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DELIVERABLE: D4

Report on impact assessment of nvPM emissions from non-regulated engines

An Agency of the European Union

Disclaimer

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EXECUTIVE SUMMARY

This report describes the activities performed in the frame of Task 4 of the SAMPLEIV project (Assessment of environmental impacts framework contract – Research on characteristics of aircraft engine emissions, EASA Contract Number – EASA.2020.FC05). It constitutes the Deliverable D4 "Report on impact assessment of nvPM emissions from non-regulated engines" of the Specific Contract 02 to the framework contract.

The results reported here come from the continuation of the analysis performed under Specific Contract 1 (SC01) of this framework contract. The study performed under the same Task 4 of SC01 is reported in the corresponding deliverable [1].

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LIST OF ABBREVIATIONS

APU	Auxiliary Power Unit
D4	Deliverable 4
EASA	European Union Aviation Safety Agency
EI	Emission Index
ICAO	International Civil Aviation Organization
IFR	Instrument Flight Regime
LTO cycle	Landing and Take-off cycle
nvPM	Non-volatile Particulate Matter
nvPMF	Non-volatile Particulate Matter Mass - First estimation
nvPNF	Non-volatile Particulate Matter Number – First estimation
SAF	Sustainable Aviation Fuel
SC01	Specific Contract 1
SC02	Specific Contract 2
VFR	Visual Flight Regime

Moreover, the next abbreviations will be used for each SAMPLEIV Consortium Partner:

SAMPLEIV Consortium Partner	Abbreviation
INSTITUTO NACIONAL DE TÉCNICA AEROESPACIAL “ESTEBAN TERRADAS”	INTA
ROLLS-ROYCE PLC	RR
THE UNIVERSITY OF MANCHESTER	UoM
CARDIFF UNIVERSITY	CU
ZHAW ZURICH UNIVERSITY OF APPLIED SCIENCES	ZHAW
UNIVERSIDAD POLITÉCNICA DE MADRID	UPM

Table 1. SAMPLEIV Consortium Partners Abbreviations

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1. GENERAL DESCRIPTION: STUDY FRAMEWORK DEFINITION

The terms of reference of:

TASK 4: IMPACT ASSESSMENT OF NVPM EMISSIONS FROM NON-REGULATED ENGINES AND SELECTION OF ENGINES FOR EMISSION MEASUREMENTS

are as follows:

- Evaluate the relevance of non-regulated engine emissions in the European civil airports.
- Specify a set of candidate representative non-regulated engines to EASA to be confirmed for measurement in Task 5.

The following civil engine categories are included in the terms of reference:

- Turbofan engines with a maximum certified rated thrust lower than 26.7 kN
- Turboprop engines
- Piston engines
- Helicopter Turboshaft engines
- Auxiliary Power Units (APU) installed in civil aircraft.

Note: Emissions performance of turboshaft helicopter engines and APU can be very similar. Therefore, efforts on d) and e) for emissions characterisation can be combined.

Subtask 1: Activity of aircraft with non-regulated engine emissions at European Airports

The contractor shall perform an aircraft and helicopter activity data collection for representative European Airports and determine the share of movements with engines specified in Task 4 description, for each engine category and for each engine type. Similar engine types can be grouped into families. In addition to the activity data, the contractor shall also take the size of engines and where available, the estimated emission characteristics into account (e.g. low fuel burn but high expected emission factors) as a basis for Subtask 2.

Subtask 2: Candidate non-regulated engines to be measured

Based on Subtask 1 outcome, the contractor shall investigate the accessibility of non-regulated engines, which could be measured and propose candidate engines to EASA.

2. SUMMARY OF SC01 WORK

2.1. Methodology

The work that has been performed required the definition of certain temporal and geographic limits. At the same time, the relevance of the different engine categories was assessed in order to justify that the selection made for the study is fully representative.

All these three elements are required for the definition of the databases used for the detailed analysis of the traffic and the emissions. In addition, the type of flight regime (IFR or VFR) may be important in the data gathering and classification.

We have assumed that using 2019 traffic for the study will be representative enough of the situation expected for the near future. Traffic levels, drastically reduced by COVID-19 pandemic measures, are likely to be recovered in the 2024-2025 period.

For the purpose of this study, we have selected the 31 EASA members, considered representative of the European traffic core. These 31 States includes 35 of the 50 busiest airports in Europe.

The definition of non-regulated engines, with respect to their emissions characteristics, includes those not covered by ICAO Annex 16 Volume II regulations. As previously indicated, five categories can be established:

- Turbofan engines with a maximum certified rated thrust lower than 26.7 kN
- Turboprop engines
- Piston engines
- Helicopter turboshaft engines
- Auxiliary Power Units (APU) installed in civil aircraft

In this categorization two simplifications can be done: helicopter turboshaft and APU share very similar structural characteristics and may be dealt as a single group. At the same time, piston engines are comparatively lower power machines and produce a much-moderated global amount of emissions, in spite of their high carbon monoxide and unburnt hydrocarbon emission factors. Their number of movements is small, the majority of them being concentrated in non-commercial airports with low global traffic and not appreciable emission problems.

A test of this assessment was performed in a small sample of airports.

2.2. Databases

The study uses the 2019 EUROCONTROL flight database as representative of the flights in the 31 EASA member and associated countries. That database registers all civil flights operated in IFR (Instrumental Flight Regime). Then, it is necessary to check whether VFR (Visual Flight Regime) flights represent a non-negligible part of the total traffic. At the same time, the number of piston flights was checked as well, with the same purpose.

For this specific purpose, a sample of three Spanish airports, Malaga (AGP), Seville (SVQ) and Vigo (VGO) has been selected, analysing all their 2019 operations, classified by flight regime and type of aircraft. Airport selection has been made trying to cover different traffic mixes. Malaga is a big airport

2.3. Study procedure

The study was performed through the traffic analysis, during a representative week, of a group of 12 European airports covering the different geographic areas and the most likely combinations of airport size and type of traffic. The airports are classified in three groups, large, medium and small, according to their respective amount of traffic.

The initially selected airports are the following:

Large:	Frankfurt	Rome Fiumicino	Zurich	Stockholm-Arlanda
Medium:	Porto	Riga	Sofia	Hannover
Small:	Trondheim	Rodhes	Eindhoven	Bratislava

"Large" are airports with more than 15 million passengers per year (2019 data), where typically a large network carrier has its hub. The selected ones rank 3rd, 11th, 17th and 27th in the 2019 traffic in Europe and cover the main geographical areas of the Continent.

"Medium" airports had between 15 and 6 million passengers in 2019. The largest, Porto, ranks 49th by 2019 traffic in Europe. In addition to network carriers, also low-cost companies have a significant presence in these airports, which have also a wide geographical coverage and their traffic includes business, holiday and local categories.

"Small" airports had less than 7 million passengers in 2019. The largest share is local or touristic traffic. Regional airlines and charters operate in these airports, as well as some services by network and low-cost carriers.

The representative week period to count flights and emissions was the intermediate week of June 2019, that it is demonstrated to be the average of that year weekly traffic.

2.4. Results SC01

For each one of the selected airports, identified by their ICAO code, the number of operations in the study week was analysed and classified in these five categories:

- Regulated engines
- Non-regulated engines (jets)
- Turboprop engines

- APUs (including turboshafts)
- Piston engines

The results are presented in [1], and correspond to the representative week period. Each engine is identified by its series denomination, model, category and thrust or power. In each airport, it is indicated the number of flights by aircraft powered by the different engines, how many engines are installed in the aircraft and the total number of each engine cycles.

A brief compilation of the engine type results can be seen in Table 2.

Table 2. Engine use results by airport [1]

Airport (ICAO code)	Regulated jets	Non-regulated jets	Turboprops	Piston	APU
Frankfurt (EDDF)	11,479	108	104	1	5,304
Rome (LIRF)	6,618	2	38	0	3,292
Zurich (LSZH)	5,232	330	194	18	2,573
Stockholm (ESSA)	4,558	78	532	0	2,313
Porto (LPPR)	2,000	52	22	0	985
Riga (EVRA)	1,296	32	556	0	874
Sofia (LBSF)	1,132	26	112	3	551
Hannover (EDDV)	1,224	80	86	20	616
Eindhoven (EHEH)	904	12	28	4	208
Rodhes (LGRP)	1,220	16	72	0	606
Trondheim (ENVA)	758	22	360	7	527
Bratislava (LZIB)	428	68	28	4	208
TOTAL	**36,849**	**826**	**2,132**	**57**	**18,057**

A summary of the results, indicating the relative utilisation (in terms of number of flights) of each engine type at the different selected airports is shown in Figure 1 (large airports), **Figure 2** (medium airports) and **Figure 3** (small airports).

