Emissions from Aircraft and Handling Equipment in Copenhagen Airport

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Abstract

This paper explains a detailed emission inventory for Copenhagen Airport with a spatial resolution of 5x5m comprising the emission sources main engines, APU's and handling equipment. Handling is the largest emission source of NO_x and PM on the airport apron. The emission contributions from APU are also considerable, whereas the apron emissions of NO_x and in particular PM from main engines are small. Conversely, on the apron, main engines is the largest emission source of HC and CO, and for the airport regarded as a whole main engines becomes the largest emission source for all pollutants. The PM results for main engines (FOA3.0 method) show that more than 50 % of the PM emissions originate from the sulphur of the jet fuel. This indicates a PM decrease of around 50 % if jet fuel sulphur content becomes zero, and most likely the APU emissions of PM will be significantly reduced also.

Keywords: Emissions, airport apron, main engines, APU, handling equipment.

1. Introduction

Arising from the concern of airport workers health, in 2009-2011 a detailed investigation of the air pollution in Copenhagen Airport has been performed by the Danish Centre for Environment and Energy, Aarhus University (DCE). Main attention was given to the airport apron area (part of apron shown in Figure 1) where handling activities occur. The airport study comprises a detailed baseline emission inventory for aircraft main engines, auxiliary power units (APU) and handling equipment, as well as subsequent dispersion modeling of the air quality arising from these sources (Ellermann et al., 2011).

This paper presents the emission inventory for the airport having a spatial resolution of 5 m x 5 m. A description of flight operational data, usage of APU and handling activities as well as the digitization of these will be given along with input emission factors. Total emission results of CO, HC, NO_x and PM will be explained for the airport as a whole and for the apron area in focus. Spatially distributed PM results for the apron will also be shown suited for the further dispersion modelling work.

2. Method

Figure 1 shows an intersection of the airport. Terminal gates are numbered (e.g. B7 or C28) and marked with a small (black) dot. The main engine start-up marks are designated with larger (red) dots (e.g. P or Q1). The aircraft taxi ways close to the gates are visible as (green) curves and (red) lines and connect to the shared taxiways that lead from/to the runways (blue lines). The remaining small (black) dots in Figure 1 are points in the digitalized road network.

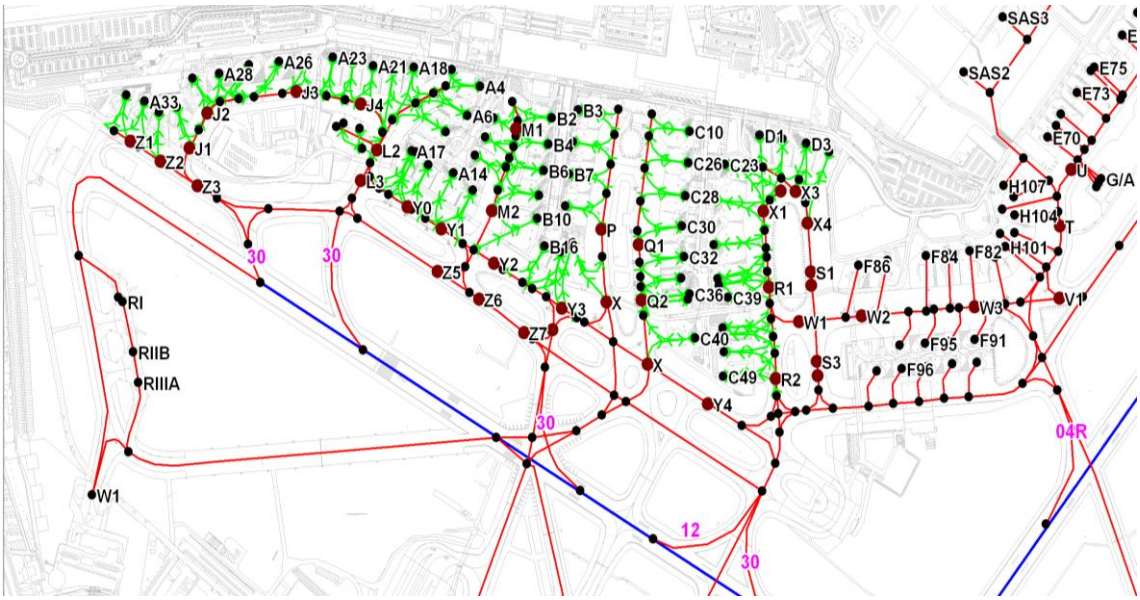

Figure 1: Airport map, showing gates, start-up marks, taxiways and part of runways.

