B737-800 series in FR. Interestingly, this was not the case for EC81, since related flights have always been operated with turboprops, mostly AT7, due to the existing approach and landing procedures in Melilla (IATA: MLN, ICAO: GEML). That also made them remarkable for low emissions.



(**a**)

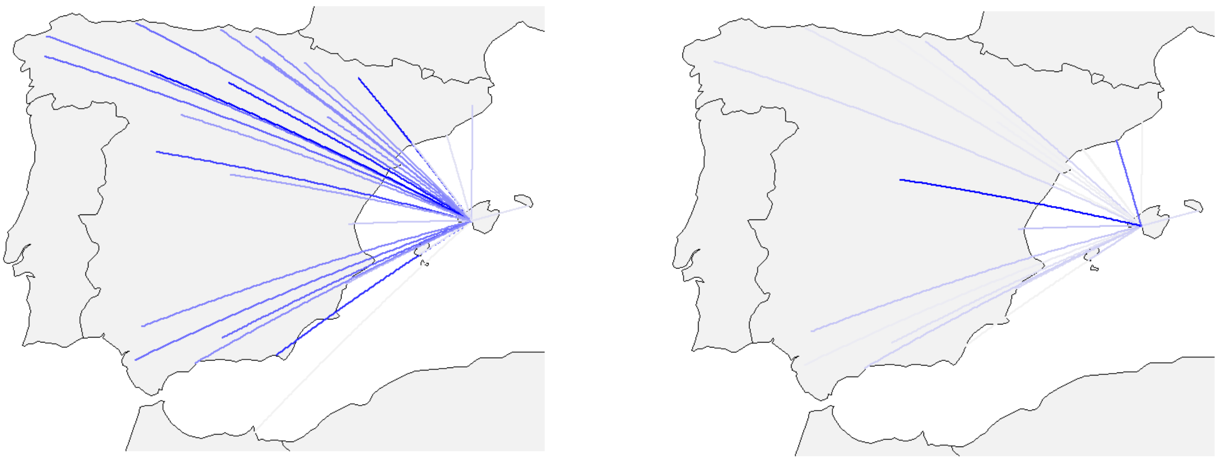


(**b**)

Figure 10. Carbon dioxide emissions from main domestic corridors operating in AGP airport, where a rough sketch means more emissions than the thinner one as follows: (**a**) Partial emission per passenger and route (arithmetic average: 75.69, standard deviation: 22.37); (**b**) Total emission of routes concerned. Source: own elaboration from the data provided by [19,20].

3.2.5. Related Aspects Concerning Domestic Routes Operating in the PMI Airport

The Palma de Mallorca airport (IATA: PMI, ICAO: LEPA), as shown in Table 1, has been identified as Spain's third leading air facility in terms of the number of passengers and air operations over the study period. Because of the singular nature of the Balearic Islands, which stands as a highly popular tourist destination in Europe, such an airport has been characterized for attracting several air carriers whose total number of seats offered has been growing steadily in the last few years, with the exception of restrictions placed on movement around Europe due to coronavirus lockdowns between the years 2020 and 2021. According to the last expected growth at the airports in the Balearic Islands, PMI has recently led to an increase of 11% in scheduled seats (31.2 million) [26]. Indeed, for the present year, once travel restrictions eased and then completely lifted, the three airports of such a Spanish archipelago have undergone unprecedented growth. All of these factors have created an ample offer of flights at PMI that have not only been operating towards many major European city destinations scheduled and charter services, but also into medium-sized cities, and even sometimes outlying towns to major cities across Europe. All of this means that travelers interested in flying into PMI usually have access to the low prices and wide choices that are available in the truly competitive EU single aviation market. The outcome is an enormous representative offer of the common European air transport sector with great pulling power, which includes both low-cost and legacy airlines. Nonetheless, this great expansion of direct flights into such an attractive tourist destination situated in the Mediterranean Sea has not always ensured that the long-term level of capacity would be better adjusted to meet the level of demand, either in terms of optimizing traffic density or in the range of the destination from tourist source countries. As shown in Figure 11a, in the case of those national departure airports that serve PMI, widespread high specific emission values apart from some routes between islands, respectively EC58 and EC86, have been observed. Unlike domestic routes into mainland Spain, some of them are even related to seasonal flights from small airports, and a very seasonal demand on both corridors, whose usual carriers (YW and UX) have traditionally operated turboprop aircraft (AT7), thus achieving a low emission performance [21], has not been noted. By contrast, as can be seen in Figure 11b, the route (EC8) with the greater choice and the largest number of seats offered has the highest emission levels.