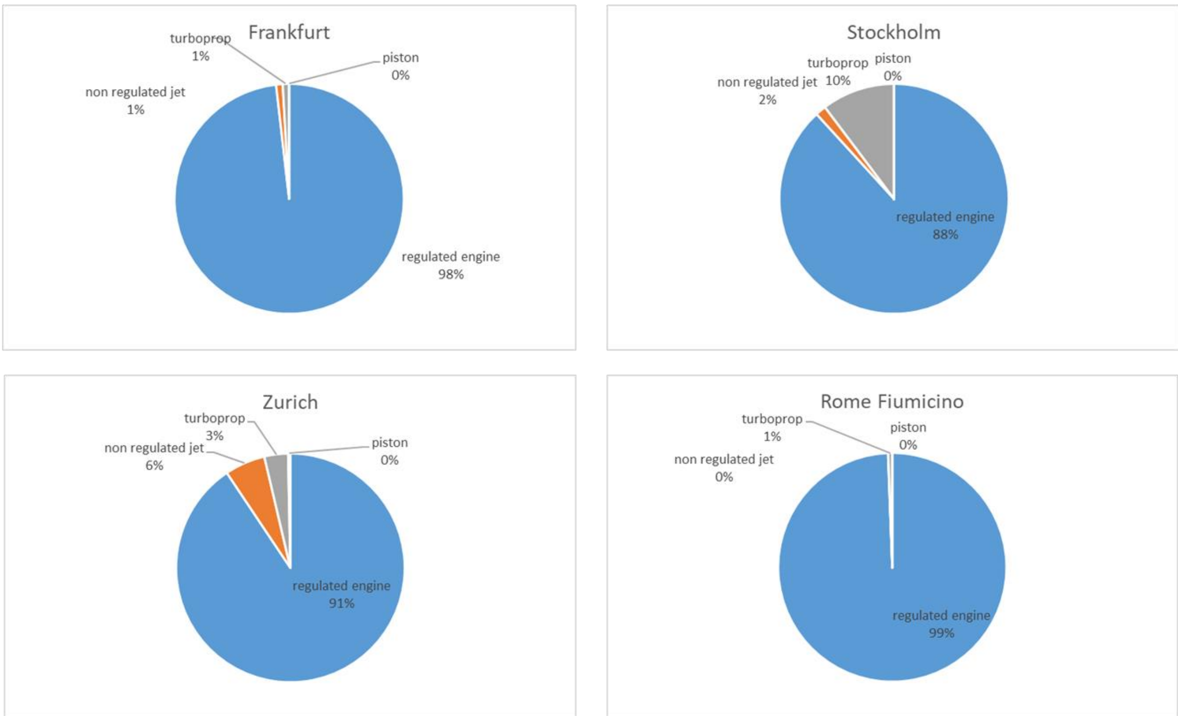

Figure 1. Relative utilisation (in terms of number of flights) of each engine type at the different selected airports (large airports).

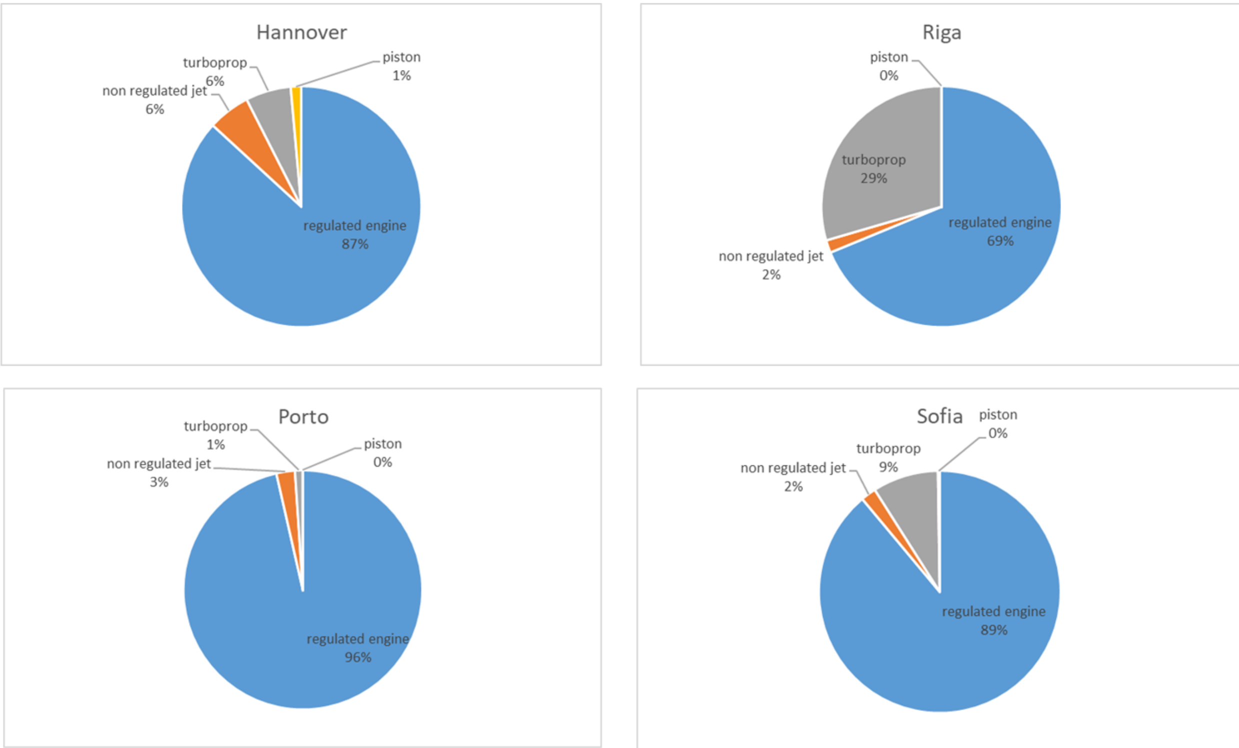

Figure 2. Relative utilisation (in terms of number of flights) of each engine type at the different selected airports (medium airports).

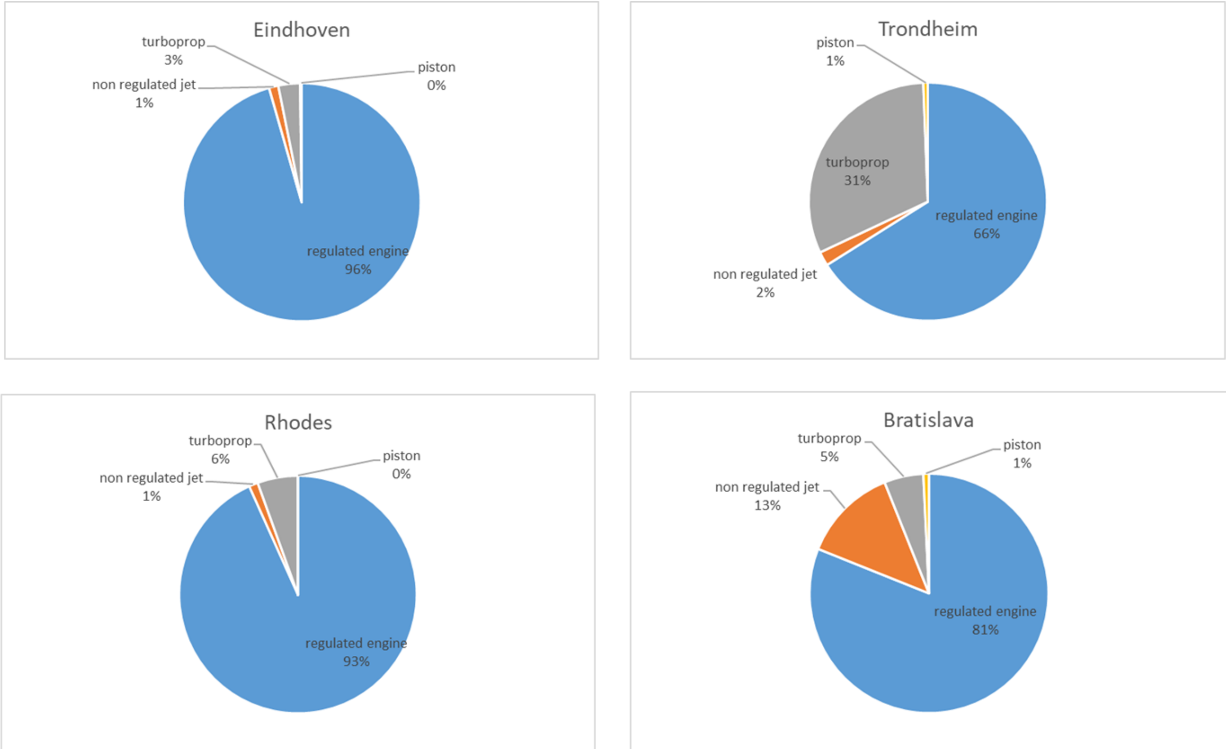

Figure 3. Relative utilisation (in terms of number of flights) of each engine type at the different selected airports (small airports).

