How much do ground operations contribute to global warming?

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ABSTRACT: *The efforts to reduce the impact of airports operations on climate have increased over the last decades. However, the extent to which the emissions released at airport level effectively contribute to climate change and global warming is largely uncertain. In this paper we aim to investigate this contribution, considering in a comprehensive "Ground scenario" the total energy consumed by the airport infrastructure and the fuel consumption necessary for taxiing, ground support equipment and ground operations. Subsequently, we quantify the impact reduction which can possibly be achieved by introducing the following operational improvements: introduction of electric towing vehicles for taxiing, upgrade of the airport infrastructure according to energy efficiency criteria, and electrification of ground vehicles and operations. The results of this work show that, although the overall airport contribution to the global temperature increase is small with respect to the one of other operations in the aviation sector, the possible reduction in CO2 emissions due to the implementation of the described operational improvement is not negligible.*

Keywords: airport, climate change, CO2 and non-CO2 emissions, taxiing, infrastructure, ground operations

1. INTRODUCTION

Aviation sector has brought, over the years, a great benefit to European society and economy, allowing people to move faster between the different countries and facilitating the transports of goods. Consequently, air traffic has steeply grown over time and in 2019, passenger traffic in the ECAC area reached 11.1 million flights (1).

Because of this growth, the contribution of aviation to climate change and its environmental impact have also increased, particularly in terms of greenhouse gases (GHG) emissions (around 2-3% of CO_2 emissions globally and 4% in Europe (2)).

The Covid-19 crisis caused an abrupt contraction of the activities in the aviation sector, which is still far from recovery. However, once the current pandemic is overcome, air traffic is expected to resume its growth by 3–4% per year (3). This suggests that the aviation impact on climate will increase over the next decades unless effective countermeasures are implemented.

Numerous projects and initiatives at the European and global level are investigating and testing mitigation actions to reduce aviation GHG emissions (2) (4). However, more efforts are required to fully understand the net impact of these (and future) mitigations on climate change. The ClimOP project (5) is a Horizon 2020 European initiative selected by the Innovation and Networks Executive Agency (INEA) within the action "Aviation operations impact on climate change" that pursues this scope. ClimOP aims specifically at assessing:

- The contributions to climate change due to eight specific in-flight and ground operations.
- The expected reduction of such contributions that can be achieved

through the deployment of eight Operational Improvements (OIs), i.e. changes in operations, infrastructure, equipment that might potentially mitigate the climate impact of aviation.

In this paper we will describe and discuss the results that ClimOP obtained in modelling a "Ground scenario", which investigates the impact of the ground operations, equipment and infrastructure, i.e.:

- Taxiing.
- Airport infrastructure, and more specifically the office buildings.
- Ground support equipment and operations.

These aspects are often ignored in the literature because of their supposed lower climate impact with respect to in-flight operations. However, in some cases the operational improvements described in this paper have already been planned or implemented in real airports all around the world (6), and therefore it is worth to explore their actual benefits in terms of climate change mitigation. The goal of this study is to fill this gap by computing the total contribution of airport operation and infrastructure to climate change

2. MODELS AND METHOD

In the Ground Scenario considered in ClimOP (13, 14), the impact on climate of three different OIs is assessed and compared to the business as usual (BAU). The three considered OIs are:

- Electric towing, as a lower-emissions alternative to current taxiing operations.
- The upgrade of the airport infrastructure according to energy efficiency criteria.
- The electrification of ground vehicles and operations.

Our preliminary assumption is that the contributions of the three different OIs are independent. Based on this assumption, for each OI a specific model is developed and the contributions to climate change are individually computed; the results are subsequently added up.

To measure the effect of the OIs and compare it to the BAU case, the following parameters (KPIs) are considered in the analysis:

- CO_2 emissions in tons per year.
- Emissions in tons per year of other GHGs, specifically CO, NO_x , $PM_{2.5}$, PM_{10}.
- Fuel consumption (litres per year).
- Energy consumption (kWh per year)
- ATR20 and ATR100, i.e. the Average Temperature Responses in 20 years and 100 years, respectively, which represent the global average temperature variation ΔT (in K) as an effect of the emissions.