(**a**) (**b**)

Figure 11. Carbon dioxide emissions from main domestic corridors operating in PMI airport, where a rough sketch means more emissions than the thinner one as follows: (**a**) Partial emission per passenger and route (arithmetic average: 76.18, standard deviation: 30.21); (**b**) Total emission of routes concerned. Source: own elaboration from the data provided by [19,20].

3.3. Overall Findings Based on Key Performance Indicators

In order to make a comparative evaluation of direct impacts resulting from aviation emissions in operational terms, as can be seen below, proper ratios of the specific emissions to air according to the ten selected aircraft types have been calculated and presented.

3.3.1. Benchmarking of Air Pollution

Regarding carbon dioxide emissions on the basis of the distance flown through Spanish airspace in domestic routes only, twin-turboprop aircraft appear to be most appropriate in scheduling corridors up to 550 km, as shown in Figures 12 and 13, respectively.

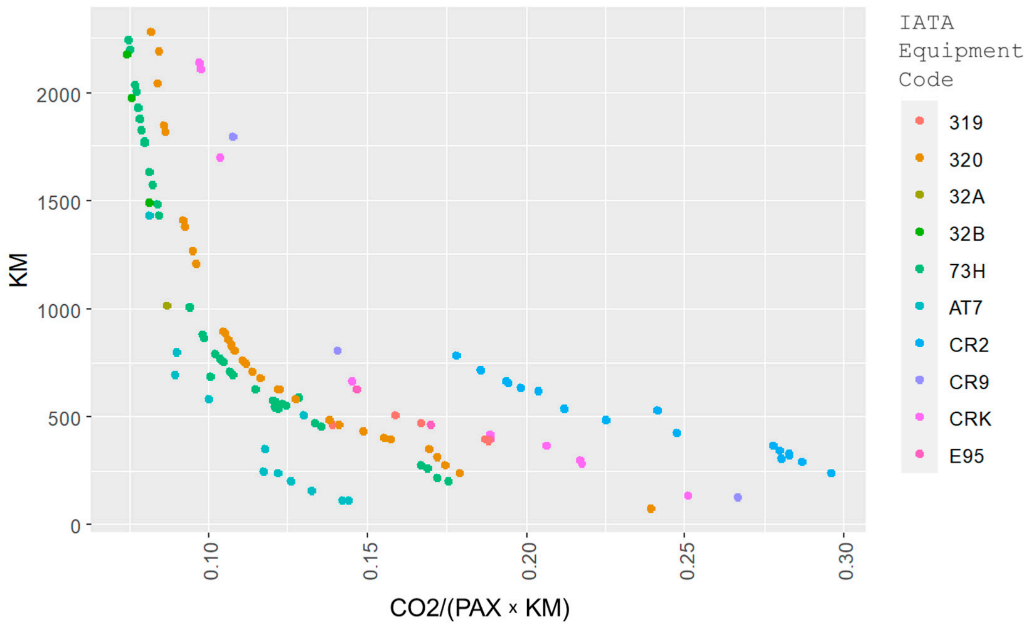


Figure 12. The relative ratio of carbon dioxide emissions in kilograms (kg) per passenger (PAX) and kilometer (km) according to the distance traveled in kilometers (km) by each aircraft selected. Source: own elaboration based on data compiled from [19] and weighted from [20].