2.5. Conclusions and recommendations based on engine utilisation (SC01)

The main conclusions that were extracted from the study performed in Task 4 of SC01, based on movements at different types of airports, are summarized hereafter:

- Piston engine effects are totally negligible. Their importance could be slightly higher, as only IFR flights are computed here but, the total number is not significant at all.
- Turboprops are relatively numerous in airports with large number of local flights, most of them in the North of Europe, as Stockholm, Riga or Trondheim, but their number is much smaller than that of regulated engines in all but the smallest ones, like Riga or Trondheim.
- Regulated jets are a wide majority in all airports but Riga or Trondheim, where are only double than turboprops.
- Nonregulated jets are very few. The largest market participation is in Zurich and Bratislava, due to high business jets traffic, but not comparable with the number of regulated engines.
- APUs have a large number of potential operations in all the airports. However, there is a certain incertitude about their use. In some airports, airlines may use ground power equipment and save APU use. In addition, APU installation is a standard option or a possible retrofit modification in many commercial small jets and turboprops, what makes difficult to ascertain their operational number. In some turboprops without an APU, the crew may apply for the same purposes, the propeller brake function, consistent in disconnecting one

propeller and use its engine for generating energy for the aircraft. In any case, the number of APUs is big enough to become an important airport emission element.

As a global conclusion, it seems interesting for Task 5 SAMPLE purposes the study of one turboprop and one APU emissions. The selected types will depend on their respective population in the previous tables and on their availability for the test period.

With respect to the population, a clear winner in the turboprop area is the Pratt&Whitney PW100 family (77% of all the turboprop cycles in the selected 12 airports), in particular its two variants PW 127 (21%) and PW150 (36%). Next one is the PT6 family with the 11% of total cycles.

In the APU range, narrow body aircraft are dominated by Pratt&Whitney APS3200 (36%), closely followed by the Honeywell GTCP 131 (34%), while widebodies, with more powerful machines, use more often Honeywell GTCP 331 (6%).

3. RESULTS SC02

The purpose of Task 4 in SC02 is to complement the analysis performed in Task 4 of SC01 by considering not only the number of movements of each engine type at the different airports, but also an estimation of their nvPM emissions, to finally be able to select the engine or engines to be tested in the frame of SAMPLEIV.

Based on the results and conclusions of SC01, for each one of the selected airports, identified by their ICAO code, the estimated nvPM emissions, in the study week, have been evaluated and classified in these three categories:

- Non-regulated jets
- Turboprop engines
- APUs

The results are presented in the following sections and correspond to the representative week period.

3.1. Turboprops

Input data on nvPM emissions for turboprops, both in terms of mass and number, are obtained from different sources. The most important is the database maintained by the Federal Office of Civil Aviation of Switzerland [2]. The database provides, for each engine, the fuel flow and the EIs at the four regimes of the LTO cycle. Based on all the available data, the total LTO cycle nvPM emissions, both in mass and number, have been determined for the engines which operate at the selected airports (**Table 3**).

Table 3. Total LTO cycle nvPM emissions of turboprops [2].

		(g)	number
Model	**Power (kW)**	**nvPMF total**	**nvPNF total**
PT6A-20	410.14	5.596	2.45E+16
PT6A-21	410.14	6.025	6.12E+16
TPE331-3U-303G	626.39	7.288	2.76E+16
PT6A-60A	782.98	10.123	2.88E+16
TPE331-12UA-701	858.3	9.833	2.97E+16
PT6A-65B	874.71	10.999	2.92E+16
PT6A-67B	894.84	12.272	3.01E+16
PT6A-67D	953.75	12.975	3.07E+16
PW118A	1342	20.838	3.44E+16
PW119B	1380	27.481	3.68E+16
PW121	1454	24.584	3.68E+16
PW123D	1454	25.626	3.65E+16
PW127E	1611	28.619	3.79E+16

		(g)	number
Model	Power (kW)	nvPMF total	nvPNF total
PW127F	1846	29.880	3.93E+16
PW127G	1846	37.665	4.77E+16
AE 2100	2787	52.836	4.77E+16
AE 2100A	2787	52.836	4.77E+16
PW150A	3415	63.216	4.77E+16

To assess the dependency of each nvPM emissions with the engine size, the emissions have been plotted against the engine power. The results are shown in (nvPM mass) and Figure 5 (LTO nvPM number). A very good linear correlation can be appreciated between the LTO nvPM mass and the engine power (**Figure 4**). In the case of particle number, there is also a clear relationship between this magnitude and the engine power (**Figure 5**).

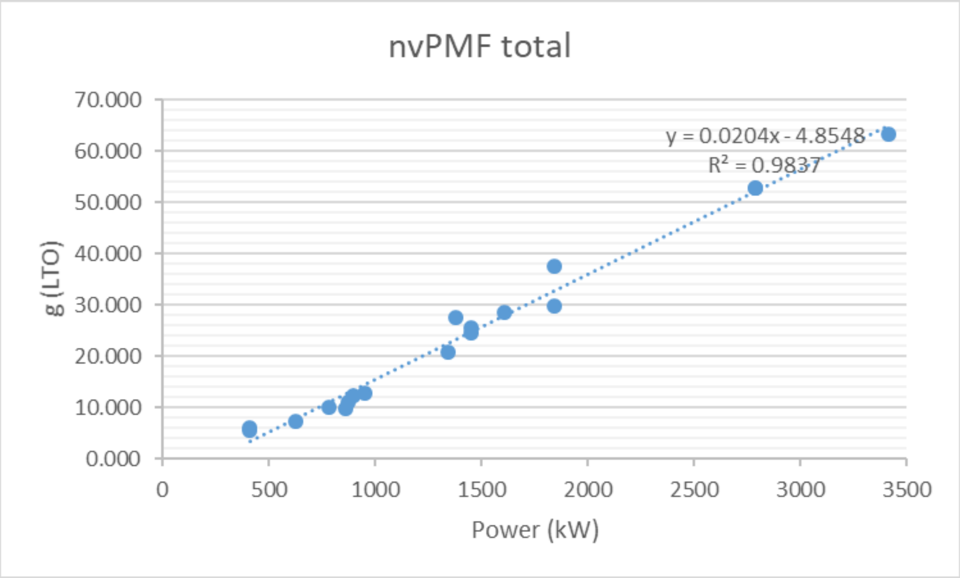

Figure 4. LTO nvPM emissions (mass) as a function of the engine power.

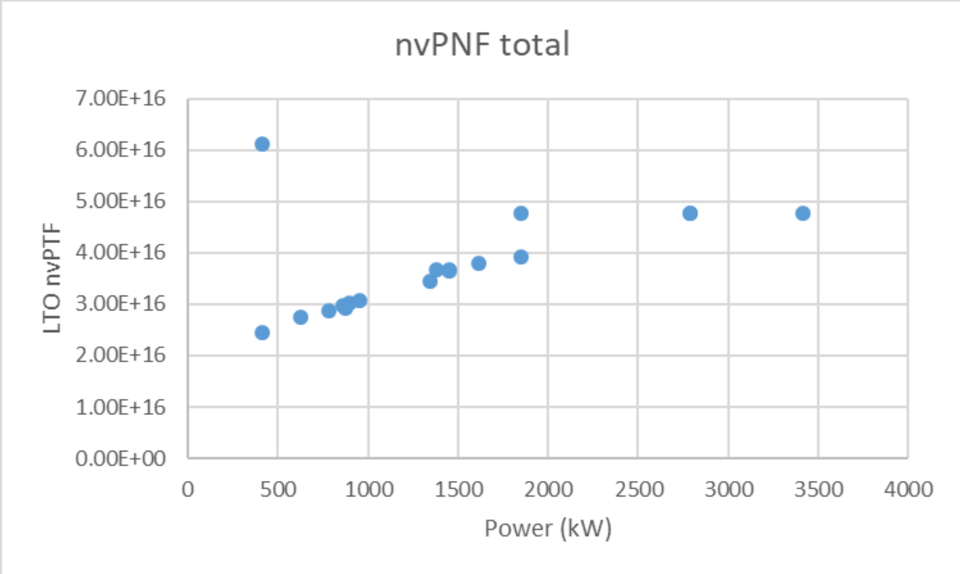

Figure 5. LTO nvPM emissions (number) as a function of the engine power.

Based on this analysis, and for the engine models for which there is no data available, the assumption to evaluate their nvPM mass is that:

- Members of a family with available data for other versions: emissions are proportional to the power of the closest model of the family.
- Independent models are associated to the engines with similar technology and power levels.

To facilitate the presentation and analysis of the results, the turboprop engines which are used in the selected airports are classified in 6 different categories according to their power. This classification is shown in Table 4.

Table 4. Classification of the turboprop engines used in the selected airports in power ranges.

Power range (kW)	Engine
410-626	M-601E
	PT6
	PT6A
	PT6A-112
	PT6A-114
	PT6A-114A
	PT6A-20
	PT6A-21
	PT6A-42A
	TPE331-3U-303G
780-953	PT6A-60A
	PT6A-65B
	PT6A-67B
	PT6A-67D
	PT6A-67B
	TPE-331
	AI-20M
	TPE331-12UA-701

Power range (kW)	Engine
1342-1454	PW100
	PW118A
	PW119B
	PW120
	PW120A
	PW121
	PW123D
1611-1846	AI-24VT
	PW124B
	PW125B
	PW127E
	PW127F
	PW127G
	PW127M
2787	AE 2100
	AE 2100A
3415	PW150A
	T56A-15

The results are then presented in **Figure 6** to**Figure 8**, and correspond respectively to the group of large, medium and small airports at the representative week period. For each airport, the chart shows the percentage of the total LTO nvPM mass of the engines within each power range.

