Science of the Total Environment 707 (2020) 135326

Contents lists available at ScienceDirect

Science of the Total Environment

journal homepage: www.elsevier.com/locate/scitotenv

Methodology choice could affect air quality interpretation? A case study for an international airport, Marco Polo, Venice

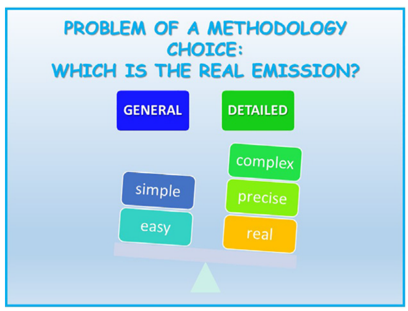
Elena Innocente [a,*], Eliana Pecorari [a], Daniele Zannoni [a,b], Giancarlo Rampazzo [a]

[a] Department of Environmental Sciences, Informatics and Statistics (DAIS), Università Ca' Foscari Venezia, Campus scientifico, Via Torino 155, 30172 Mestre VE, Italy
[b] Institute of Condensed Matter Chemistry and Energy Technologies, Italian National Research Council, C.so StatiUniti 4, Padova, 35127, Italy

HIGHLIGHTS

- Assess the contribution of aircraft emission of Venice Airport in the regional emission inventory.
- Emission factors and inventories are a fundamental tools in air quality management.
- No legal references that ensure a standard for an airport environmental assessment.
- Use two methodologies to estimate aircraft emission: EMEP/CORINAIR and EDMS.
- Comparison between EMEP/CORINAIR and EDMS methods has been made.

GRAPHICAL ABSTRACT



ARTICLE INFO

Article history:
Received 16 April 2019
Received in revised form 26 October 2019
Accepted 30 October 2019
Available online 23 November 2019

Keywords:
Aircraft exhausts
airport air quality impact
emission estimate
urban air quality

ABSTRACT

Venice Marco Polo Airport (VCE) is one of the most important airport of Italy, but is also placed in a delicate context; due to the proximity of the airport to the Venice historical city and the fragile ecosystem of the Lagoon that surround the city.

For all these reasons the priority was to assess the possible impact of Marco Polo Airport in Venice area.

For this reason a collaboration between Save Spa, the company that manage Marco Polo airport, and the Department of Environmental Sciences, Informatics and Statistics, of Ca' Foscari University was stated in order to: (I) understand the impact on air quality of an airport structure in a vulnerable context (II)analyze the airport emission trend (III) analyze how the number of flights and aircraft type can influence emission.

During this collaboration two methodologies for emission estimation (EMEP-CORINAIR and Emissions and Dispersion Modeling System, EDMS) were tested in order to understand what was the best tool to estimate aircraft exhausts emissions.

Results, reported in this paper show a deep difference between the two methods, with a general decrease in emission estimation using EDMS model, except in a $NO_x$and HC cases.

Subsequently the difference in emission in two typical operating days of 2009 was investigated. Results show that schedule and number of flights affect deeply emission estimation.

* Corresponding author at: Department of Environmental Sciences, Informatics and Statistics (DAIS), Università Ca' Foscari Venezia, Campus scientifico, Via Torino 155, 30172 Mestre VE, Italy.

E-mail address: elena.innocente@unive.it (E. Innocente).

https://doi.org/10.1016/j.scitotenv.2019.135326
0048-9697/

1. Introduction

The evaluation of emission factors and inventories has been for a long time a fundamental tools for air quality assessment and management. Air Quality emission estimates are important for developing emission control strategies, ascertaining sources, effects and appropriate mitigation strategies. The estimate of the emissions produced by the main pollutants sources represents also a key element in the chain of the modeling system.

Detailed information are required to create a realistic inventory or an adequate emission input and different methodologies have been studied, created and approved by scientific or government agencies in relation to the type of sources considered and aims of the study or environmental impact assessment requirement.

Despite this and the huge development in recent years, there are still elements that are not completely considered, that can lead to strong difference in emission estimates in relation to the choice made by the user.

These aspects are becoming more and more important for specific sources like airports. In fact, aircraft engine emissions are an important anthropogenic source of soot particles in the upper troposphere and in the vicinity of the airports. They influence climate and contribute to global warming. (IPCC, 1999, 2007; Lee et al., 2009; Abegglen, 2016). In addition, their impact on air quality and on human health and the environment has been confirmed (Ratliff et al., 2009; Barrett et al., 2010, 2012; Levy et al., 2012; Schlenker and Walker, 2012; Ashok et al., 2013; Yim et al., 2013; Pecorari et al., 2016; Abegglen, 2016). Recent growth of flight request has led to the continuous increase of commercial air traffic. The annual future growth rate is estimated to be 3.4 – 6.1% (Eurocontrol, 2008). As a consequence, this has led to rising public awareness and concerns about the aircrafts emissions and their impact on people health.

On the other hand there are no guidelines or no legal references in national or international law yet that can ensure a standard for an environmental assessment and sustainable development of an airport. This lack in legislation do not allow an exhaustive evaluation of atmospheric pollutant emission impact of an airport, and without a standard airports and aircraft producers do not implement policies that can lead to technical improvement and best practices that can reduce emission. On the other hand a legal reference could help an airport to have a transparent behavior towards stakeholders.

Recent collaboration between the Marco Polo Airport and Ca' Foscari has given the possibilities of testing two methodologies to estimate aircraft emission. The first estimate was based on the more detailed EMEP/CORINAIR methodology while the second one was made with the dedicated software EDMS 5.1.4.1 (Emissions and Dispersion Modeling System), developed by the Federal Aviation Administration (FAA) in cooperation with the United States Air Force (USAF) (FAA, 2013). Both are based on the ICAO emission factors, but the second one permit a better representation of aircraft emissions in relation to the engine choice and to the realistic taxi times. Despite this software, which is created for airport emission for airport specific emission evaluation, it is not commonly used by stakeholders involved in the implementation of an emission inventory.