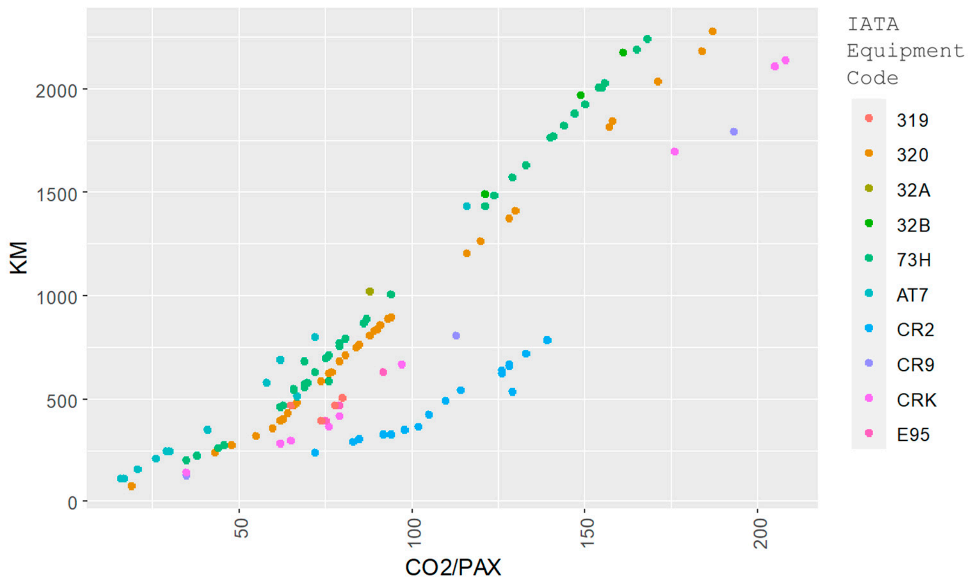


Figure 13. The relative ratio of carbon dioxide emissions in kilograms (kg) per passenger (PAX) according to the distance traveled in kilometers (km) by each aircraft selected. Source: own elaboration based on data compiled from [19] and weighted from [20].

3.3.2. Benchmarking of Fuel Consumption

Concerning fuel consumption (jet A1) caused by related aviation activity from operating those 139 domestic routes over 10 years between 2011 and 2020, its evolution has been calculated according to the U.S. Gulf Coast Kerosene-Type Jet Fuel Spot Price in terms of Free on Board (FOB) [27]. As presented below in Figures 14 and 15, respectively, there appears to be a trend toward increasing emissions during periods of low fuel prices.