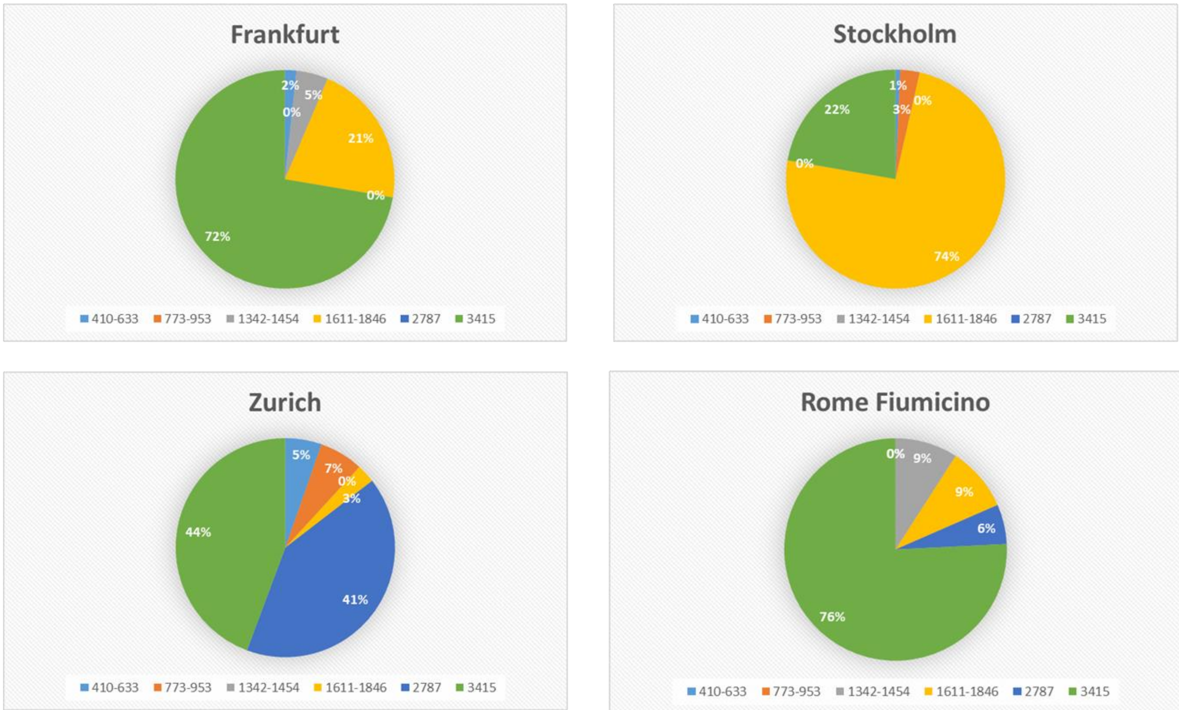

Figure 6. Total LTO nvPM mass of the engines within each power range, relative to the total (at large airports).

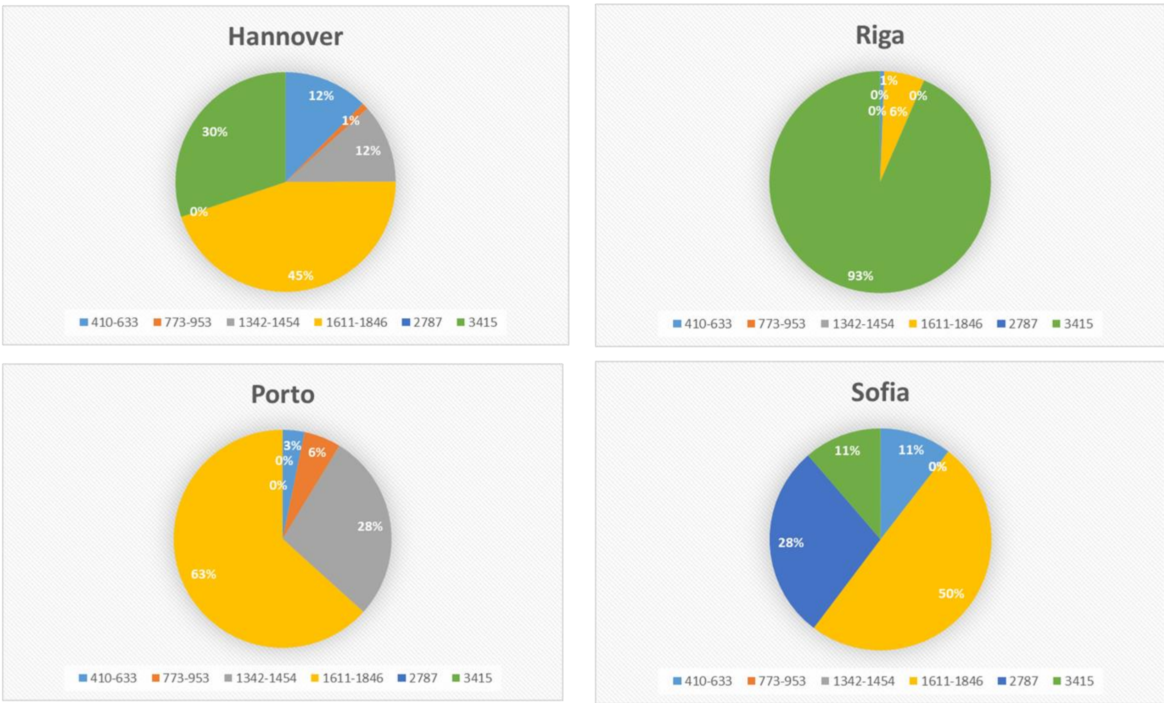

Figure 7. Total LTO nvPM mass of the engines within each power range, relative to the total (at medium airports).

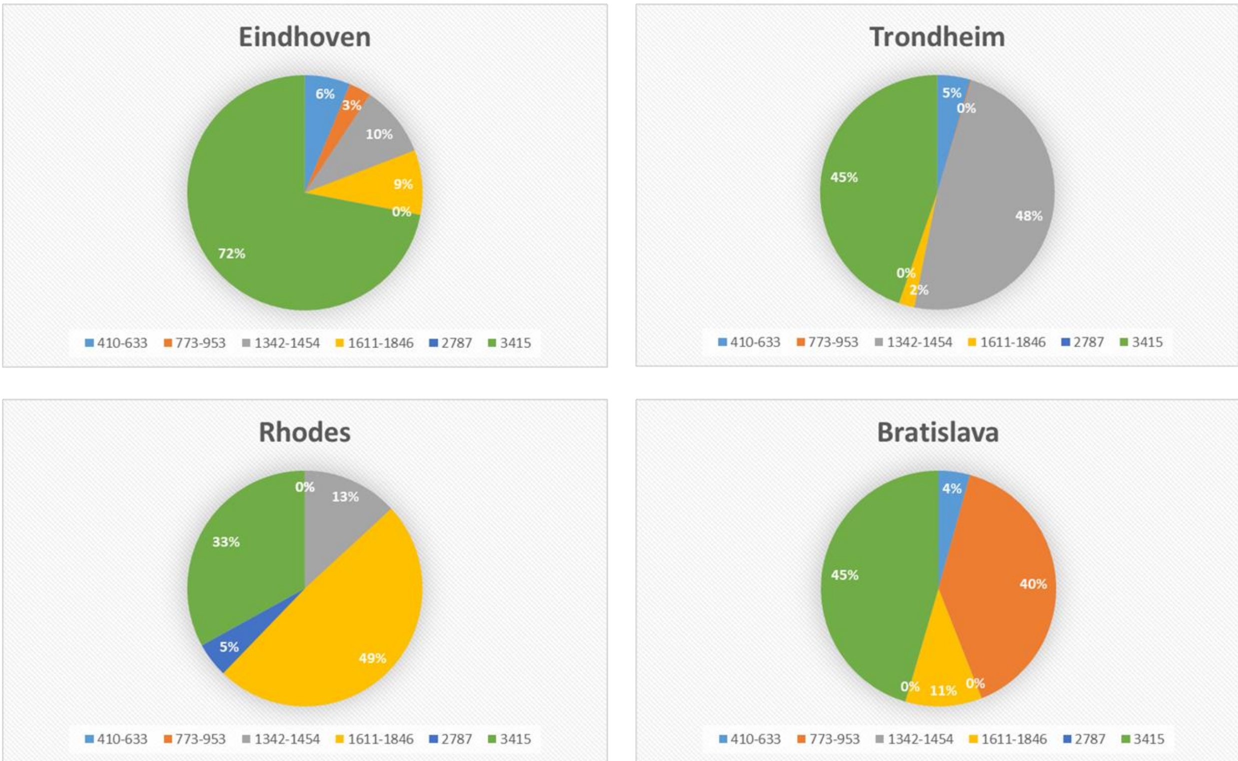

Figure 8. Total LTO nvPM mass of the engines within each power range, relative to the total (at small airports).