These KPIs are computed both for the BAU case and after OIs implementation, at first separately for the three OIs and then all together for the unique Ground scenario. In this paper, ATR is computed using Eq. 8 of Sausen and Schumann (7):

$$\Delta T(t) = \int_{t_0}^{t} G_T(t - t')\, RF^*(t')\, dt'$$

where t_0 is the starting year of the time period, t is the final year of the time period being calculated. G_T is the impulse response (Green) function for the global mean surface temperature ΔT change (7):

$$G_T(t) = \alpha_T e^{-t/\tau_T}$$

where tabulated values of the α_T and τ_T are constants shown in Table II of Sausen and Schumann (7). RF^* is the radiative forcing as calculated in (7):

$$RF^*(t') = \frac{\ln(C(t')/C_0)}{\ln 2}$$

where $C(t')$ and C_0 respectively represent the CO_2 concentration in the atmosphere (measured in ppm) at time t' and at time t_0.

In the following sections we describe the three models that were developed to measure the mitigation effect of the three ground OIs. In some cases, airport data was used to develop and validate the models. The source of the information adopted in this study is a medium-size European airport.

2.1. SUSTAINABLE TAXIING

The central idea of this OI is that emissions could be greatly reduced during the taxi phase (i.e. when the aircraft moves from its parking position to reach the runway for the departure or back after the landing) by switching off one or all the aircraft engines, and using other strategies to move the aircraft on the ground. Several alternatives are currently being studied (8). In this paper we focus on electric towing, which consists in moving the aircraft using designed electric tow trucks. The results are compared with the BAU case in which the aircraft perform taxiing operations with all engines activated.

Data

The data used for assessing are:

- Airport movements during a peak day, extracted from a global OAG timetable for 2018 (9).
- Average taxi times for 2018 published by EUROCONTROL (10).
- ICAO Fuel and emissions data for aircraft extracted from the Aviation Environmental Design Tool (AEDT) (11) (12).

Assumptions

To estimate the overall fuel consumption (and subsequently the GHGs emission) needed for taxi operations during an entire a day, all the aircraft in our European middle-size airport are classified in four different classes based on features like size and performances. Each class is represented by one of the four aircraft below aircraft:

- The Embraer 190 represents all Embraer E-jets and Airbus A220’s.
- The Airbus A320-200 represents all A320 family aircraft, including the NEO.
- The Boeing 737-800 represents all B737 aircraft including the Max.
- The Airbus A350-900 represents a twin engine wide body aircraft.

These are the most common types of aircraft which is possible to find in a generic European airport.

Moreover, to estimate yearly emissions due to taxiing, we suppose that the number of aircraft movements in a generic day is equal to 80% of the movements in a peak day.

Finally, it is assumed that on average four minutes are needed for aircraft engines warming up (before the take-off) and three minutes are needed for aircraft engines cool down (after the take in). During this time, both aircraft engines must run even if the taxiing is performed by a towing vehicle.

Model

From the ICAO data we derive the information about fuel consumption and emissions of the four aircraft types cited in the assumptions. These values are then considered as representative for all the aircraft in our airport belonging to the respective class.

In the BAU case, we combine this information with the EUROCONTROL data about the taxi times and compute the fuel consumption and CO_2 emissions during the peak day (OAG timetable). To calculate the average values of the KPIs over the entire year 2018 we multiply the peak-day results by 0.8*365, meaning that the average day will have 80% of the movements of the peak day. The emissions of other GHGs and pollutants are calculated based on conversion factors from CO_2 emissions. Finally, we calculate the

Average Temperature Response (ATR) at 20 and 100 years by using Eq. 8 of Sausen and Schumann (7).

To compute the climate KPIs after the implementation of electric towing, the process is the same as above, the main difference being that taxi times are used to compute energy consumption of the electric tugs. Subsequently, the energy consumption is converted into the corresponding CO_2 emissions (for more details see the submitted deliverable D2.4 of the ClimOP project (13)). Lastly, to compute the total CO_2 emissions from taxiing operation, the emissions generated in the warming up and cooling down of the aircraft engines due to the fuel necessary to warm up (before take-off and after landing, respectively) are added.