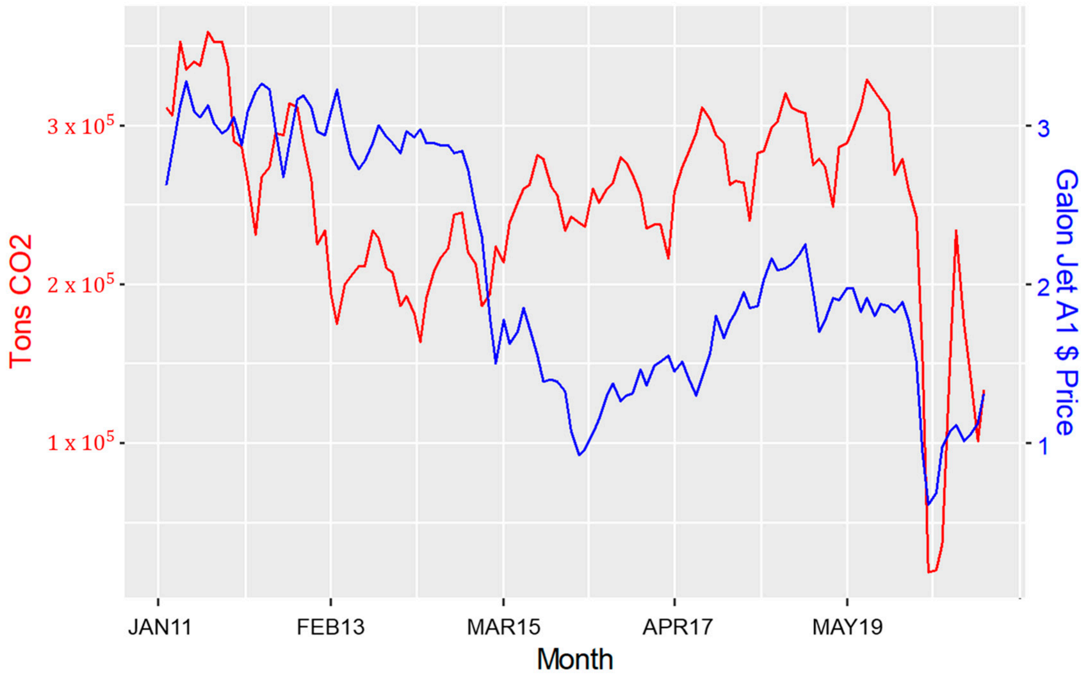


Figure 14. Comparative performance of carbon dioxide emissions and fuel prices. Source: own elaboration based on data compiled from [19] and weighted from [20] according to [28,29].

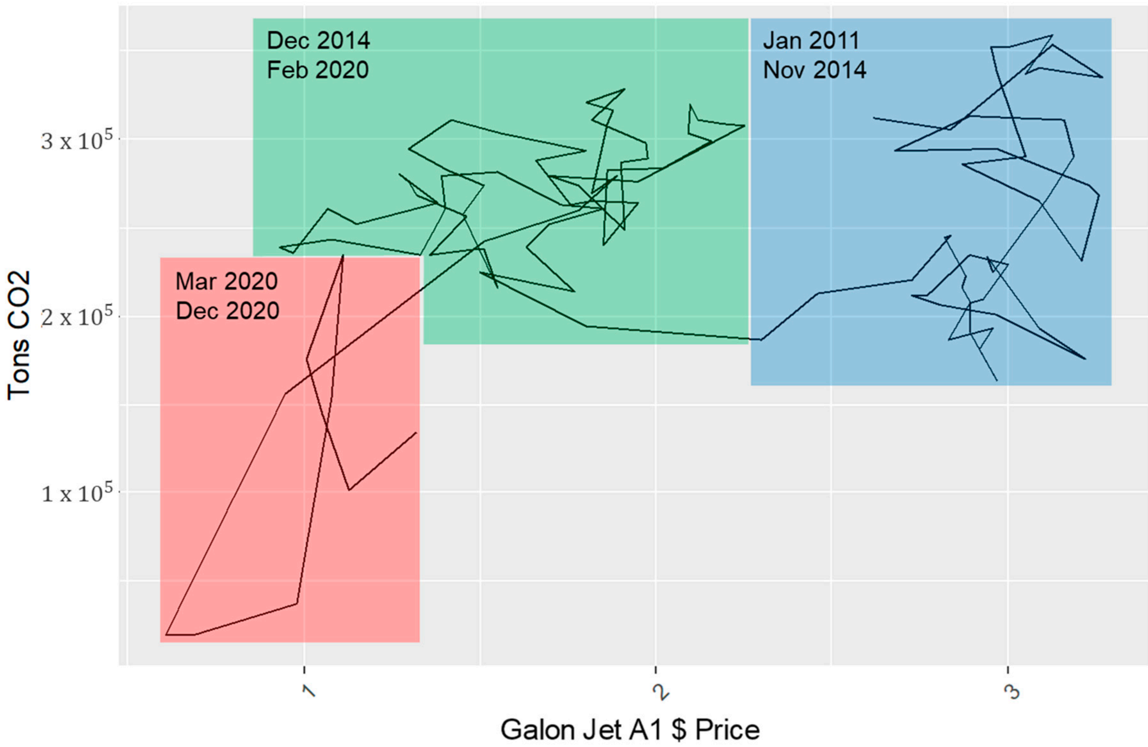


Figure 15. Trend analysis of carbon dioxide emissions and fuel prices. Source: own elaboration based on data compiled from [19] and weighted from [20] according to [28,29].