This paper aimed to answer important questions related to air quality management: i) different choices in the emission estimate methodologies can affect the quantification of an airport emission inventory? ii) Does this difference affect the concentrations estimations and consequently the evaluation of the real airport impact in the surroundings, especially for airports in urban areas? iii) is it possible to define a range of realistic values that can be used as a reference for eventual future legislation? iv) is there a feasible method that could be settled as more realistic or a better interpretation of emissions?

2. Methodology

In the following sections work methodologies will be presented. The first paragraph (2.1) is dedicated to the characterization of the study area. Description of the data used and the methodology of building emission inventory is reported in section 2.2 – 2.3.

2.1. Study area

Venice Marco Polo Airport (IATA: VCE; ICAO:LIPZ) is one of the most important Italian airports for both domestic and international flights (10,371,380 passengers and almost 92,263 aircraft movements in 2017). Due to the importance of Venice as a leisure destination, it features flights to European metropolitan areas as well as some partly seasonal long-haul routes to the United States, Canada and the Middle East. Understanding the impact of airport emission on air quality can be crucial in this area, not just for the pollutants that can be emitted but for the contextualization in which this airport is sited. In fact, VCE airport represents one of the several anthropogenic pollutants emission sources that affect the area. The small boat and shipping traffic, the commercial and cruise dock operations and the artistic glass-making factories affect the historical center of the city. The industrial zone of Porto Marghera includes chemical and metallurgical plants, oil refineries and a coal power plant. Moreover, heavy traffic streets and a motorway passes through the urban zone of the mainland where all types of related emission sources affect the area (Rampazzo et al., 2008a, 2008b). Moreover, Venice is located in the eastern part of the Po Valley that is considered to be the most polluted area in Europe (Bressi et al., 2016, Caserini et al., 2017). Here, the presence of large cities and the density of industries causes air pollution problem worsened by the local meteorological conditions and by the regional diffuse pollution that characterizes the area (Pecorari et al, 2013, 2014; Barnaba et al., 2007; Gonzalez et al., 2000; Chu et al., 2003).

2.2. Aircraft movements and emission trends

For an exhaustive comprehension of the "dimension" of the airport the number of flights over years 2009–2017 were evaluated in order to understand the trends of number of flights and the composition of the fleet, essential to evaluate the change in emission estimation.

Aircraft data have been provided by SAVE S.p.A.: number of movements, departures/arrivals hours, aircraft types and ICAO codes; radar and taxi trajectories.

2.3. Emission estimate

2.3.1. Two methodologies of estimation

In order to understand if different techniques in emission estimate can affect the results, airport emissions have been calculated with two methodologies: the first estimate was based on the more detailed EMEP/CORINAIR methodology while the second one was made with the dedicated software EDMS 5.1.4.1.

The first EMEP/CORINAIR methodology is based on aircraft movement data. Emissions are estimated for all different aircraft types which are in use and have been registered by landing-takeoff cycle (LTO) (approach landing, taxi in, start up, taxi out, take off, climb out) movements in the airport chosen.

Detailed methodology may also include the actual times-in-mode at individual airports. Emission factors are not available for all the substances: only NO_x, HC, and CO emissions have been evaluated. Moreover, not all the aircrafts occurring at Marco Polo are represented in the EMEP emission factors database. Consequently, a substitution was made, which was based on the modification of general aircrafts suggested in the guide lines (EMEP, 2009) using the information given by SAVE S.p.a.

The second estimate has been assessed using the EDMS 5.1.4.1 software (EDMS, 2013) that provides emission factors of chemical species and fuel consumption according to aircraft model, operational mode in landing-takeoff cycle (LTO) (approach landing, taxi in, start up, taxi out, take off, climb out) (Song and Shon 2012) and "times in mode" that refers to the amount of time an aircraft spends in different portions of LTO (FAA, 2013). This model is considered to be a powerful tool, because it uses latest aircraft engine emission factors from the ICAO and EUROCONTROL data bank (Song and Shon, 2012).

Besides fuel consumption, the emission and dispersion of several pollutants (NOx, etc) were investigated in this study. (NO_x, HC, CO, PM_{10}, SO_x, CO_2).

Despite the fact that the two methods use same parameters, the possibility of more exact definition in the EDMS methodology changes completely results. First of all taxi times can be clearly specified for each aircraft movement, while it is an averaged value in EMEP methodology.

Moreover, all occurring aircraft types and coupled engine type are considered in the database increasing the specificity of the EDMS method. EMEP method is based on the assumptions that aircraft type can be related to general aircrafts, with definite parameters, which are given by the guideline without detailed description. Time in modes has limited timing choices and engines types are limited. On the contrary, EDMS permit a very detailed database and our access to Venice airport information permitted us a better description of each aircraft, of each engine, of each movement and of each timing. This gives us the opportunity making a very detailed description. As a result, data are more realistic, however it is still not established if the results are under or over estimated.

2.3.2. Emission scenarios

Aircraft emission estimates have been evaluated with the two methodologies for two typical days that represents the touristic, maximum day of activity, and the non touristic, mean day of activity, scenarios in Marco Polo Airport of Venice (VCE) during 2009.

The two selected days are in summer (touristic day) and in autumn (non touristic day).

A second estimate on annual base has been evaluated to test the effect of the choice on the elaboration of an emission inventory.

2.3.3. Comparison between the two methodologies of emission estimation

A comparison between the two methodologies has been made. As previously explained, only data for NO_x, HC and CO exhausts could be compared due to the lack of specific information on other substances in the first method. Emission factors for the single aircrafts has been evaluated and the effects on the daily emission rate has been discussed.