2.2. UPGRADE OF THE AIRPORT INFRASTRUCTURE

The goal of this assessment is to determine the potential savings in emissions (and consequently the potential reduction in impact for climate change) due to the improvements in the airport infrastructure according to energy-efficient criteria.

Airport buildings consume a significant amount of energy to maintain comfortable occupancy conditions, which require space heating and domestic hot water preparation, ventilation and air conditioning/cooling, power supply for lighting and other airport systems (e.g., elevator.). In this paper we first carry out the climate assessment as in BAU; then we carry out the climate assessment assuming the implementation of the following energy efficiency measures:

- Insulation of exterior walls.
- Optimization of windows.
- Introduction of LED lights.

Data

The energy consumption data of a medium-size airport has been made available to the ClimOP consortium (13, 14).

Assumptions

We simulate the energy consumption of a model office built with EnergyPlus (15), an open-source software developed by the US Department of Energy, assuming that the building is situated in the same European climate zone (ASHRAE classification of geographical distribution of climate conditions (16)) in which our medium-size airport is located. The simulated building is a medium-sized office building, with three floors, covering a total area of about 5000 m^2, and with a window-to-wall ratio of 33%. It is built starting from the energy consumption data (14) that was made available to the ClimOP consortium.

We estimate the energy consumption of our conceptual office building also in the year 2050 using EnergyPlus, but assuming a future climate scenario (SRES B1) as described in ClimOP submitted deliverable D2.4 (13).

To convert airport infrastructure energy consumption to the correspondent CO_2 emissions we use various conversion factors:

- from Electric energy to Primary energy (15);
- from Thermal energy to Primary energy (15);
- from Primary in GJ to Primary energy in TOE (17);
- from Primary energy in TOE to tons of CO_2 (18).

Finally, to obtain a function which describes yearly emissions over time (taking into consideration that energy consumption of the building depends on the climate scenario), we linearly interpolate over time the values of CO_2 emissions in 2019 and 2050.

Model

In the BAU case, we compute the CO_2 emissions due to the energy consumption of our middle-size airport by fine-tuning the free parameters of our EnergyPlus building simulation. Then, we compute ATR20 and ATR100 following Sausen and Schumann (7).

To compute the climate KPIs after the deployment of the OI, we follow the same steps described for the BAU case. The only difference is that now the three infrastructural upgrades for energy efficiency are included in EnergyPlus when we simulate the energy consumption of our office building.

2.3 ELECTRIFICATION OF GROUND VEHICLES AND OPERATIONS

The goal of this assessment is to determine the potential savings in emissions (and consequently the potential reduction in impact for climate change) due to a complete electrification of all ground equipment in an airport.

A long-term positive impact on climate due to the difference in emissions between the burning of fuels in traditional diesel and petrol vehicles, and the emissions produced from generating the required energy to power an electric vehicle is described in literature (19) (20). Our aim is adapting this knowledge to the specific case of the ground fleet in an airport.

In this paper we first carry out the climate assessment as in BAU (with the current ground fleet composition); then we carry out the climate assessment assuming that all petrol and diesel vehicles are replaced by equivalent electric ones.

Data

Ground fleet vehicles data provided by the ClimOP partner SEA (13, 14).

Assumptions

Ground fleet vehicles are classified in three different groups based on their size (small, medium and large) and their traction (petrol, diesel or electric). For each group, average constants (e.g. fuel consumption for km, energy consumption per km, CO_2 emissions for energy consumed, ...) have been derived from the literature and used to compute the climate and KPIs (the reader is referred to ClimOP submitted deliverables D2.3 (21) and D2.4 (13) for more detailed information).

We assume that all the petrol and diesel vehicles have an equivalent electric one. In the model the last replace the previous after the electrification operational improvement.