4. Discussion

According to the results obtained, and taking into consideration other previously published works on greenhouse gas emissions from commercial aviation, the findings are now discussed. In most EU member states, over the years, the public transportation sector has been enhancing steadily, with most reporting an increase in the number of routes in operation. Regarding collective modes of transportation until 2020, due to the outbreak of COVID-19, the number of passengers carried by air over regular routes and on regular schedules had experienced vibrant growth in the European aviation market. However, the air transport sector has recently been hampered by structural difficulties that make it more vulnerable to other transport modes. This is because the air sector is both highly cost-intensive and highly dependent on the global aviation leasing market, as well as fuel costs and wage bills due in part to the existence of minimum fuel requirements and high professional qualifications, respectively. Results from the study show there is a wide dynamic performance of air activity and, consequently, jet fuel consumption. Apparently, there are a number of factors that contribute to this fact, such as the aircraft's operational availability, adequacy of aircraft and crew for operational purposes, and the impact of the offered routes on airline profitability. While many airlines analyzed in this study have different types of cabins and seat configurations on various aircraft in their fleets, it is particularly important to consider their business strategies in which fleet modernization and renewal programs are carried out, not only for enhancing efficiency and profitability in transport activities, but also the promotion of sustainable transport. This statement is also precisely in line with what some previous papers pointed out on such a matter. For instance, regarding carbon emissions of European commercial air traffic, it was found that the main driver for efficiency in emissions is the modernization of the aircraft fleet [12]. The other essential element for more sustainable aviation is related to the use of alternative fuels, including exploring opportunities for alternative raw materials, such as renewable jet fuel by using advanced fermentation (AF) fuel from perennial grasses [30], since scaling up the SAF production is vital to enable an effective aviation's low-carbon transition.

In the research, only domestic routes have been examined, sometimes of seasonal nature, others even operated on some of the 23 routes under the Public Service Obligation (PSO) scheme so far imposed in Spain [21], the majority being feeder air routes, since legacy airlines are often looking to fly more short-haul domestic routes with regional aircraft with up to 100 seats for more efficient operation under the hub and spoke model. In contrast, low-cost carriers usually fly more point-to-point routes with medium-haul airliners for more profitable operations. Of the 139 corridors analyzed in the study, the highest fuel consumption ratio per kilometer has precisely been found in those serving as feeders to hubs from smaller airports due to the lack of international destinations at the source. Moreover, it is because they have been operated several times with small regional turbojets, such as CR2 or CR9, that emissions have been estimated by exceeding 0.20 kg of CO2 per passenger and kilometer. This concerns in particular the following routes: EC76, EC71, EC24, EC102, EC75, EC89, EC60, EC86, EC58, EC9, EC77, EC91, EC32, EC121, EC88, EC18, EC41, and EC93. Although the research results have been calculated according to the most representative airliner scheduled on each route over the study period, the previous corridors have been operated by using regional airplanes with a low seating capacity that are most suitable for thin route service, as the air traffic density is flat. Furthermore, outcomes of emission monitoring have highlighted the highly varying importance of scheduling airplanes on thin routes over the past years until the beginning of recent trends toward fleet harmonization with the entry of more fuel-efficient aircraft for sustainable transportation. Examples of this are, among others, the EC83, EC72, and EC15, whose scheduled flights had been mostly operated with up to six, three, and five different airplane types, respectively, and then it became necessary to introduce a unique regional jet model, specifically the CRK. These routes account for the most significant cases in facing the challenge of estimation methods used to calculate related emissions. This underlines the need for identifying the most representative airplane on each route at the statistical level.