Subsequently, a comparison between the annual emission estimation with the two methods were performed, in order to compare and evaluate potential differences.

2.3.4. Emission trends and impacts in Venice area

The temporal differences of emission characteristics are important in order to asses emission trends and understand if the composition of the fleet could affect emission estimation: therefore, EDMS model was used to evaluate the emissions of years 2009, 2010, 2013 and 2014.

3. Results and discussion

3.1. Marco polo fleet and air traffic trends.

As stated above Marco Polo airport in Venice is one of the most important Italian airports for both domestic and international flights. As reported in Fig. 1 the number of flights increased strongly from 2009 to 2011 and then it decreased till 2014. Subsequently the number of movements strongly increased, exceeding the amount of 2014.

It must to be observed (Fig. 2) that the fleet composition vary over years, aircraft, like MD82 that was present with a considerable percentage, disappear by the majority of aircrafts in 2013, probably due to the nearly complete withdraw in 2014 from the fleet of principal airlines company that operates in VCE.

Despite that, there are some aircraft model, specifically A319, A320, A321 that are present with the major percentages over all years.

3.2. Marco Polo airport emissions and impact in Venice area

Annual emission~~s~~ data, as previously presented, are futile data without the context of Venice.

The Regional Public Agency, ARPAV, regularly estimates an emission inventory for the Venice province. The most recent data refers to 2010 and 2013 (INEMAR- ARPAV, 2010; INEMAR- ARPAV, 2013); these data were used to calculate Marco Polo emissions impact in the Venice context. Authors calculated Marco Polo emissions percentages for three years: 2010, 2013 and 2014 (Table1). Emissions from 2010 are compared with the emission inventory of the same year due to the availability of the data. Impact of Marco Polo Airport on the total emissions is about 1% for NO_x and CO emissions while it is close to 0% for PM and HC. If these results are compared with only the transportation groups clearly higher percentages turn out (2% for NO_x and CO; 1% for HC) except for PM. The 2013 emission inventory is the reference for the others two years: 2013 and 2014. Considering these years, percentages reach 2% on total emission for NO_x and CO while HC and PM shares do not change (Table1). Higher and more evident is the impact on the transportation reaching 4% for NO_x and CO, 3% for HC and 1% for the PM. This is clearly due to the increase of flights but also to the decrease of the general transportation emissions in the area. Considering the total transport impact on Venice, airport doesn't represent a big impact. However, in the following years the number of flights are predicted to be increased, as a consequence, an attention on airport emission control could be required.

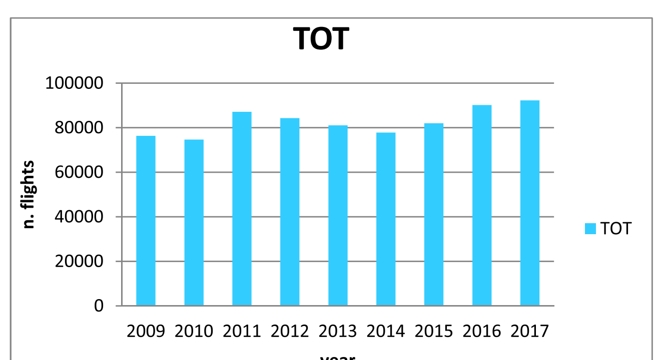


Fig. 1. Number of flights over years in Marco Polo airport.