These charts show that the larger engines, particularly in the power range 1611-1846 kW and those with a power of more than 3000 kW are responsible for most of the nvPM mass emissions. Those engines correspond essentially with the PW100 family and the PW150 respectively. The results are compatible with the results obtained in SC01 considering only the number of movements.

The detailed results, where for each airport the emissions of each individual engine are shown, are presented in the Annex at the end of this document.

3.2. Non-regulated jets

Input data on nvPM emissions for non-regulated jets is very scarce. For the purpose of this evaluation, the measurements performed on a TFE731 engine [3] have been used as input data, together with other two smaller engines with F_{00} between 15 and 17 kN. This reference data, in terms of LTO nvPM mass and number is shown in Table 5.

Table 5. Total LTO cycle nvPM emissions of the TFE731-60 engine [3] and average of three non-regulated jets with F_{00} between 15 and 22 kN.

Engine					
Series	**Model**	**Type**	**Thrust (kN)**	**nvPM LTO (g)**	**nvPM LTO (number)**
TFE731	TFE731-60	non-regulated	22.24	10.78	3.78E+17
average		non-regulated	18.15	15.76	4.24E+17

For the rest of the engine models, the assumption to evaluate their nvPM mass is that it is proportional to their max. rate thrust, compared with the three engines average value.

To facilitate the presentation and analysis of the results, the small jet engines which are used in the selected airports are classified in 3 different categories according to their thrust. This classification is shown in **Table 6**.

Table 6. Classification of the small jet engines used in the selected airports in thrust ranges.

Thrust range (kN)	Engine
7-10	FJ33-5A
	FJ44
	HF120
	PW600
12-16	JT15D
	TFE731
	PW500
25-27	CFE738
	PW300
	PW306C
	PW306D

The results are then presented in **Figure 9**, and correspond to all evaluated airports at the representative week period. For each airport, the chart shows the total LTO nvPM mass of the engines within each thrust range.

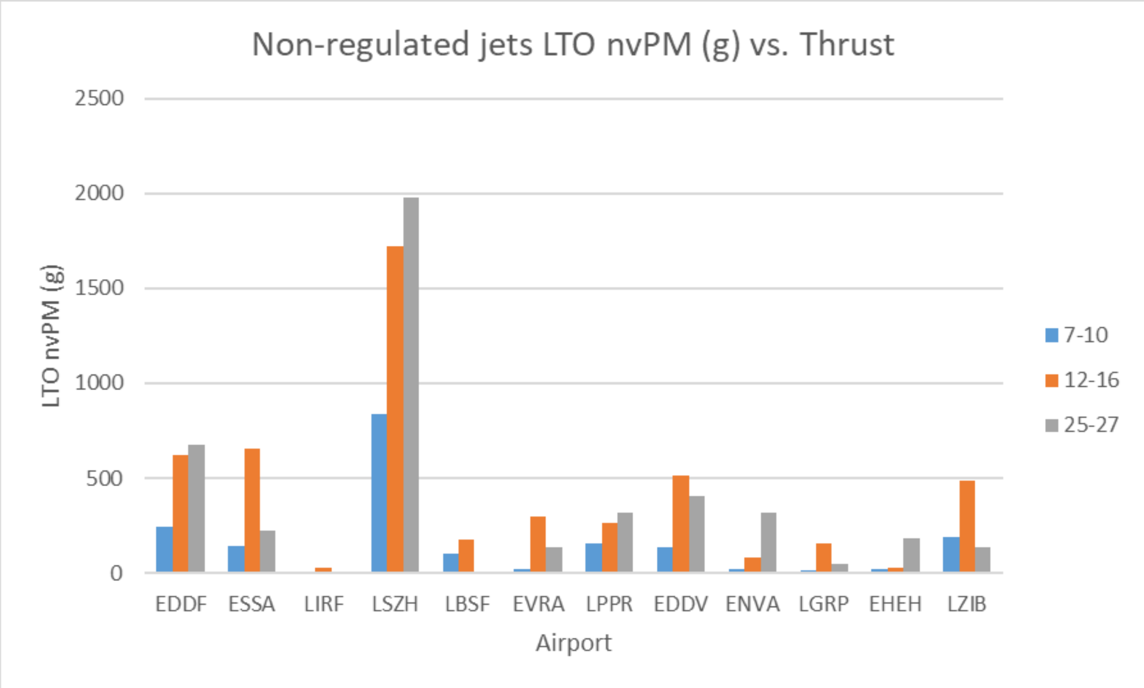

Figure 9. Total LTO nvPM mass of the engines within each thrust range (at all airports).

The results in Figure 9 show that again the larger engines, particularly in the thrust range 12-16 kN and 25-27 kN are responsible for most of the nvPM mass emissions. Those engines correspond essentially with the TFE731 family and the PW300 series respectively. The results are compatible with the results obtained in SC01 considering only the number of movements.

The detailed results, where for each airport the emissions of each individual engine are shown, are presented in the Annex at the end of this document.

Finally, a comparison is made between the emissions of the turboprops and those of the small jets, to assess which of the two categories is more relevant at the selected airports. The results are shown in **Figure 10** and **Figure 11** where respectively the total LTO nvPM mass, and mass per flight of all operations involving both categories of engines are plotted for the twelve different airports.

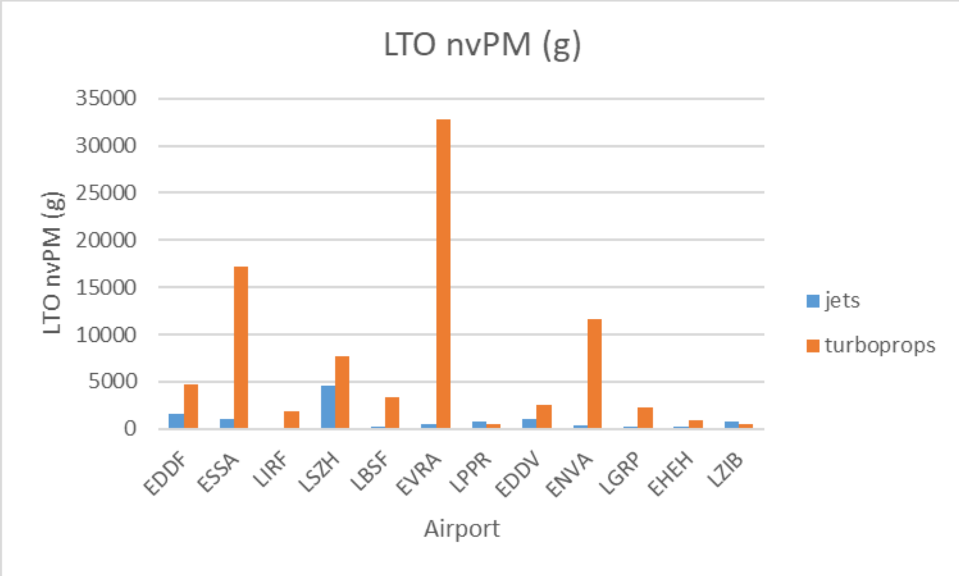

Figure 10. Total LTO nvPM mass of all operations involving turboprops and small jets (at all airports).

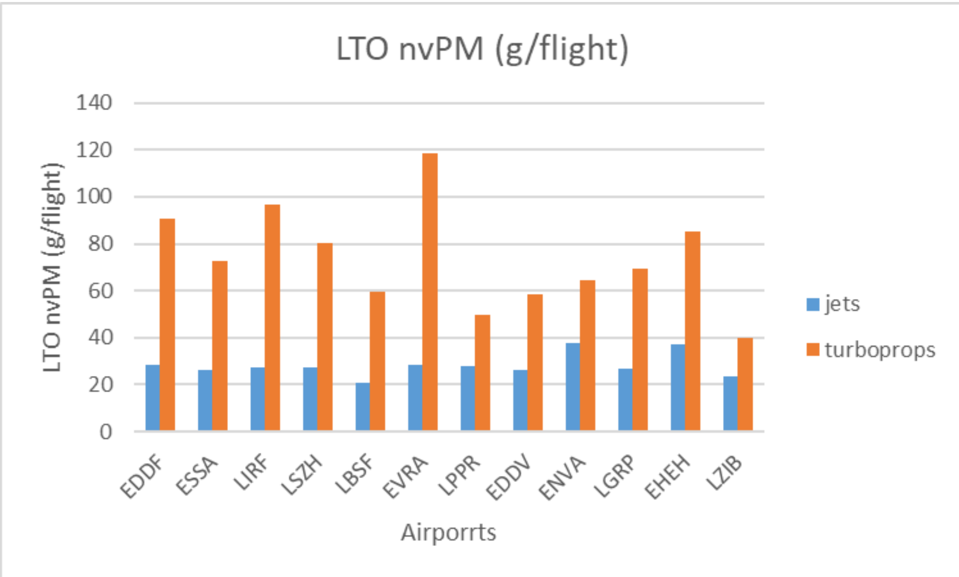

Figure 11. Total LTO nvPM mass per flight of all operations involving turboprops and small jets (at all airports).