2.1 Activity data

Flight operations

The airport has provided flight activity data for four days in 2009 with preferable use of each of the runways 12, 30, 04L+04R and 22L+22R. The data consist of aircraft type, registration number, airline operator, gate, off/on block time, specification of start/landing runway and time.

Usage of auxiliary power unit (APU)

The time period for use of aircraft auxiliary power units (APU) are taken from the International Civil Aviation Organization Airport Air Quality Guidance Manual (doc. 9889), c.f. (ICAO, 2008). The total APU time before aircraft off block is divided into “APU Start” and ”Boarding” each associated with different APU engine loads (Table 1).

Table 1: Time intervals for APU usage in Copenhagen Airport.

APU condition →	**Arrival**	**APU Start**	**Boarding**	**During push-back**	**Main engine start**
APU load →	**Normal**	**Start-up**	**Normal**	**Normal**	**High**
2 engine aircraft	300 s	180 s	216 s	Calculated	35 s
4 engine aircraft	300 s	180 s	318 s	Calculated	140 s

During aircraft push-back the APU engine is assumed to be running at normal loads on the way to the main engine start-up mark. At this point the aircraft is stationary during main engine start-up (time duration, Table 1) at high APU engine loads.

Main engine start-up

In the model, the aircraft is pulled by the push-back tractor with a speed of 5 km/h (1.5 m/s) along the green lines toward the point of main engine start-up.

Usage of handling equipment

The handling companies have provided information of handling equipment types in use at the gate after aircraft arrival and prior to aircraft departure along with the total handling time per arrival/departure, the working time per equipment type and average engine load factors. The

handling information are grouped into the four aircraft size categories B-E, comprising the whole range of aircraft types present in the flight operational data from the smallest jets in B to the largest jets in E (A330/A340/B747/B777).

According to the handling companies the toilet truck and water truck are used in connection with aircraft departure, whereas catering and refueling of the aircraft are made after arrival. The fuel truck is used for refueling of aircraft at the gates not equipped with fuel pipe lines.

The push-back tractors are used to pull jet aircraft from the gate towards the point of main engine start-up. The push-back tractors pull with a speed of 5 km/h (1.5 m/s), and hence, for each departure, the time duration for tractoring after off-block depends of the distance between the gate and the point of main engine start-up.

For the subsequent emission calculations, a complete list of the handling equipment is available from the handling companies comprising equipment ID number, fuel type, engine size, and engine age/or EU emission stage.

Table 2: Handling equipment types and activity data for Copenhagen Airport.

	Arrival				**Departure**				
Aircraft category →	**B**	**C**	**D**	**E**	**B**	**C**	**D**	**E**	
Handling period (min) →	**15**	**20**	**30**	**40**	**15**	**20**	**30**	**40**	
Equipment type	Working time (min)				Working time (min)				Load factor
Baggage truck	9	10	15	25	9	10	15	25	0.15
Conveyor belt	10	20	20	20	10	20	20	20	0.15
Push-back at gate	0	0	0	0	10	10	10	10	0.15
Push-back moving	0	0	0	0	0	0	0	0	0.75
Container loader	0	15	27.5	35	0	15	27.5	35	0.45
Container transporter	0	15	27.5	35	0	15	27.5	35	0.35
Fuel (dispenser truck)	10	15	30	50[a]	0	0	0	0	0.1
Fuel (refuelling truck)	10	15	30	50[a]	0	0	0	0	0.1
Cleaning highloader	0	0	10	15	0	0	10	15	0.45
Cargo/Post tractor	0	5	5	5	0	5	5	5	0.15
Toilet truck	0	0	0	0	0	10	20	20	0.25
Catering B/C/D/E	1	3	5	5	0	0	0	0	0.1/0.2/0.22/0.22
Water truck	0	0	0	0	0	7,5	15	15	0,25

2.2 Digitalization of activity data

The movement of the aircraft and the activities for APU, push-back tractor, main engine start-up and handling are digitized in a 5x5 m grid on the electronic map of the airport (map intersection shown in Figure 1). The text below describes the model assumptions made in order to determine the chronological sequence of time for each activity and the time duration spend in each calculation cell.