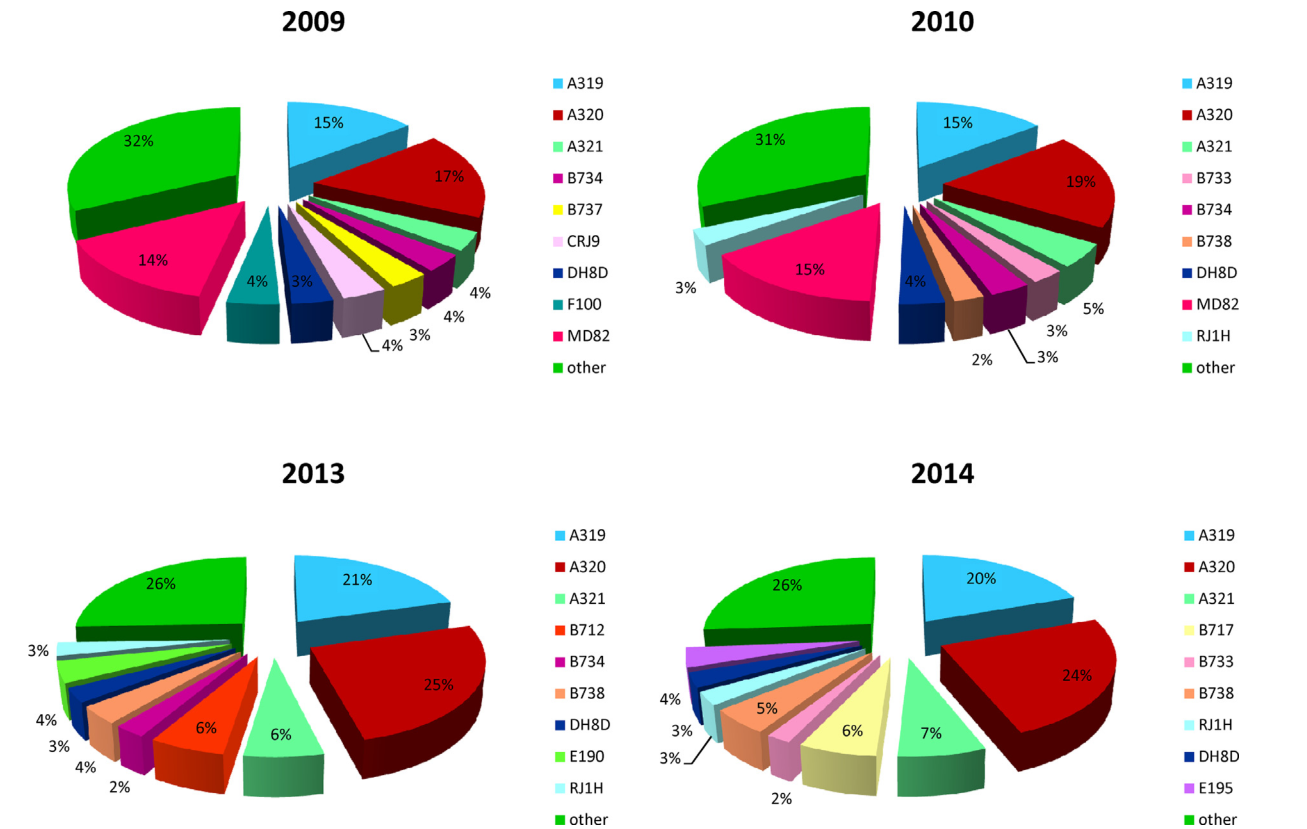


Fig. 2. Fleet composition over years.

Table 1
Marco Polo Airport emission contextualization for years 2010, 2013 and 2014. (Macro 7 + 8 are transport sectors, 7 is road traffic, 8 refers to other mobile sources).

2010	NOx	HC	CO	PM10
Airport on Macro 7 + 8	2	1	2	0
Airport on Total	1	0	1	0
Transport on Total	64	21	51	36
* referenced to Emission Inventory of 2010				
2013				
Airport on Macro 7 + 8	4	3	4	1
Airport on Total	2	0	2	0
Transport on Total	57	14	45	29
* referenced to Emission Inventory of 2013				
2014				
Airport on Macro 7 + 8	4	3	4	1
Airport on Total	2	0	2	0
Transport on Total	57	14	45	29
* referenced to Emission Inventory of 2013				

3.3. Trend of emission using EDMS model

Using EDMS model the trend of emission was estimated for 2009, 2010, 2013 and 2014. Results are comparable with the emissions calculated by Regional Public Agency, ARPAV.

As stated above the number of flight didn't vary deeply between 2009 and 2014 (76342 flights in 2009, 74,683 flights in 2010, 80,999 in 2013 and 78,143 in 2014 respectively) but the emission estimated variate sensibly.

As previously expected the estimated emission globally increased between 2009 and 2014, (Fig. 3), even though there are fluctuation, emission is not proportional to number flights because of variation in aircraft types.

An example of this is the apparent inconsistency in Figs. 1 and 2, such as TOT in 2010 is less than in 2009 although the number of flights are reverse. As calculations were made with the similar method, this effect is due to the differences in the type of aircrafts moving during the two years.

The global increase in the estimated emission, was not clearly expected considering the changes in fleet composition, that lead, to the disposal of more pollutant aircraft like MD82 during those years.

This absence of decrease of emission estimation between 2009 and 2014, that was expected due to fleet renewal, could be due to "others" fraction (Fig. 2). Actually "others" contained probably older and less performing aircraft.

3.4. Methodology comparison for emission estimation in the two typical days

Fig. 4 report differences in emission estimation between the two methods in the two typical days.

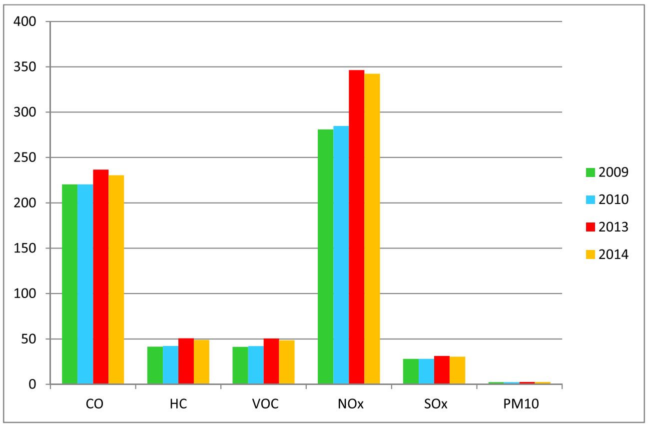


Fig. 3. Trend emission (t) for 2009, 2010, 2013, 2014 calculated with EDMS.

A significantly lower of pollutant emission was observed in the two days using EDMS method, except for HC in TKO + climb modes. This discrepancy was perceived in both examined days and is particularly strong for HC and CO approach mode (80/91% and 75–81% respectively).

This remarkable difference between EMEP/CORINAIR and EDMS could be due to the differences in emission factors and modeling approach. EDMS have a complete emission factor database and permits to consider real taxi times whereas EMEP-CORINAIR methodology requires a less detailed representation of aircrafts (general aircrafts are used when information are missing) and a less precise relation between taxi times and emissions ~~for the~~ belonging to several LTO modes.

Table 2 represents the results of the differences between the two modeled values in percentage.

It can be generally stated that the emission factors, for the three pollutant considered, are significantly lower in case of EDMS model, except for few cases. In case of Embraer one needs a special consideration: the higher of percentage in emission outstanding all studied pollutant. Considering EMEP-CORINAIR method Embraer emissions are very low especially in taxiing times, probably due to a limit of the method, that is not very performing during this phase.

Despite of this strong overestimation in case of Embraer emission factor, the total amount of estimated HC, CO and NO_x in both days (Fig. 4) as the number of Embraer flights were negligible (3 in summer, 5 in autumn).