In terms of particle mass, at most airports turboprops are responsible for more emissions that small jets. The exceptions are Porto and Bratislava. And it is interesting the case of Zurich, a large airport where the emissions from turboprops and small jets are almost comparable.

3.3. APUs

The results from Task 4 in SC01, proved that the emissions from Auxiliary Power Units (APUs) may be relevant due to the potential large number of cycles of utilisation at the selected airports.

A summary of the APUs being used at those airports and the number of cycles of each one is shown in **Table 7**.

Table 7. Classification of the APUs being used at the selected airports and the number of cycles of each model.

APU	Aircraft	Power	Number of Cycles
P&WC APS 500	DHC-8-1/2/300, ERJ-135/140/145	35kVA	**81**
P&WC APS 1000	DHC8-400	40kVA	**463**
P&WC APS 2000	B737NG	55kVA	**62**
P&WC APS 2300	Embraer 170/175/190/195	40kVA	**1418**
P&WC APS 3200	A320 family	90kVA	**6493**
P&WC APS 5000	B787 family	2x225 kVA	**232**
Honeywell GTCP 36	B737NG family	40-65 kVA	**143**
Honeywell GTCP 85	B737/100/200, B737NG	55 kVA	**76**
Honeywell GTCP 131	MD90, B737NG, A220, A320 family	90 kVA	**6159**
Honeywell GTCP 331	A220, A330, A340, B757, B767, B777	90-150 kVA	**2.604**
Honeywell HGT 1700	A350	2x225 kVA	**71**
Honeywell RE 220	CRJ700/900, Sukhoi SJ100	60 kVA	**837**
P&WC PW900	B747/400, B747-8, A380	2x90-120 kVA	**354**

There is very little information in the literature on EIs from APUs. There are some references ([5], [6], [7]) where the influence of certain parameters in the APUs EIs is assessed, like the impact of fuel hydrogen content on non-volatile particulate matter [7] of a Garrett Honeywell GTCP85 APU, or comparison of the behavior of different SAF fuels on the same APU [6]. In another case [5], partial measurements of installed APUs at aircraft in actual movements in an airport are provided.

Since it is not possible from those publications to assess comparable LTO nvPM emissions of an APU, it has been decided to use as a reference the information provided in the ICAO Airport Local Air Quality Design Manual [4]. The relevant information is shown in **Figure 12**.

Aircraft group	Short-haul[9]	Long-haul
Duration of APU operation	45 min	75 min
Fuel burn	80 kg	300 kg
NO_x emissions	700 g	2400 g
HC emissions	30 g	160 g
CO emissions	310 g	210 g
Total particulate matter mass (tPMmass) emissions	40 g	50 g
nvPMnumber emissions	5.75E+17 #	3.75E +17 #

Figure 12. Representative nvPM emissions of APUs, from the ICAO Airport Local Air Quality Design Manual [4].

As a comparison, the LTO nvPM emissions of turboprops and the small jet are reproduced again in **Table 8** and **Table 9**, respectively.

Table 8. Total LTO cycle nvPM emissions of turboprops [2].

		(g)	number
Model	**Power (kW)**	**nvPMF total**	**nvPNF total**
PT6A-20	410.14	5.596	2.45E+16
PT6A-21	410.14	6.025	6.12E+16
TPE331-3U-303G	626.39	7.288	2.76E+16
PT6A-60A	782.98	10.123	2.88E+16
TPE331-12UA-701	858.3	9.833	2.97E+16
PT6A-65B	874.71	10.999	2.92E+16
PT6A-67B	894.84	12.272	3.01E+16
PT6A-67D	953.75	12.975	3.07E+16
PW118A	1342	20.838	3.44E+16
PW119B	1380	27.481	3.68E+16
PW121	1454	24.584	3.68E+16
PW123D	1454	25.626	3.65E+16
PW127E	1611	28.619	3.79E+16
PW127F	1846	29.880	3.93E+16
PW127G	1846	37.665	4.77E+16
AE 2100	2787	52.836	4.77E+16
AE 2100A	2787	52.836	4.77E+16
PW150A	3415	63.216	4.77E+16

Table 9. Total LTO cycle nvPM emissions of non-regulated jets: [3].

Engine				nvPM LTO (g)	nvPM LTO (number)
Series	Model	Type	Thrust (kN)		
TFE731	TFE731-60	non-regulated	22.24	10.78	3.78E+17
average		non-regulated	18.15	15.76	4.24E+17

Comparing these values, it can be observed that the total particulate matter mass of APUs for each aircraft operation, between 40 and 50 g, is comparable to the LTO nvPM mass of a large turboprop (with a power of around 3000 kW), or also a large non-regulated jet, in the limit of the certification threshold (26.7 kN).

The nvPM number of APUs for each aircraft operation is one order of magnitude higher than the LTO nvPM number of turboprops, and the same order of magnitude than the LTO nvPM number of a large non-regulated jet.

The main element of uncertainty considering emissions of APUs is however at which extent and for how long they are used in each aircraft operation at a given airport. There is very little information on actual operation utilisation, and the results are far to be conclusive [8].

The reality is that, as it was proven in SC01 [1], APUs have a large number of potential operations in all the airports. However, there is no clear indication about their use, due to different factors:

- In some airports, airlines may use ground power equipment and save APU use.
- In addition, APU installation is a standard option or a possible retrofit modification in many commercial small jets and turboprops, what makes difficult to ascertain their operational number.
- In some turboprops without an APU, the crew may apply, for the same purposes, the propeller brake function, consistent in disconnecting one propeller and use its engine for generating energy for the aircraft.

It can be concluded then that, although the number of APUs is big enough to become an important airport emission element, there is too much uncertainty to quantify their relevance, compared particularly to non-regulated engines.

4. CONCLUSIONS AND RECOMMENDATIONS

From the results reported previously, and together with the conclusions already obtained from the study under SC01, some final conclusions can be extracted:

- The largest impact is produced by turboprops, followed by non-regulated jets.
- With the scarce data available, APUs might have a noteworthy potential but it is uncertain the number of cycles to be accounted for and the level of power used.
- For testing candidate selection, the most relevant types seem to be high power turboprops and medium thrust non-regulated jets.
- APUs number is so high that it seems to justify one type testing. By the reasons already commented, the selection should be done on the basis of their number and not on emissions.

And the recommendations for the subsequent SAMPLEIV tasks are the following:

- It seems interesting for SAMPLEIV purposes the study of one turboprop and one APU emissions.
- The selected types will depend on their respective population in the previous results and on their availability for the test period.
- With respect to the population, a clear winner in the turboprop area is the Pratt&Whitney PW100 family, in particular its two variants PW 127 and PW150.
- In the APU range, narrow body aircraft are dominated by Pratt&Whitney APS3200, while wide bodies use more often the Honeywell GTCP 131.

The most relevant engine types and models for testing are indicated in **Table 10**. The APUs may be selected, on number of potential cycles basis, from **Table 7**.

Table 10. Recommended engines to be tested.

Power range (kW)	Engine
410-626	M-601E
	PT6
	PT6A
	PT6A-112
	PT6A-114
	PT6A-114A
	PT6A-20
	PT6A-21
	PT6A-42A
	TPE331-3U-303G
780-953	PT6A-60A
	PT6A-65B
	PT6A-67B
	PT6A-67D
	PT6A-67B
	TPE-331
	AI-20M
	TPE331-12UA-701
1342-1454	PW100
	PW118A
	PW119B
	PW120
	PW120A
	PW121
	PW123D
1611-1846	AI-24VT
	PW124B
	PW125B
	PW127E
	PW127F
	PW127G
	PW127M
2787	AE 2100
	AE 2100A
3415	PW150A
	T56A-15

Thrust range (kN)	Engine
7-10	FJ33-5A
	FJ44
	HF120
	PW600
12-16	JT15D
	TFE731
	PW500
25-27	CFE738
	PW300
	PW306C
	PW306D

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ANNEX I. DETAILED RESULTS PER AIRPORT

The detailed results are presented in the following tables and correspond to the representative week period. Each engine is identified by its series denomination, model, category and thrust or power. In each airport, it is indicated the total number of each engine cycles and their total nvPM mass for the corresponding LTO cycles.

The percentages allow to identify which engines are most used, and which ones are responsible for most of the nvPM mass emissions.