Model

First, we analyse the data of the ground fleet vehicles at a typical medium-size airport (14). From this analysis we obtain the number of vehicles and the correspondent km driven by each size/traction class in the considered airport. Then, we compute the fuel and energy consumptions, and consequently the CO_2 emissions, of the entire ground fleet. The total amounts of other GHGs and pollutants are emitted in proportion to the CO_2 emissions (M. Grampella, *priv. comm*). Finally, ATR20 and ATR100 are calculated following Sausen and Schumann (7).

To compute the climate KPIs after the OI, the steps of the model are the same above described for the BAU case, with the difference that the emissions are associated with the generation of electric energy necessary to power the electric equivalent of the ground vehicles.

2.4 MODEL GENERALISATION AND HARMONISATION

The initial scopes presented in the introduction of the paper were:

- Estimating the overall contribution of airport ground operations and infrastructure to climate change.
- Estimating the possible overall reduction in impact that could be obtained throughout the described set of OIs.

In the following section, results of two different case studies are presented: the MS case study refers to the European medium-size airport, while the ECAC case study extends the analysis to all the airports geographically located in the ECAC's Member States (22).

To calculate the climate KPIs for the ECAC case study, we need to generalize the three models described in the previous sections in such a way they can be used for all the airports in ECAC. For the upgrade of the infrastructure OI, first we simulate energy consumption of the already described ideal building in EnergyPlus assuming that the building is located in each one of the 4 most common European climate zones (ASHRAE classification of geographical distribution of climate conditions (16)). When we choose a generic European airport, we can directly link it to the climate zone of its geographical location. This task is completed as described in ClimOP submitted deliverable D2.4 (13). This is a fundamental step to take into consideration the correct climate environment when we simulate the yearly energy consumption of our infrastructure. Then we consider the results estimated using EnergyPlus for the conceptual building in the corresponding climate zone and scale them using a logarithmic function of the number of aircraft movements in the airport itself.

For the electrification of ground fleet OI, we need as input for our generalized model the number of small, medium and large vehicles in the considered European airport. We estimate these three values using three different linear function again of the number of yearly aircraft movements in the airport. The coefficients of the linear functions are calculated through a linear regression of the air traffic and ground vehicle data of two European medium-size airports which were made available to the ClimOP consortium (13, 14). Subsequently, we calculate the distance travelled by each vehicle category at any given airport, as follows:

$$N_{\text{Airport vehicles}} : N_{data\ \text{vehicles}} = x_{\text{km}} : data_{\text{km}}$$

where $data\ vehicles$ represents the total number of vehicles of our reference European medium-size airport $data\ km$ represents the overall distance (in km) travelled by these vehicles. These values are separately computed for each size class. In addition, in the BAU case, we use traction class percentages to derive the total Km route by each size/traction class. These percentages are extrapolated from the information we have about the two European medium-size airport and are assumed as constants for all the European airports.

In the sustainable taxiing OI the situation is more complex. The scaling approach with respect to yearly flight movements that we have previously introduced to generalize the other two OIs cannot be used to estimate the overall impact of taxiing operations because different airports have very different taxiing times. To overcome this problem, an estimate of the total emissions from taxiing is calculated by considering:

- The set of the 10 busiest airports in Europe.
- The average taxi times at these airports.
- An A320 as a unique representative aircraft type.

3. RESULTS

The list of KPIs and the results obtained for both the MS and the ECAC case studies with the comparison of the different OIs are shown in Table 1 and Table 2. Histogram visualising CO_2 emissions contribution for the ECAC case study with the comparison of the different OIs is shown in Figure 1. Overall ATR over the years for ECAC case study with the comparison of the different OIs is shown in Figure 2. Histogram visualising non-CO_2 emissions contribution for the MS case with the comparison of BAU and after OIs situation is shown in Figure 3.

For the MS case study (BAU) CO_2 emissions for taxiing operations constitute about 88% of the total CO_2 emissions. Remaining contribution derives from the ground fleet operations and from the energy consumed by the airport infrastructure, which have about the same order of magnitude. For the ECAC case study (BAU) the percentage contribution to overall CO_2 emissions of the three frameworks replicates what happens for the medium-size airport. The yearly total CO_2 emissions produced all over Europe considering the entire Ground-operation scenario is estimated at 4.96 million tons. The medium size airport contribution is limited to 0.014% of the overall CO_2 produced. In terms of global warming, the MS emissions correspond to about 0.15 μK in 20 years and 2.4 μK in 100 years. The overall effect at the European level is almost two orders of magnitude larger, with an expected contribution to global warming estimated at about 11 μK in 20 years and 180 μK in 100 years.