Moreover, it should to be considered that the most common aircrafts, A320, B737-400 and MD82, present a large reduction in emission factor in both days: such behavior allows a general reduction of emission changing from EMEP CORINAR method to EDMS model.

It is notorious that higher NOX emission is produced during higher engine thrust, therefore in TKO-climbe phase, whereas higher CO and HC emission peaks are estimated in taxiing modes that occurs at low thrust level. Emissions are generally higher in summer due to the larger number of flights and the presence of three additional aircrafts (A310, B757 and F28).

Although the amount of aircraft exhaust emission differs between EMEP/CORINAIR and EDMS simulation results data distribution are similar in both methods, suggesting a correct of taxiing

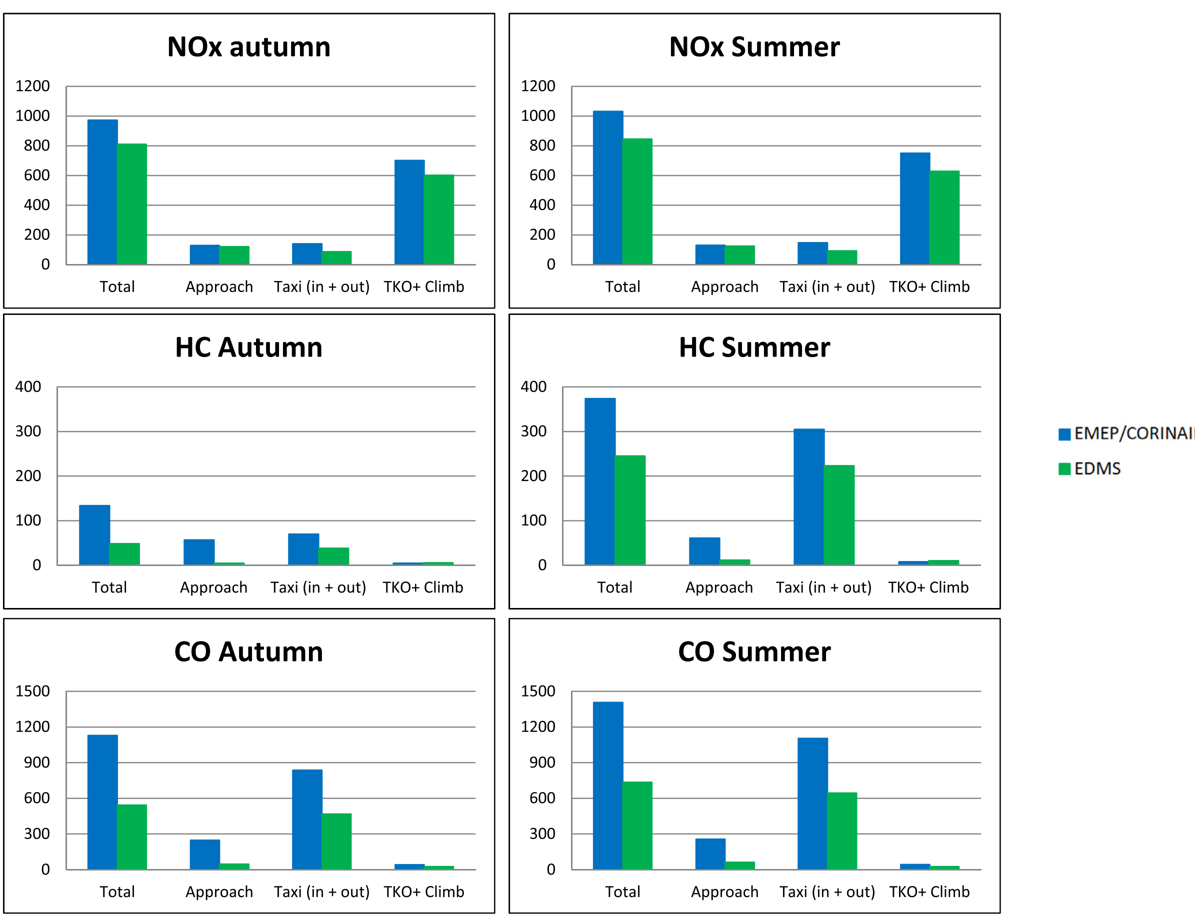


Fig. 4. Differences in emission (t) estimates between EDMS and EMEP CORINAR methods.

Table 2
Difference, in percentage, in emission estimation between EMEP CORINAIR method and EDMS.

		A310	A320	A330	ATR42	ATR72	B737-100	B737-400	B757	B767	BAe146	Dash8Q	Embraer	F28	MD82	Saab2000
	Approach	16	−15	2	−10	−65	21	21	9	5	13	−62	−98	4	−14	3
	Taxi (in + out)	−27	−45	−48	−30	−81	−33	−28	−20	−57	−37	−60	2143	−54	−30	180
NOx	TKO	−26	−11	−29	31	−64	9	28	−32	−13	6	−59	−93	0	−37	21
	Climb	−28	−17	−31	52	−64	3	19	−32	−2	−6	−43	−96	−7	−41	146
	tot	−22	−19	−29	2	−70	0	12	−27	−9	−9	−56	510	−12	−35	81
	Approach	16	−94	−33	0	−30	19	2	33	101	11	−26	378	−9	−9	−21
	Taxi (in + out)	−64	−67	−62	218	−11	−16	−36	−34	69	−18	156	1228	−27	−3	75
CO	TKO	−92	49	−90	56	−24	22	14	−25	102	−84	−33	1076	26	−39	3
	Climb	−92	−64	−91	69	−16	12	14	−27	121	−86	−6	473	39	−63	113
	tot	−62	−75	−62	160	−16	−11	−34	−32	74	−19	99	1045	−25	−7	52
	Approach	−35	−95	−49			13	24	−75	292	−71		−50	38	−100	−100
	Taxi (in + out)	−84	−39	−67			28	−33	−90	207	28		1915	−17	−100	−62
HC	TKO	−27	167	0			52	28	−61	155	−82			277	−100	
	Climb	−42	164	−18			19	−2	−68	226	−84			108	−100	−96
	tot	−82	−74	−64			26	−31	−89	211	10		1603	−14	−100	−65

Table 3
Difference, in emission estimation between EMEP CORINAIR method and EDMS for 2009 and 2013.