Aircraft movements

The aircraft movements are split into the phases taxi to departure, taxi queuing, take off, climb out, descent, runway deceleration, taxi runway and taxi to gate. The documentation behind noise monitoring at Copenhagen Airport is used to map out the aircraft taxiways and aircraft start and landing speeds (Svane et al., 1997). Further assumptions regarding aircraft taxi speed, aircraft runway acceleration/deceleration and climb/landing gradients are made to simulate the movements of the aircraft in the airport as described by Winther et al. (2006).

APU, push-back tractor and main engine start-up

The APU activities after aircraft arrival, during APU start-up and aircraft boarding occur at the gate. In the model, the APU engine is running during the push-back of the aircraft (in some situations one main engine is turned on) along the green lines toward the point of main engine start-up. Aircraft dimension data determine the vertical placement of the APU in each case.

Handling equipment

It is difficult to determine precisely the exact chronological time intervals of work for the individual equipment types during the handling of the aircraft. Thus, in the model the specific working duration is increased to cover the entire handling period, and the emission rates are decreased correspondingly. An exception is made for push-back tractors. These machines are assumed to be operating in a 10 minute period before off-block time for departures where push-back assistance is needed. The handling activities are assumed to take place on the right side of the aircraft in the area stretched by the aircraft length x wing length.

2.3 Emission factors

As input for the subsequent inventory calculations, fuel consumption and emission rates must be available for the individual aircraft types present in flight operational data (main engines and APU) as well as for the ground based handling equipment.

Main engines

By using the aircraft registration number as an entry the specific engine type and number of engines are found in the global aircraft database "JP Airline-Fleets 2009/2010" (www.flightglobal.com). The engine fuel flows (kg/s), emission indexes (g/kg fuel; CO, HC, NO_x) and soot numbers are looked up in the ICAOs Engine Exhaust Emission Database (www.caa.co.uk) for jet engines. For turbo prop aircraft fuel flows and emission indexes of CO, HC and NO_x are used from the emission database kept by the Swedish FOI (Totalförsvarets Forskningsinstitut, www.foi.se).

Emission indexes for PM on a mass basis are not available from the ICAO or FOI databases. Instead these emission indexes are calculated by using the ICAO validated FOA3.0 method (ICAO, 2008) for jet engines as a function of the engine specific soot number and HC emission and the sulphur content in the jet fuel. For turbo prop aircraft, PM emission indexes are derived from work made by Rindlisbacher (2009).

APU and main engine start-up

CO, HC, NO_x and PM emission factors for APU (kg/h) are taken from ICAO (2007), and fuel factors come from the German LASPORT (LASat for airPorts) air quality calculation model for airports (Janicke, 2010). The APU emission data are grouped into aircraft seating capacities and old/new aircraft types. This aircraft classification is made for the aircraft types used in Copenhagen Airport in order to stratify correctly the APU fuel and emission factors. The HC emissions for main engine start-ups are calculated from the method given in LASPORT.

Handling equipment

For diesel engines the emission factors of CO, HC, NO_x and PM are grouped according to the EU emission directives for non road engines (Stage I-IV) and road transport vehicles (Euro I-V), and supplementary information are used for older engines. The fuel consumption and emission factors (g/kWh) for non road engines are taken from the mobile part of the official Danish emission inventories reported for the UNECE CLRTAP convention (Winther, 2012). In the case of road transport vehicles (e.g. cleaning and catering trucks) the EU ESC (European Stationary

Cycle) emission limits (g/kWh) are directly used. For old and new gasoline fuelled baggage tractors, respectively, the engine technologies are similar to the engine technologies for gasoline cars in the 1970's (ECE 15/00-01) and the first generation of catalyst cars (EURO 1). Time related fuel and emission factors are derived by combining the g/kWh specific fuel consumption/emission factor with the detailed handling equipment data for technology level and engine size, and the average information of engine load factor and equipment working time.

3. Results

Table 3 shows the fuel consumption, emissions and emission factors for main engines, APU and handling equipment for one day in Copenhagen Airport, taken as an average for the four days represented by flight data. The calculated emission results are generally explained by the size of the derived fuel related emission factors and the calculated fuel consumption.

Table 3: Fuel consumption, emissions and emission factors for main engines, APU and handling equipment for one average day in Copenhagen Airport.