After OIs implementation (percentage situation is similar for both MS case study and ECAC case study), the CO_2 emissions reduction is quite visible, more than 50%. The major contribution derives as we can expect from the sustainable taxiing framework, about 47%; anyway, also contributions from the other OIs implementation is not negligible, around 5%. Moreover, if we consider the three scenarios of OIs implementation separately, we observe that the electrification of the ground fleet contributes to an 84% reduction of the associated emissions. In terms of global warming, now the middle-size airport contribution is reduced to about 0.07 μK in 20 years and 1.2 μK in 100 years. At the European level expected contribution to global warming is now estimated at about 5.2 μK in 20 years and 90 μK in 100 years. Finally, in addition to the climate-impact mitigation, the considered OIs have a beneficial impact also on the local air quality. Specifically, the emissions of pollutants such as carbon monoxide, nitrogen oxides, and particulate matter are reduced in proportion to the amount of fuel that is saved for the different operations.

KPI	*BAU*	*After OI*	*OI*
CO_2 *(tons)*	$6,06 \cdot 10^4$	$2,76 \cdot 10^4$	*SETX*
	$5,54 \cdot 10^3$	$4,19 \cdot 10^3$	*INFR*
	$2,93 \cdot 10^3$	$4,67 \cdot 10^2$	*ELEC*
CO (tons)	$5,70 \cdot 10^2$	$2,05 \cdot 10^2$	*SETX*
	$-$	$-$	*INFR*
	$1,61 \cdot 10^1$	$4.02 \cdot 10^{-1}$	*ELEC*
NO_x *(tons)*	$8,16 \cdot 10^1$	$2,93 \cdot 10^1$	*SETX*
	$-$	$-$	*INFR*
	$2,28$	$9,99 \cdot 10^{-1}$	*ELEC*
$PM_{2.5}$ *(tons)*	$1,38 \cdot 10^1$	$4,98$	*SETX*
	$-$	$-$	*INFR*
	$3,88 \cdot 10^{-1}$	$9.73 \cdot 10^{-3}$	*ELEC*
PM_{10} *(tons)*	$1,73 \cdot 10^1$	$6,22$	*SETX*
	$-$	$-$	*INFR*
	$4,84 \cdot 10^{-1}$	$1,21 \cdot 10^{-2}$	*ELEC*
ATR20 (K)	$1,26 \cdot 10^{-7}$	$5,72 \cdot 10^{-8}$	*SETX*
	$1,41 \cdot 10^{-8}$	$1,14 \cdot 10^{-8}$	*INFR*
	$6.07 \cdot 10^{-9}$	$9.68 \cdot 10^{-10}$	*ELEC*
ATR100 (K)	$1,95 \cdot 10^{-6}$	$8,89 \cdot 10^{-7}$	*SETX*
	$3,53 \cdot 10^{-7}$	$2,79 \cdot 10^{-7}$	*INFR*
	$9,44 \cdot 10^{-8}$	$1,51 \cdot 10^{-8}$	*ELEC*
Fuel (l)	$2,38 \cdot 10^7$	$1,09 \cdot 10^7$	*SETX*
	$-$	$-$	*INFR*
	$6,71 \cdot 10^5$	$-$	*ELEC*
Energy (kWh)	$-$	$5,42 \cdot 10^6$	*SETX*
	$2,60 \cdot 10^4$	$2,12 \cdot 10^4$	*INFR*
	$1,01 \cdot 10^4$	$2.03 \cdot 10^6$	*ELEC*

Table 1 - List of KPIs and the results obtained for MS case study with the comparison of the different OIs. SETX refers to the electric towing taxiing; INFR to the upgrade of the infrastructure; ELEC to the electrification of ground fleet vehicles.