	2009		2013	
	EMEP-CORINAIR	EDMS	EMEP-CORINAIR	EDMS
Fuel	29052.3	24001.6	31065.7	26759.6
NOx	259.0	281.0	396.4	346.4
HC	99.9	41.5	76.5	50.7
CO	435.2	220.4	552.2	236.7

times for CO and HC and TKO-climb for NO_x. The advantage in using EDMS is a more precise emission estimation, based on activity and fleet composition (Herndon et al., 2008), that allow a reduction in exhaust estimation as reported in Fig. 4.

Subsequently in order to understand more precisely how the methodical differences can affect an annual emission estimation, a more complex analysis was performed for the years 2009 and 2013. Results are reported in Table 3.

As it was mentioned above the fleet composition and the number of flights differ in these years, allowing a comparison with newer type of aircrafts also.

However also comparing the two methodologies annual emission estimation EDMS assessed lower emission of pollutant, except for NO_x that were higher with EDMS estimation in 2009. HC decrease from 2009 to 2013, even though flight number grows. Those variations were probably caused by a more precise database and, in case of HC a change in fleet composition. Different behaviors of pollutants is due to the non-linearity of the estimate.

In fact, more specificity is added to calculation, as for the introduction of all the engines types, more complexity is added.

Finally reductions in exhaust estimation using EDMS were probably due to more precise taxi times and classification of aircraft.

This annual analysis allows us to understand how the assimilation in type of aircraft imposed by EMEP CORINAIR methods could generate a probable error in estimation. It also shows us how the precision of taxi times are important: the shortage of EMEP CORINAIR method in this LTO phase can produce an error, especially in HC and CO estimation.

3.5. Daily time series emission comparison

EDMS model allow the prediction of high temporal resolution of emission. Fig. 5 shows the modeled time series for two representative days introducing characteristic seasonal scenarios.

Time series calculated with EDMS shows similar to EMEP results of Pecorari et al, that the trends of the two representative days are variant. This difference could be ascribed to flight scheduling: during autumn, flight traffic peaks are detected between 7:00–12:00 and 15:00–19:00. In summertime there is a fall of exhaust at about 14:00–15:00 due to lower number of flights. Peaks changes strongly in relation to the pollutant, due to LTO mode.

The number of flight clearly affect pollutant emission, but also the aircraft model and taxi times can play a role: in case of HC the significant difference between autumn and summer emission is straight connected to taxi in and out modes of F28.

These parameters, such as diversity in scheduling, number of flights and aircraft model produce a decrease in the quantity of estimated emitted pollutant, in 4% for NO_x, 26% for CO and 80% for HC between summer and autumn.

Compared to EMEP CORINAR data, reported in Pecorari et al. (2016), daily distribution of pollutant is more detailed, finer time resolution could be achieved by EDMS because of its higher sensitivity.

Moreover EDMS reported ~~a~~ very low values of HC and CO that are very low, compared to EMEP/CORINAIR values reported in Pecorari et al. (2016). That is probably due to differences in the calculation method of time in mode emissions.

This relevant characteristic of EDMS allows, probably, an exhaustive and realistic description of emission related to daily flight scheduling.

These major differences between EDMS and EMEP CORINAIR highlight the importance of the choice of method used to asses airport emissions in order to have a detailed description of possible airport impact.

4. Conclusions

This study present a comparison of two formal methods for emission estimation, in order to find a "standard" in method.

The main findings of this works are summarized as follow:

- The number of flights at Marco Polo Airport increases during all the evaluated period (2009–2017), despite of 2011–2014 years that present a decline in number of landing and take off. This trend could be attributable to the economical crisis that was present in Europe during those years.