Frankfurt

Engine				# Engines		nvPM LTO (g)	
Series	**Model**	**Type**	**Thrust (kN)**	**total**	**%**	**#**	**%**
CFE738	CFE738	non-regulated	26.3	12	**11.1%**	274	**17.8%**
FJ44	FJ44	non-regulated	10	22	**20.4%**	191	**12.4%**
HF120	HF120	non-regulated	9.1	2	**1.9%**	16	**1.0%**
JT15D	JT15D	non-regulated	12	4	**3.7%**	42	**2.7%**
TFE731	TFE731	non-regulated	15.6	14	**13.0%**	190	**12.3%**
PW500	PW500	non-regulated	15	30	**27.8%**	391	**25.4%**
PW600	PW600	non-regulated	7	6	**5.6%**	36	**2.4%**
PW300	PW300	non-regulated	25.67	12	**11.1%**	268	**17.4%**
	PW306C	non-regulated	25.67	4	**3.7%**	89	**5.8%**
	PW306D	non-regulated	26.28	2	**1.9%**	46	**3.0%**
				108	100.0%	1542	100.0%

Engine				# Engines		nvPMF LTO (g)	
Series	**Model**	**Type**	**Power (kW)**	**total**	**%**	**#**	**%**
PT6	PT6	turboprop	633	6	**5.8%**	80.034	**1.7%**
PW100	PW100	turboprop	1342	8	**7.7%**	166.7	**3.5%**
	PW119B	turboprop	1380	2	**1.9%**	54.962	**1.2%**
	PW124B	turboprop	1611	10	**9.6%**	286.192	**6.1%**
	PW127F	turboprop	1846	24	**23.1%**	717.122	**15.2%**
	PW150A	turboprop	3415	54	**51.9%**	3413.683	**72.3%**
				104	100.0%	4718.693	100.0%

Stockholm

Engine				# Engines		nvPM LTO (g)	
Series	Model	Type	Thrust (kN)	total	%	#	%
CFE738	CFE738	non-regulated	26.3	4	**5.1%**	91	**9.0%**
FJ44	FJ44	non-regulated	10	16	**20.5%**	139	**13.6%**
JT15D	JT15D	non-regulated	12	14	**17.9%**	146	**14.3%**
TFE731	TFE731	non-regulated	15.6	24	**30.8%**	325	**31.9%**
PW500	PW500	non-regulated	15	14	**17.9%**	182	**17.9%**
PW300	PW300	non-regulated	25.67	2	**2.6%**	45	**4.4%**
	PW306C	non-regulated	25.67	2	**2.6%**	45	**4.4%**
	PW306D	non-regulated	26.28	2	**2.6%**	46	**4.5%**
				78	100.0%	1018	100.0%

Engine				# Engines		nvPMF LTO (g)	
Series	Model	Type	Power (kW)	total	%	#	%
AI-20	AI-20M	turboprop	3125	**8**	**1.7%**	265.715	**1.5%**
PT6	PT6	turboprop	633	**8**	**1.7%**	106.712	**0.6%**
	PT6A-114A	turboprop	503	**2**	**0.4%**	13.303	**0.1%**
	PT6A-60A	turboprop	782.98	**6**	**1.3%**	60.739	**0.4%**
T56	T56A-15	turboprop	3425	**2**	**0.4%**	159.59	**0.9%**
TPE331	TPE331-12UA-701	turboprop	858.3	**44**	**9.2%**	432.67	**2.5%**
PW100	PW125B	turboprop	1678	**80**	**16.7%**	2483.935	**14.4%**
	PW127M	turboprop	1846	**274**	**57.3%**	10320.122	**59.8%**
	PW150A	turboprop	3415	**54**	**11.3%**	3413.683	**19.8%**
				478	100.0%	17256.469	100.0%

Rome Fiumicino

Engine				# Engines		nvPM LTO (g)	
Series	Model	Type	Thrust (kN)	total	%	#	%
TFE731	TFE731	non-regulated	15.6	2	**100%**	27	**100%**
				2	100%	27	100%

Engine				# Engines		nvPMF LTO (g)	
Series	Model	Type	Power (kW)	total	%	#	%
AE2100	AE 2100	turboprop	2787	2	**5.3%**	195.672	**10.2%**
PW100	PW120	turboprop	1342	8	**21.1%**	166.7	**8.7%**
	PW124B	turboprop	1611	6	**15.8%**	171.715	**8.9%**
	PW150A	turboprop	3415	22	**57.9%**	1390.76	**72.3%**
				38	100.0%	1924.847	100.0%

Zurich

Engine				# Engines		nvPM LTO (g)	
Series	Model	Type	Thrust (kN)	total	%	#	%
CFE738	CFE738	non-regulated	26.3	26	**7.9%**	594	**13.1%**
FJ33	FJ33-5A	non-regulated	8.21	6	**1.8%**	43	**0.9%**
FJ44	FJ44	non-regulated	10	62	**18.8%**	538	**11.8%**
HF120	HF120	non-regulated	9.1	2	**0.6%**	16	**0.3%**
JT15D	JT15D	non-regulated	12	6	**1.8%**	63	**1.4%**
TFE731	TFE731	non-regulated	15.6	38	**11.5%**	515	**11.3%**
PW500	PW500	non-regulated	15	88	**26.7%**	1146	**25.2%**
PW600	PW600	non-regulated	7	40	**12.1%**	243	**5.3%**
PW300	PW300	non-regulated	25.67	40	**12.1%**	891	**19.6%**
	PW306C	non-regulated	25.67	12	**3.6%**	267	**5.9%**
	PW306D	non-regulated	26.28	10	**3.0%**	228	**5.0%**
				330	100.0%	4544	100.0%

Engine				# Engines		nvPMF LTO (g)	
Series	Model	Type	Power (kW)	total	%	#	%
AE2100	AE2100A	turboprop	2787	60	**31.3%**	3170.157	**41.1%**
PT6	PT6	turboprop	633	30	**15.6%**	400.17	**5.2%**
	PT6A-114	turboprop	447	2	**1.0%**	13.303	**0.2%**
	PT6A-60A	turboprop	782.98	2	**1.0%**	20.246	**0.3%**
	PT6A-65B	turboprop	874.71	2	**1.0%**	21.998	**0.3%**
	PT6A-67B	turboprop	894.84	18	**9.4%**	220.895	**2.9%**
	PT6A-67D	turboprop	953.75	18	**9.4%**	233.551	**3.0%**
PW100	PW127F	turboprop	1846	2	**1.0%**	59.76	**0.8%**
	PW127M	turboprop	1846	4	**2.1%**	150.659	**2.0%**
	PW150A	turboprop	3415	54	**28.1%**	3413.683	**44.3%**
				192	100.0%	7704.422	**100.0%**

Sofia

Engine				# Engines		nvPM LTO (g)	
Series	Model	Type	Thrust (kN)	total	%	#	%
FJ44	FJ44	non-regulated	10	10	**38.5%**	87	**31.7%**
JT15D	JT15D	non-regulated	12	4	**15.4%**	42	**15.2%**
TFE731	TFE731	non-regulated	15.6	6	**23.1%**	81	**29.7%**
PW500	PW500	non-regulated	15	4	**15.4%**	52	**19.0%**
PW600	PW600	non-regulated	7	2	**7.7%**	12	**4.4%**
				26	100.0%	274	100.0%

Engine				# Engines		nvPMF LTO (g)	
Series	Model	Type	Power (kW)	total	%	#	%
AE2100	AE 2100	turboprop	2787	18	**16.1%**	951.047	**28.4%**
AI-24	AI-24VT	turboprop	2074	10	**8.9%**	292.599	**8.7%**
M-601	M-601E	turboprop	560	6	**5.4%**	62.441	**1.9%**
PT6	PT6	turboprop	633	16	**14.3%**	213.424	**6.4%**
	PT6A	turboprop	633	2	**1.8%**	26.678	**0.8%**
	PT6A-21	turboprop	410.14	8	**7.1%**	48.202	**1.4%**
PW100	PW124B	turboshaft	1611	22	**19.6%**	629.622	**18.8%**
	PW127E	turboshaft	1611	14	**12.5%**	400.669	**12.0%**
	PW127F	turboshaft	1846	4	**3.6%**	119.52	**3.6%**
	PW127M	turboshaft	1846	6	**5.4%**	225.988	**6.7%**
	PW150A	turboshaft	3415	6	**5.4%**	379.298	**11.3%**
				112	100.0%	3349.488	100.0%

Riga

Engine				# Engines		nvPM LTO (g)	
Series	Model	Type	Thrust (kN)	total	%	#	%
CFE738	CFE738	non-regulated	26.3	4	**12.5%**	91	**20.2%**
FJ44	FJ44	non-regulated	10	2	**6.3%**	17	**3.8%**
JT15D	JT15D	non-regulated	12	8	**25.0%**	83	**18.3%**
TFE731	TFE731	non-regulated	15.6	16	**50.0%**	217	**47.8%**
PW300	PW300	non-regulated	25.67	2	**6.3%**	45	**9.8%**
				32	100.0%	453	**100.0%**

Engine				# Engines		nvPMF LTO (g)	
Series	Model	Type	Power (kW)	total	%	#	%
PT6	PT6	turboprop	633	4	**0.7%**	53.356	**0.2%**
	PT6A	turboprop	633	2	**0.4%**	26.678	**0.1%**