KPI	*BAU*	*After OI*	*OI*
CO_2 (tons)	$4,24 \cdot 10^{6}$	$1,90 \cdot 10^{6}$	*SETX*
	$5,38 \cdot 10^{5}$	$4,28 \cdot 10^{5}$	*INFR*
	$1,77 \cdot 10^{5}$	$2,79 \cdot 10^{4}$	*ELEC*
CO (tons)	$4,01 \cdot 10^{4}$	$1,43 \cdot 10^{4}$	*SETX*
	–	–	*INFR*
	$9,63 \cdot 10^{2}$	$2,40 \cdot 10^{1}$	*ELEC*
NO_x (tons)	$5,71 \cdot 10^{3}$	$2,01 \cdot 10^{3}$	*SETX*
	–	–	*INFR*
	$1,38 \cdot 10^{2}$	$5,97 \cdot 10^{1}$	*ELEC*
$PM_{2.5}$ (tons)	$9,73 \cdot 10^{2}$	$3,47 \cdot 10^{2}$	*SETX*
	–	–	*INFR*
	$2,34 \cdot 10^{1}$	$5,81 \cdot 10^{-1}$	*ELEC*
PM_{10} (tons)	$1,22 \cdot 10^{3}$	$4,34 \cdot 10^{2}$	*SETX*
	–	–	*INFR*
	$2,92 \cdot 10^{1}$	$7,24 \cdot 10^{-1}$	*ELEC*
ATR20 (K)	$8,78 \cdot 10^{-6}$	$3,94 \cdot 10^{-6}$	*SETX*
	$1,43 \cdot 10^{-6}$	$1,15 \cdot 10^{-6}$	*INFR*
	$3,67 \cdot 10^{-7}$	$5,78 \cdot 10^{-8}$	*ELEC*
ATR100 (K)	$1,37 \cdot 10^{-4}$	$6,12 \cdot 10^{-5}$	*SETX*
	$3,57 \cdot 10^{-5}$	$2,82 \cdot 10^{-5}$	*INFR*
	$5,71 \cdot 10^{-6}$	$9,00 \cdot 10^{-7}$	*ELEC*
Fuel (l)	$1,67 \cdot 10^{9}$	$7,48 \cdot 10^{8}$	*SETX*
	–	–	*INFR*
	$4,03 \cdot 10^{7}$	–	*ELEC*
Energy (kWh)	–	$3,91 \cdot 10^{8}$	*SETX*
	$2,63 \cdot 10^{6}$	$2,14 \cdot 10^{6}$	*INFR*
	$7,47 \cdot 10^{5}$	$1,21 \cdot 10^{8}$	*ELEC*

Table 2 - List of KPIs and the results obtained for ECAC case study with the comparison of the different OIs. SETX refers to the electric towing taxiing; INFR to the upgrade of the infrastructure; ELEC to the electrification of ground fleet vehicles.

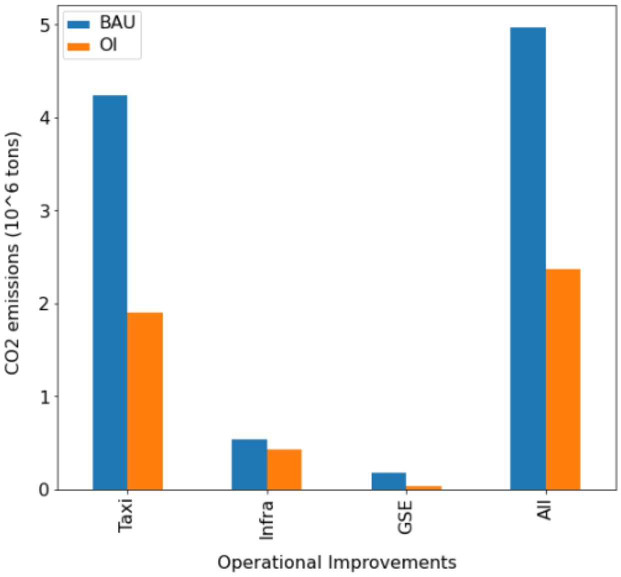

Figure 1 – Comparison of the CO_2 emissions from taxiing, airport infrastructure, and GSE and operations in the ECAC case study. Emissions in the business-as-usual case and with the proposed OIs are shown in blue and orange, respectively.