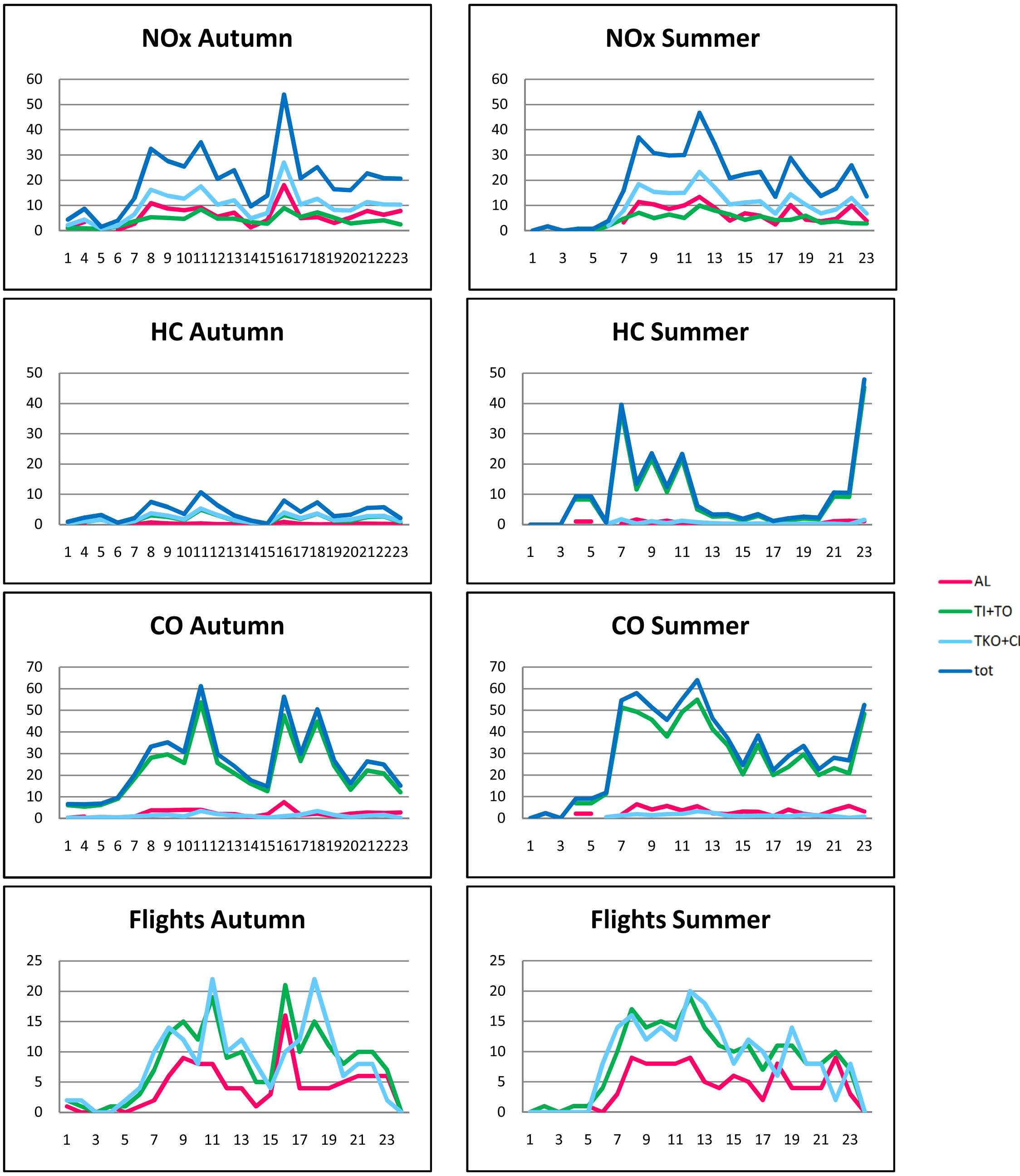


Fig. 5. Time series of emissions (kg) obtained with EDMS in the two representative seasonal days (for flights autumn and flights summer TI + TO is identical to tot).

- EDMS estimation shows significantly lower emission in almost case of all pollutant emission in total LTO phases, compared to EMEP- CORINAIR results, probably due to the different approach in calculation. EDMS, which using time in mode method is presumably more accurate and detailed. As a consequence, the choice of these methodologies could strongly affect possible subsequent assessment.
- As it is previously reported in Pecorari et al. (2016) high NO_X emission is related with TKO-climb phase produced at higher engine thrust, whereas high CO and HC emission are related with taxiing modes that occurs at low thrust level: these suggests a correct use of LTO times.
- Also seasonality could affect emission: diversity in scheduling, number of flights and aircraft model produce a decrease in emitted pollutant between summer and autumn. This difference in seasonality must be considered during environmental assessments of an airport.
- A more detailed description of the aircraft types and a detailed database for EMEP guidelines could help to improve the description of aircraft emissions. However, EDMS software is airport specific, consequently, in our vision, EMEP guidelines must be improved in order to be comparable. Moreover, no airport air quality emission legislation is available yet. Maybe, this could be a first step in airport emission control and to create collaboration between public agencies and a more and more impacting activity.
- As a consequence of those differences between emission estimation methods regarding the possibilities to have a legal reference or an objective value for airport emission, it must be considered that it is mandatory to indicate a "best practices"

in emission inventory calculation. This proceeding will be realistic, robust easy to use and become common used in airport environmental department or authorities.

Acknowledgments

The authors are grateful to SAVE S.p.A. for funding the project.

References

Abegglen, M., Brem, B.T., Ellenrieder, M., Durdina, L., Rindlisbacher, T., Wang, J., Lohmann, U., Sierau, B., 2016. Chemical characterization of freshly emitted particulate matter from aircraft exhaust using single particle mass spectrometry. Atmos. Environ. 134, 181–197.

Ashok, A., Lee, I.H., Arunachalam, S., Waitz, I.A., Yim, S.H., Barrett, S.R., 2013. Development of a response surface model of aviation's air quality impacts in the United States. Atmos. Environ. 77, 445–452.

Barnaba, F., Gobbi, G.P., de Leeuw, G., 2007. Aerosol stratification, optical properties and radiative forcing in Venice (Italy) during (ADRIEX). Q. J. R. Meteorolog. Soc. 133, 47–60.

Barrett, S.R.H., Britter, R.E., Waitz, I.A., 2010. Global mortality attributable to aircraft cruise emissions. Environ. Sci. Technol. 44, 7736–7742.

Barrett, S.R.H., Yim, S.H.L., Gilmore, C.K., Murray, L.T., Kuhn, S.R., Tai, A.P.K., Yantosca, R.M., Byun, D.W., Ngan, F., Li, X., Levy, J., Ashok, A., Koo, J., Wong, H.M., Dessens, O., Balasubramanian, S., Fleming, G.G., Wollersheim, C., Malina, R., Pearlson, M.N., Arunachalam, S., Binkowski, F.S., Leibensperger, E.M., Jacob, D.J., Hileman, J.I., Waitz, I.A., 2012. Public health, climate and economic impacts of desulfurizing jet fuel. Environ. Sci. Technol. 46, 4275–4282.