	PT6A-42A	turboprop	633.84	8	**1.4%**	106.712	**0.3%**
	PT6A-20	turboprop	410.14	2	**0.4%**	11.192	**0.0%**
PW100	PW124B	turboprop	1611	10	**1.8%**	286.192	**0.9%**
	PW127G	turboprop	1846	2	**0.4%**	75.329	**0.2%**
	PW127M	turboprop	1846	42	**7.6%**	1581.916	**4.8%**
	PW150A	turboprop	3415	486	**87.4%**	30723.15	**93.5%**
				556	100.0%	32864.52	100.0%

Porto

Engine				# Engines		nvPM LTO (g)	
Series	**Model**	**Type**	**Thrust (kN)**	**total**	**%**	**#**	**%**
CFE738	CFE738	non-regulated	26.3	4	**7.7%**	91	**12.5%**
FJ44	FJ44	non-regulated	10	18	**34.6%**	156	**21.3%**
JT15D	JT15D	non-regulated	12	2	**3.8%**	21	**2.8%**
TFE731	TFE731	non-regulated	15.6	12	**23.1%**	163	**22.2%**
PW500	PW500	non-regulated	15	6	**11.5%**	78	**10.7%**
PW300	PW300	non-regulated	25.67	10	**19.2%**	223	**30.4%**
				52	100.0%	732	100.0%

Engine				# Engines		nvPMF LTO (g)	
Series	**Model**	**Type**	**Power (kW)**	**total**	**%**	**#**	**%**
PT7	PT6A-67B	turboprop	894.84	2	**11.1%**	24.544	**5.5%**
TPE331	TPE331-3U-303G	turboprop	626.39	2	**11.1%**	14.576	**3.3%**
	PW120	turboprop	1342	6	**33.3%**	125.025	**27.9%**
PW100	PW124B	turboprop	1611	2	**11.1%**	57.238	**12.8%**
	PW127M	turboprop	1846	6	**33.3%**	225.988	**50.5%**
				18	100.0%	447.371	100.0%

Hannover

Engine				# Engines		nvPM LTO (g)	
Series	**Model**	**Type**	**Thrust (kN)**	**total**	**%**	**#**	**%**

CFE738	CFE738	non-regulated	26.3	2	**2.5%**	46	**4.4%**
FJ44	FJ44	non-regulated	10	14	**17.5%**	122	**11.6%**
JT15D	JT15D	non-regulated	12	34	**42.5%**	354	**33.8%**
TFE731	TFE731	non-regulated	15.6	2	**2.5%**	27	**2.6%**
PW500	PW500	non-regulated	15	10	**12.5%**	130	**12.4%**
PW600	PW600	non-regulated	7	2	**2.5%**	12	**1.2%**
PW300	PW300	non-regulated	25.67	8	**10.0%**	178	**17.0%**
	PW306C	non-regulated	25.67	8	**10.0%**	178	**17.0%**
				80	100.0%	1048	**100.0%**

Engine				**# Engines**		**nvPMF LTO (g)**	
Series	**Model**	**Type**	**Power (kW)**	**total**	**%**	**#**	**%**
PT6	PT6	turboprop	633	20	**23.3%**	266.78	**10.6%**
	PT6A-112	turboprop	410	8	**9.3%**	44.769	**1.8%**
	PT6A-67B	turboprop	894.84	2	**2.3%**	24.544	**1.0%**
PW100	PW118A	turboprop	1342	14	**16.3%**	291.725	**11.6%**
	PW127M	turboprop	1846	30	**34.9%**	1129.94	**44.9%**
	PW150A	turboprop	3415	12	**14.0%**	758.986	**30.2%**
				86	100.0%	2516.744	100.0%

Trondheim

Engine				**# Engines**		**nvPM LTO (g)**	
Series	**Model**	**Type**	**Thrust (kN)**	**total**	**%**	**#**	**%**
CFE738	CFE738	non-regulated	26.3	8	**36.4%**	182	**43.7%**
FJ44	FJ44	non-regulated	10	2	**9.1%**	17	**4.1%**
TFE731	TFE731	non-regulated	15.6	2	**9.1%**	29	**7.0%**
PW500	PW500	non-regulated	15	4	**18.2%**	52	**12.4%**
PW300	PW306D	non-regulated	26.28	6	**27.3%**	136	**32.7%**
				22	100.0%	416	100.0%

Engine				**# Engines**		**nvPMF LTO (g)**	
Series	**Model**	**Type**	**Power (kW)**	**total**	**%**	**#**	**%**
PT6	PT6	turboprop	633	40	**11.1%**	533.561	**4.6%**

TPE331	TPE-331	turboprop	773.78	2	**0.6%**	16.004	**0.1%**
PW100	PW118A	turboprop	1342	12	**3.3%**	250.05	**2.2%**
	PW121	turboprop	1454	156	**43.3%**	3835.029	**33.0%**
	PW123D	turboprop	1454	60	**16.7%**	1537.576	**13.2%**
	PW125B	turboprop	1678	8	**2.2%**	248.394	**2.1%**
	PW150A	turboprop	3415	82	**22.8%**	5183.749	**44.7%**
				360	100.0%	11604.36	100.0%

Rhodes

Engine				# Engines		nvPM LTO (g)	
Series	**Model**	**Type**	**Thrust (kN)**	**total**	**%**	**#**	**%**
CFE738	CFE738	non-regulated	26.3	2	**12.5%**	46	**21.4%**
JT15D	JT15D	non-regulated	12	2	**12.5%**	21	**9.8%**
TFE731	TFE731	non-regulated	15.6	8	**50.0%**	108	**50.9%**
PW500	PW500	non-regulated	15	2	**12.5%**	26	**12.2%**
PW600	PW600	non-regulated	7	2	**12.5%**	12	**5.7%**
				16	100.0%	213	100.0%

Engine				# Engines		nvPMF LTO (g)	
Series	**Model**	**Type**	**Power (kW)**	**total**	**%**	**#**	**%**
AE2100	AE 2100	turboprop	2787	4	**5.6%**	105.672	**4.8%**
T56	T56A-15	turboprop	3425	12	**16.7%**	478.711	**21.6%**
PW100	PW120A	turboprop	1342	14	**19.4%**	291.725	**13.2%**
	PW127E	turboprop	1611	38	**52.8%**	1087.53	**49.1%**
	PW150A	turboprop	3415	4	**5.6%**	252.865	**11.4%**
				72	100.0%	2216.503	100.0%

Eindhoven

Engine				# Engines		nvPM LTO (g)	
Series	**Model**	**Type**	**Thrust (kN)**	**total**	**%**	**#**	**%**
CFE738	CFE738	non-regulated	26.3	2	**16.7%**	46	**20.5%**
FJ44	FJ44	non-regulated	10	2	**16.7%**	17	**7.8%**

PW500	PW500	non-regulated	15	2	**16.7%**	26	**11.7%**
PW300	PW300	non-regulated	25.67	2	**16.7%**	45	**20.0%**
	PW306C	non-regulated	25.67	4	**33.3%**	89	**40.0%**
				12	100.0%	223	100.0%

Engine				# Engines		nvPMF LTO (g)	
Series	**Model**	**Type**	**Power (kW)**	**total**	**%**	**#**	**%**
AI-20	AI-20M	turboprop	3125	4	**14.3%**	132.857	**15.6%**
PT6	PT6A	turboprop	633	4	**14.3%**	53.356	**6.3%**
	PT6A-67D	turboprop	953.75	2	**7.1%**	25.95	**3.1%**
T56	T56A-15	turboprop	3425	12	**42.9%**	478.771	**56.4%**
PW100	PW120	turboprop	1342	4	**14.3%**	83.35	**9.8%**
	PW127G	turboprop	1846	2	**7.1%**	75.329	**8.9%**
				28	100.0%	849.613	100.0%

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Engine				# Engines		nvPM LTO (g)	
Series	**Model**	**Type**	**Thrust (kN)**	**total**	**%**	**#**	**%**
CFE738	CFE738	non-regulated	26.3	2	**2.9%**	46	**5.6%**
FJ44	FJ44	non-regulated	10	20	**29.4%**	174	**21.5%**
JT15D	JT15D	non-regulated	12	14	**20.6%**	146	**18.0%**
TFE731	TFE731	non-regulated	15.6	8	**11.8%**	108	**13.4%**
PW500	PW500	non-regulated	15	18	**26.5%**	234	**29.0%**
PW600	PW600	non-regulated	7	2	**2.9%**	12	**1.5%**
PW300	PW306C	non-regulated	25.67	4	**5.9%**	89	**11.0%**
				68	100.0%	809	100.0%

Engine				# Engines		nvPMF LTO (g)	
Series	**Model**	**Type**	**Power (kW)**	**total**	**%**	**#**	**%**
AI-24	AI-24VT	turboprop	2074	2	**7.1%**	58.52	**10.5%**
PT6	PT6A-21	turboprop	410.14	4	**14.3%**	24.101	**4.3%**
	PT6A-67B	turboprop	894.84	18	**64.3%**	220.895	**39.7%**
PW100	PW150A	turboprop	3415	4	**14.3%**	252.865	**45.4%**
				28	100.0%	556.381	100.0%

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