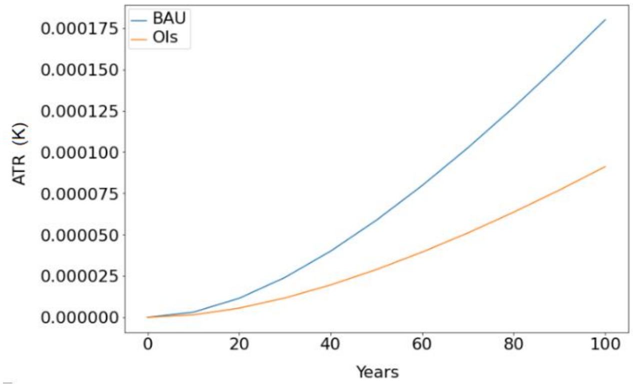

Figure 2 – Predicted Average Temperature Response (ATR) for a time horizon of 100 years in the ECAC case study. Colours are the same as in previous figures.

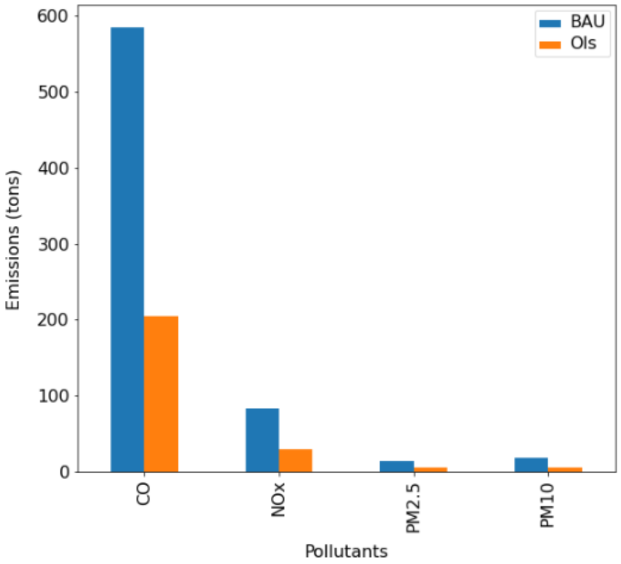

Figure 3 - Comparison of the CO2 emissions from taxiing, airport infrastructure, and GSE and operations in the case study of the individual mid-size airport. Emissions in the business-as-usual case and with the proposed OIs are shown in blue and orange, respectively.

4. DISCUSSION

The assumptions adopted in the methodology described in the previous sections introduce uncertainties in the results, which are discussed as follows.

In the electric taxiing model, one of the major sources of uncertainty is the time required for warming up and cooling down aircraft's engines. If engines are not warmed up enough before take-off or cooled down after landing, this can result in increased wear and thus maintenance. The increase of these times can significantly reduce the effectiveness of electric towing (13). In addition, we consider only 4 types of aircraft to describe the entire aircraft fleet of an airport. Moreover, yearly emissions are obtained computing them for a peak day and then assuming that in a generic day taxiing operations are represented by 80% of taxiing operations in the considered peak day. Finally, a complete model should take into account also CO_2 emissions due to APU running during take-off and CO_2 emissions produced by electric towing vehicles during buffer time (e.g. time for the tow truck to reposition from one flight to the next). A more sophisticated model for sustainable taxiing in the specific case of the specific European middle-size airport we have considered since the beginning, which try to optimise number of towing vehicles considering what has been just explained, is presented in (13).

In the model of the upgrade of the airport infrastructure, we use the same simplified office building to assess the energy demand of any airport (supposing a logarithmic relationship with respect to the number of flights during the year). The possible error introduced with this assumption is estimated through the comparison between our results and the data of the Energy Audit 2019 and it is of the order of 30%. Energy sources are another cause of uncertainty. The presented results are obtained assuming the hypothesis that the electrical energy is the only one used to satisfy the total energy demand of the airport infrastructure. However, airports commonly use a combination of energy sources. Finally, a last source of uncertainty derives from the unknown future climate scenario used to compute CO_2 emissions in 2050. Anyway, it is possible to prove that this kind of uncertainty is negligible (13).