5. Conclusions

As already stated in the opening of the paper, the principal aim of the research has been to carry out the empirical analysis of commercial airplane emissions on some short-haul flights previously selected for the study in terms of efficient performance and sustainable operation from a representative domestic market in the EU aviation sector. Specifically, this study underscores the influence that various aircraft have, in accordance with their nominal engine performances, on the outdoor air quality of such transport activities concerning environmental pollution from carbon dioxide emissions only. All of that is enveloped by the domestic market of passenger transport in Spain, particularly those air corridors operating from the five main airports, as shown in Table 1. In light of the research findings, this study is meaningful in that it does not simply analyze the emissions before and after the cruise flight as part of commercial transport services, but examines changes in fuel behavior depending on whether the airplane is provided in a situation where the aircraft is fully aware of the system.

Regarding overall consumption, it is important to highlight the routes with a more significant emission impact in the set of 139 routes selected; for instance, those with emissions above 2.2 million tons of carbon dioxide in the 10 years analyzed, such as EC6, EC111, and EC5, and in addition to that, 1.39 million tons emitted in the period (EC8). Despite that EC6 was the corridor most intensively operated in the study period, specifically 178,577 flights, the highest consumption has been detected in the corridors between Madrid and the Canary Islands. This is particularly significant in the case of EC111 and EC116, whose emissions are 2.84 million and 3.30 million of tons CO2 respectively, because of the large number of seats required all year round on such a main air corridor. Globally, as previously noted, five airports have been considered to become the most representative of the Spanish aviation market from the study, with MAD and BCN as the key facilities representing the 84.6% of total emissions. The remaining 15.4% is shared among the other main airports, namely PMI, LPA, and AGP (6.8%, 5%, and 3.6%, respectively).

Concerning consumption per passenger and kilometer, the majority of the 139 routes assessed are highly dependent on the airplane used for each of them, particularly in the case of regional aircraft types, such as CR2 and CRK, with 50 and 100 standard seats, respectively. Consumption is highly dependent on the distance traveled and, on the airliner, either turboprop or turbojet, operating flights scheduled on a given route. In line with some previous works, both in general matters [31] and in specific cases, such as in Georgia [32] and New Zealand [33], this research reinforces the importance of aircraft type used, load factors, and seat configuration to this issue. Such a clear case is that of the former Spanish air carrier named Spanair (IATA: JK, ICAO: JKK), which ceased operations on 28 January 2012, operating airplanes with high fuel costs per seat-mile (or km), such as those belonging to the McDonnell Douglas MD-80 series on routes EC6 and EC8, up to 148 and 212 flights a month in 2011, respectively. Another example can be found in those corridors traditionally operated by CR2, where a CRK has been introduced, thus leading to a significant emission reduction over the analysis period; specifically, from an average of 21,892 tons of carbon dioxide equivalent per month in May 2011 to an average of 398 tons per month in 2020. This was despite the non-variation impact on the supply of flights over the period, mainly on thin routes, such as EC121, EC72, and EC32, as well as a couple of PSO corridors, such as EC24 and EC25. Of particular note is the case of the introduction of CRK at the expense of CR9 in the Spanish domestic market, which had been used intensively on domestic routes selected until 2018, then gradually removed from the active fleet in 2019, and finally withdrawn from the corridors analyzed in April 2020. This has been caused by identifying the less efficient airliners for use on regional routes and even on thin routes, which can be gradually replaced with more efficient and environmentally friendly aircraft. The main example of this is provided by EC102, which was intensively scheduled with CR2, and later passed to be operated with 319 and CRK. This assessment indicates that the implementation of fleet renewal programs has allowed airliners to slash emissions beyond the levels mandated in the EU ETS rules on aviation. That answers the research question as to whether such investment efforts would do sustainable short-haul routes with a traveled distance of up to 500 km, and the answer to that question is an unequivocal yes when mainly operating turboprops. In any event, despite short-haul routes usually being considered as being shorter than 1100–1500 km, only 23 of 139 routes have a greater distance than 1500 km. Therefore, the limited number of medium-haul flights reinforces the idea that most domestic routes can be operated with turboprops.