Source	Activity	Fuel	HC	CO	NO_x	PM	HC	CO	NO_x	PM
		kg/day					g/kg fuel			
APU	APU arrival	2716	1.8	13.1	22.6	3.1	0.663	4.811	8.325	1.155
APU	APU at APU start	1115	21.8	38.7	6.6	0.4	19.539	34.734	5.929	0.339
APU	APU boarding	2013	1.3	9.5	16.9	2.3	0.663	4.726	8.379	1.154
APU	APU at ME start	478	0.2	1.8	4.4	0.7	0.477	3.770	9.112	1.412
APU	APU during push back	479	0.3	2.2	4.1	0.7	0.722	4.530	8.536	1.364
Handling	Handling arrival	1496	7.8	29.0	49.3	3.3	5.246	19.400	32.949	2.206
Handling	Handling departure	1905	10.6	38.4	69.5	4.4	5.563	20.162	36.487	2.294
ME	Taxi arrival (taxiway)	24966	62.1	574.4	108.6	2.8	2.489	23.007	4.350	0.114
ME	Taxi departure (taxiway)	22469	56.8	520.8	97.2	2.6	2.526	23.179	4.325	0.117
ME	Taxi departure (queuing)	35177	84.0	794.5	152.7	3.9	2.387	22.586	4.342	0.112
ME	Landing (runway decel.)	1935	4.6	43.4	8.5	0.2	2.353	22.440	4.369	0.115
ME	Landing (runway taxi)	1320	4.1	32.4	5.6	0.2	3.141	24.523	4.275	0.121
ME	Take off (runway)	28421	1.9	16.0	706.3	4.8	0.068	0.564	24.853	0.170
ME	Landing (descent)	3572	9.4	83.3	15.4	0.4	2.620	23.317	4.319	0.118
ME	Take off (climb out)	7571	0.5	4.3	186.3	1.3	0.066	0.562	24.614	0.168
ME	ME at ME start	3210	95.3	71.9	14.2	0.3	29.684	22.397	4.414	0.105
ME	ME during push back	492	1.2	13.7	2.1	0.0	2.511	27.891	4.177	0.100
Push back	Push back moving	129	0.3	1.1	4.6	0.2	2.037	8.651	35.689	1.239
Push back	Push back at gate	232	0.5	2.0	8.2	0.3	2.021	8.612	35.517	1.234
Total		139694	364.5	2290.5	1483.1	32.0				

Figure 2 shows the emission percentage shares for handling, APU and main engines for the airport in total and for a limited area of the apron ("inner apron") situated between the terminal fingers. The NO_x and PM emission shares for the inner apron are significantly high for handling and APU. For handling, the high emissions are due to the high fuel related emission factors for the diesel fueled handling equipment (Table 3). Having somewhat lower emission factors, the large fuel consumption for APU is the main reason for the high emissions in the APU case.

For main engines the NO_x and PM emissions are small on the inner apron due to the very small emission factors during taxiing. Conversely, the main engines emit large amounts of HC and CO while taxiing and during engine start-up, due to the poor combustion performance at these engine loads. The HC and CO emission shares become even higher for the airport in total. During take off the emissions of NO_x are high due to the high engine combustion temperature.

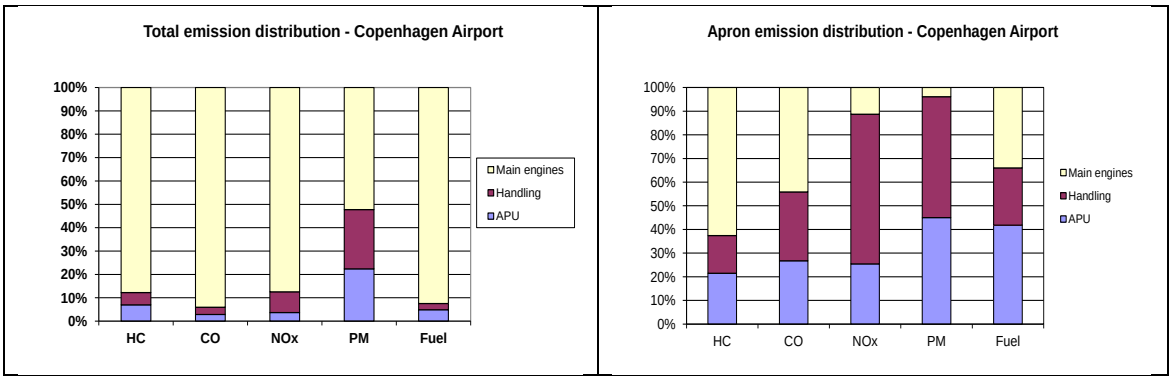

Figure 2 The percentage emission share for the airport and the inner part of the apron.