In the electrification of ground fleet and operations model, the first simplification consists in classifying the entire ground fleet in only three size categories (small, medium and large) considering average factors for each class in the following computation. Furthermore, data provided by the ClimOP partner SEA sometimes only consists in an average use of the vehicles, which can significantly vary at other airports depending on their seasonality and other airport necessities (e.g. airports in area with cold winters are expected to have more snow and de-icing vehicles than the airports in the Mediterranean regions). An additional assumption which increases the level of uncertainty is that the proportion of each traction class of vehicles (with respect to the total number of vehicles in each size class) is constant across all airports.

In addition to all the above uncertainties, it is necessary to focus on the assumptions we made to generalise and harmonise the three OIs model in the ECAC case study. The taxiing model considers only one aircraft type, and the impact of electric taxiing is estimated using the average taxi times at the ten busiest airports in Europe. In the infrastructure model, we scale energy consumption of the conceptual office building to obtain energy consumption in a specific airport using a logarithmic function of the number of aircraft movements. Such a proxy is estimated as the result of a logarithmic fit of the number of employees as a function of the number of aircraft movements in the ten busiest airports in Europe (14). The rationale of this choice is that a busier airport expectedly has more employees and thus more office buildings. However, additional data from other airports would be necessary to validate the relation between these two quantities. Similarly in the ground fleet model, data of two European medium-size airports has been used to calculate a linear model that estimates the airport ground fleet size based on the yearly number of flights. The uncertainty introduced by this fit has been estimated using data of the ground fleet of a third, seasonal airport in Europe (14). It is estimated in about 50% in terms of total CO_2 emissions.

An additional source of uncertainty is that, in all our computations, we assume that electrical energy is generated all over Europe using the same mix of energy sources (e.g. coal, oil, gas, renewable sources). This mix doesn't exactly reflect the specific energy production which differs across countries and regions and, for this reason, can increase the uncertainties in the estimation of emissions and impact on climate change. Second, we compute the increase in ppm (as needed in Sausen and Schuman's equations 7 and 8 for RF* and ATR) by multiplying the tons of CO_2 emissions times a conversion factor that was obtained taking as indicators the global CO_2 emissions and increase in ppm for 2018 (used values are in (23) (24)). We suppose that the ratio between the increase in ppm and the tons of CO_2 emitted is a constant which can be used to describe the single contribution given by local emissions in changing atmosphere gas concentration.

5. CONCLUSIONS

This paper provides an estimate of the total contribution to climate change of the emissions generated at airport level by the office buildings, taxiing and ground support operations. In addition, the potential impact on climate of three operational improvements aimed at reducing such emissions is calculated.

In the BAU, about 88% of the total emissions is due to taxiing operations. Remaining contribution is related to the ground fleet operations and to the energy consumed by the airport infrastructure, which have about the same order of magnitude.

The major contribution for the reduction derives from the introduction of electric towing vehicles for the aircraft taxi phase, a reduction estimated at 47%. Then another 5% reduction can be reached by upgrading the airport infrastructure in accordance with more efficient criteria and electrifying the ground fleet used for everyday ground operations.

In terms of global warming, the considered operational improvements applied at the European level would reduce Ground scenario impact on ATR from 11 μK to 5.2 μK in 20 years, and from 180 μK to 90 μK in 100 years.

It should be emphasised that the proposed operational improvements do not simply move the location of the emissions from the airport ground to the location where the electric energy is produced, which would constitute an improvement of the local air quality but would not make a difference in terms of climate impact. Instead, the generation of electricity by most energy sources (oil, gas and particularly wind, solar and other renewables) releases on average less GHGs compared to the corresponding amount emitted by fossil-fuel engines. Although the overall airport contribution to the global temperature increase is small, the possible reduction in CO_2 emissions due to the implementation of the described operational improvements is significant and, on average, it is estimated at more than 50% less than in the current business as usual.

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