6. Research Limitations and Future Directions

Despite the limited number of previous works on the matter of aircraft emissions caused by short-haul flights operated by regular airlines in Europe's single aviation market, in particular very scarce in the case of the Spanish domestic market, the findings of the present paper seem to suggest the opportunity to locate any common patterns among case studies from various geographical areas. However, there are several limitations to the research issue, and the results may not apply to the whole of the wider global aviation market in passenger transport, since fleets are often not homogeneous across the world, so a benchmark is difficult to establish. Owing to the limitations of the study, the research has evolved around two primary sources. On the one hand, related air traffic data were collected from the national airport services operator [19]. On the other hand, standard estimations of fuel consumption and emissions for each type of aircraft were calculated according to guidelines provided by the international organization of reference in the field of aviation [20]. However, all calculations have been based on the average values from aggregated data concerning cruise flights during the sampling period on the 139 routes selected. Thus, it has not been possible to consider a harmonized approach using an adequate intake estimation model based on flight data recorded by the airport operators in Spain, including serial number and registration of the aircraft, engine type, number of passengers carried, and emission factors. The reason for such a research limitation is due to the existence of operational data belonging to the business domain of both airport managers and air navigation service providers being specifically declared as confidential by either party, such as airlines or airliner manufacturers. Despite these limitations, the study has estimated the aggregated emissions per route, thus comparing the situation of each one according to the most representative aircraft operated over the research period. This has made it possible to analyze the difference in emissions per distance, thus highlighting the environmental impact depending on each aircraft type, both in absolute and relative terms (per passenger and kilometer).

Even though findings from the research are confined to the passenger transport services provided by scheduled airlines operating in the Spanish domestic market, it can be assumed that similar results could be achieved by future works on similar cases in the EU single aviation market. To deepen the knowledge of the research issue, it may be interesting to study the behavior of intercontinental air corridors, not only by transport capacity but also by the passenger, hence allowing the assessment of the actual use of the aircraft and its consumption. In that sense, it can be interesting to examine the wage costs of aircraft crews, when available, in order to make a full cost breakdown, thus highlighting the impact of fuel on the total operating costs of the airlines' operating corridors selected. The research issue also addresses the challenge of sustainable and efficient jet fuel procurement in the aviation sector, which is of great interest to both carriers and public authorities. Hence, it would be of great interest for further studies to focus on the economic viability of alternative fuels for intensive aviation purposes on scheduled flights, since economic analysis is potentially useful in identifying and clarifying the issues involved in making public policies relating to the environmental impact of air transportation. Another environmental challenge with regard to which the aviation sector has lately faced is the intensive use of general aviation for private chartered flights. Given that the present study focuses on carbon emissions from regular commercial flights into and out of Spain, charter flights have not been accounted for in the base of air quality monitoring estimation. Perhaps future research should shed some light on such a particular matter, as business aviation is usually operated with small-engine airplanes, mainly turbojets that often burn excessive fuel per passenger carried. Additionally, it would be interesting to look at how certain airlines are currently managing to evolve their fleet with the worst jet CO_2 emissions to eco-efficient, sustainable clean-sheet aircraft, such as the Airbus A320neo family (32D, 32A, 32B), as it would allow to determinate how this contributes to the optimization of the use of more efficient airplanes, and thereby more sustainable scheduled flights.

Although the research approach has only been focusing on carbon dioxide (CO_2) emissions from the domestic aviation sector in Spain, it would be interesting to analyze other outdoor air contaminants, such as nitrogen oxides (NOx), hydrocarbons (HC), carbon monoxide (CO), and sulfur gases, as well as soot and metal particles. Future studies on the matter might be carried out in a manner similar to some earlier works about air quality monitoring tools, both with low-cost multi-channel monitors under specific laboratory conditions for indoor environments [34,35] and with low-cost sensors for outdoor environments [36,37]. This could serve as the basis for planning experiments to accurately estimate emissions depending on each model engine if abundant funding from external sources were available, due to the high costs of this kind of testing. Nevertheless, the variety of flight conditions in operating passenger transport services is large and some aspects of aircraft engine emissions may need to be reviewed to understand the performance of the aircraft as a whole.