Figure 3 shows the total PM emissions for APU, handling, main aircraft engines and road transport. The latter PM source, being estimated from traffic counts (five relevant zones) and average emission factors (Ellerman et al., 2011), is rather insignificant. The average sulphur content in the jet fuel (942 ppm; airport refueling services) is used as an input for the FOA3.0 method in order to estimate the engine specific PM emission indices. Sulphate bound particles constitute a major part of the total PM emissions from aircraft engines, and derived from the FOA3.0 results, a PM decrease of around 50 % is expected if sulphur is completely removed from the jet fuel. Most likely the APU emissions of PM will be significantly reduced also.

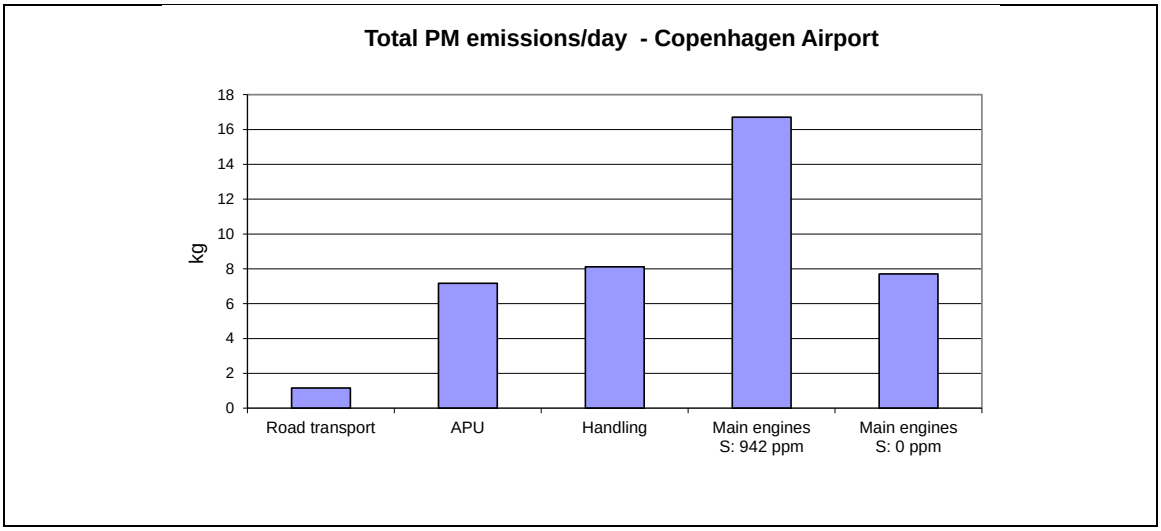

Figure 3: Total PM emissions (kg per day) by source in the airport.

Figure 4 shows the average PM emissions per day for a section of the apron area. The emission maps are shown separately for handling activities (upper picture), APU's (middle picture) and main engines (lower picture) and have a spatial resolution of 5x5 m suited for the subsequent air quality dispersion modeling work. The emission contributions are clearly visible from handling on the right side of the aircraft, the use of push-back tractors and APU's before off-block. The emission trail for the push-back tractor and the APU is also visible for the aircraft moving towards the main engine start-up point. At this point the main engine and APU emissions are also very visible. The map also clearly depicts the main engine emissions from the start-up marks and on the taxi ways towards the runways and close to the gates moving into aircraft parking position.