Bressi, M., Cavalli, F., Belis, C.A., Putaud, J.F., Fröhlich, R., Martins dos Santos, S., Petralia, E., Prévôt, A.S.H., Berico, M., Malaguti, A., Canonaco, F., 2016. Variations in the chemical composition of the submicron aerosol and in the sources of the organic fraction at a regional background site of the Po Valley (Italy). Atmos. Chem. Phys. 16, 12875–12896.

Caserini, S., Giania, P., Cacciamani, C., Ozgena, S., Lonati, G., 2017. Influence of climate change on the frequency of daytime temperature inversions and stagnation events in the Po Valley: historical trend and future projections. Atmos. Res. 184, 15–23.

Chu, D.A., Kaufman, Y.J., Zibordi, G., Chern, J.D., JietaiMao, Chengcai Li, Holben, B.N., 2003. Global monitoring of air pollution over land from the Earth Observing System-Terra Moderate Resolution Imaging Spectroradiometer (MODIS). J. Geophys. Res. 108, 4661.

EMEP CORINAIR Emission Inventory Guidebook, 2009. EEA – European Environment Agency. Technical guidance to prepare national emission inventories. The joint EMEP/EEA air pollutant emission inventory guidebook supports the reporting of emissions data under the UNECE Convention on Long-range Transboundary Air Pollution (CLRTAP) and the EU National Emission Ceilings Directive. (accessed 01.15).

EDMS 5.1.4.1 (Emissions and Dispersion Modeling System), 2013. EDMS is designed to assess the air quality impacts of airport emission sources; in 1998 FAA - Federal Aviation Administration – identified EDMS as the required model for air quality modeling procedures.

Eurocontrol, 2008. Challenges of Growth 2008, Summary Report.

FAA Federal Aviation Administration, 2013. Emission Emissions and Dispersion Modeling System (EDMS) User's Manual. FAA-AEE-07-01. Office of Environment and Energy, Washington, DC. (accessed. 10–06.07.13).

Gonzalez, C.R., Veefkind, J.P., de Leeuw, G., 2000. Aerosol optical depth over Europe in August 1997 derived from ATSR-2 data. Geophys. Res. Lett. 27, 955–956.

Herndon, S.C., Jayne, J.T., Lobo, P., Onasch, T.B., Fleming, G., Hagen, D.E., Whitefield, P.D., Miake-Lye, R.C., 2008. Commercial aircraft engine emissions characterization of in-use aircraft at Hartsfield-Jackson Atlanta. Int. Airport. Environ. Sci. Technol. 42, 1877–1883.

INEMAR-ARPAV, 2010. Disaggregated emission inventory 2010.

INEMAR-ARPAV, 2013. Disaggregated emission inventory 2013.

IPCC Climate Change, 2007. Synthesis Report. Contribution of Working Groups I, II and III to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change.

IPCC, Penner, J.E., Lister, D.H., Griggs, D.J., Dokken, D.J., McFarland, M. (Eds.), 1999. Prepared in collaboration with the Scientific Assessment Panel to the Montreal Protocol on Substances that Deplete the Ozone Layer Cambridge University Press, UK. pp 373 Available from Cambridge University Press.

Lee, D.S., Fahey, D.W., Forster, P.M., Newton, P.J., Wit, R.C.N., Lim, L.L., Owen, B., Sausen, R., 2009. Aviation and global climate change in the 21st century Atmos. Environ. 43, 35203537.

Levy, J.I., Woody, M., Baek, B.H., Shankar, U., Arunachalam, S., 2012. Current and future particulate-matter-related mortality risks in the United States from aviation emissions during landing and takeoff. Risk Analy. 32, 237–249.

Pecorari, E., Squizzato, S., Masiol, M., Radice, P., Pavoni, B., Rampazzo, G., 2013. Using a photochemical model to assess the horizontal, vertical and time distribution of $PM_{2.5}$ in a complex area: relationships between the regional and local sources and the meteorological conditions. Sci. Total Environ. 443, 681–691.

Pecorari, E., Squizzato, S., Longo, A., Visin, F., Rampazzo, G., 2014. Secondary inorganic aerosol evaluation: application of a transport chemical model in the eastern part of the Po Valley. Atmos. Environ. 98, 202–213. https://doi.org/10.1016/j.atmosenv.2014.08.045.

Pecorari, E., Mantovani, A., Franceschini, C., Bassano, D., Palmeri, L., Rampazzo, G., 2016. Analysis of the effects of meteorology on aircraft exhaust dispersion and deposition using a Lagrangian particle model. Sci. Total. Environ. 541, 839–856.

Rampazzo, G., Masiol, M., Visin, F., Pavoni, B., 2008b. Gaseous and PM10-bound pollutants monitored in three environmental conditions in the Venice area (Italy). Water Air Soil Pollut. 195, 161–176.

Rampazzo, G., Masiol, M., Visin, F., Rampado, E., Pavoni, B., 2008a. Geochemical characterization of PM10 emitted by glass factories in Murano, Venice (Italy). Chemosphere 71, 2068–2075.

Ratliff, G., Sequeira, C., Waitz, I., Ohsfeldt, M., Thrasher, T., Graham, M., Thompson, T., 2009. Aircraft Impacts on Local and Regional Air Quality in the United States PARTNER Report 15 Final Report (Report No 2009 PARTNER-COE-2009-002).

Schlenker, W., Walker, W.R., 2012. Airports, Air Pollution, and Contemporaneous Health. NBER Working Paper No. 17684, Issued in December 2011.

Song, S.-K., Shon, Z.-H., 2012.Emissions of Greenhouse Gases and Air Pollutants from Commercial.

Yim, S.H.L., Stettler, M., Barrett, S.R.H., 2013. Air quality and public health impacts of UK Airports part II: impacts Assessment and Policy Analysis. Atmos. Environ. 67, 184–192.