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Conflicts of Interest: The authors declare no conflict of interest.

Appendix A

Table A1. List of Commercial Airplanes Considered in the Research.

IATA Designator	ICAO Designator	Aircraft Type	Manufacturer (as of 14 October 2022)
AT7	AT72	Aerospatiale-Alenia ATR 72	Avions de Transport Régional GIE
319/32D	A319	Airbus A319 ceo/sharklets	Airbus SAS
320/32A	A320	Airbus A320 ceo/sharklets	Airbus SAS
321/32B	A321	Airbus A321 ceo/sharklets	Airbus SAS
738/73H	B738	Boeing 737-800/winglets	The Boeing Company
712	B712	Boeing 717-200	The Boeing Company
CR2	CRJ2	Canadair Regional Jet (CRJ) 200	MHI RJ Aviation ULC
CR9	CRJ9	Canadair Regional Jet (CRJ) 900	MHI RJ Aviation ULC
CRK	CRJX	Canadair Regional Jet (CRJ) 1000	MHI RJ Aviation ULC
E95	E195	Embraer 195	Embraer S.A.
295	E295	Embraer 195-E2	Embraer S.A.
M81/M82/M83/M87	MD81/MD82/MD83/MD87	McDonnell Douglas MD-80/90	The Boeing Company

Table A2. List of Scheduled Airlines Considered in the Research.

IATA Designator	ICAO Designator	Trade Name	Air Operator's Certificate (AOC) Issued by DGAC (as of 14 October 2022)
UX	AEA	Air Europa	ES.AOC.004
X5	OVA	Air Europa Express	ES.AOC.020
YW	ANE	Air Nostrum	ES.AOC.002
NT	IBB	Binter Canarias	ES.AOC.011
PM	CNF	Canaryfly	ES.AOC.100
IB	IBE	Iberia	ES.AOC.001
I2	IBS	Iberia Express	ES.AOC.117
formerly JK	formerly JKK	Spanair	withdrawn
V7	VOE	Volotea	ES.AOC.115
VY	VLG	Vueling	ES.AOC.060

Table A3. List of Representative Engines Considered in the Research.

Propulsion	Aircraft	Engines
Turboprop	ATR 72-500 (72-212A)	2 × Pratt & Whitney Canada PW100
Turboprop	ATR 72-600 (72-212A)	2 × Pratt & Whitney Canada PW100
Turbofan	Airbus A320-271N	2 × CFM Leap-1A/PW1100G-JM
Turbofan	Airbus A321-271N	2 × General Electric CF34-8C5A1
Turbofan	Airbus A319-100	2 × General Electric CF34-8C5
Turbofan	Airbus A320-214	2 × CFM56-5B4/P
Turbofan	Airbus A321-231 (WL)	2 × IAE V2533-A5
Turboprop	ATR 72-500 (72-212A)	2 × Pratt & Whitney Canada PW100
Turboprop	ATR 72-600 (72-212A)	2 × Pratt & Whitney Canada PW100
Turbofan	Boeing 737-8AS (WL)	2 × CFM56-7B
Turbofan	Boeing 737-85P (WL)	2 × CFM56-7
Turbofan	Boeing 717-2BL/-23S/-2CM	2 × BMW RR BR715
Turbofan	Bombardier CRJ1000 (CL-600-2E25)	2 × General Electric CF34-8C5A1
Turbofan	Bombardier CRJ900 (CL-600-2D24)	2 × General Electric CF34-8C5
Turbofan	Bombardier CRJ200 (CL-600-2B19)	2 × General Electric CF34-3B1
Turbofan	Embraer E195-E2 (ERJ 190-400 STD)	2 × Pratt & Whitney Canada PW1900G
Turbofan	Embraer ERJ-195LR (ERJ 190-200 LR)	2 × General Electric CF34-10E
Turbofan	McDonnell Douglas MD-80/90	2 × PW JT8D-219

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