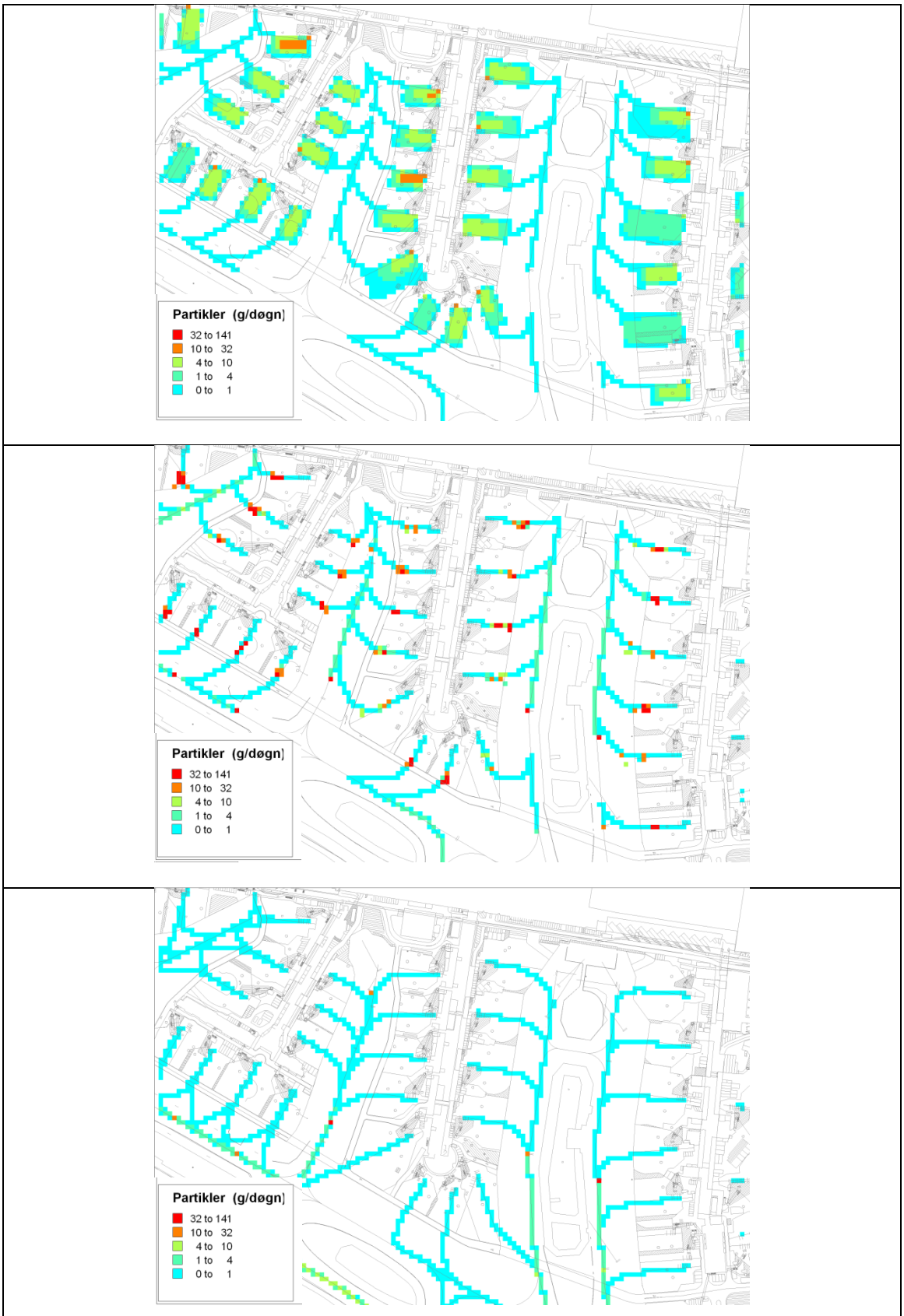

Figure 4 Total diurnal PM emissions for the apron in Copenhagen Airport (average day) for handling (upper), APU (middle) and main engines (bottom).

4. Conclusion

A detailed emission inventory for Copenhagen Airport has been made with a spatial resolution of 5x5m comprising the emission sources main engines, APU's and handling equipment. The calculated emission results are generally explained by the size of the derived fuel related emission factors and the calculated fuel consumption.

Handling is the largest emission source (shares in brackets) of NO_x (63 %) and PM (51 %) on the airport apron. The emission contributions from APU (NO_x: 25 %, PM: 45 %) are also considerable, whereas the apron emissions of NO_x (11 %) and in particular PM (4 %) from main engines are small. Conversely, on the apron, main engines is the largest emission source of HC (63 %) and CO (44 %), and for the airport regarded as a whole main engines becomes the largest emission source for all pollutants. For road transport vehicles, the total airport emission shares of NO_x (1.6 %), PM (3.5 %), HC (0.8 %) and CO (0.9 %) are small, and the emission shares are expected to be much smaller for the apron only.

The PM results for main engines based on emission indices calculated with the FOA3.0 method show that more than 50 % of the PM emissions originate from the sulphur of the jet fuel. Hence, a PM decrease of around 50 % is expected if sulphur is completely removed from the jet fuel. Most likely the APU emissions of PM will be significantly reduced also.

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