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**954377 – nPETS**

# NANOPARTICLE EMISSIONS FROM THE TRANSPORT SECTOR: HEALTH AND POLICY IMPACTS

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## History of Changes

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| 0.1 | 16/10/2023 | First internal draft | - |
| 0.2 | 18/03/2024 | Revised version after PO rejection | |
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## Contents

# List of Figures

# Glossary

| | |
|---|---|
| ELPI+ | Electrical Low Pressure Impactor |
| PMF | Positive Matrix Factorization |
| PNSD | Particle Number Size Distribution |
| PNC | Particle Number Concentration |
| SMPS | Scanning Mobility Particle Sizer |
| DMPS | Differential Mobility Particle Sizer |
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# Executive Summary


The current deliverable summarises (near-source) particle number size distributions (PNSD) measurements in the nPETS cities (Barcelona, Stockholm, Thessaloniki, Milan and Valencia). The primary goal is to identify the typical PNSD of different transport modes in ambient air namely road transport, airport, harbour and rail.

In this deliverable PNSD were characterised by an ELPI+ at 8 urban sites (4 background sites and 4 road traffic sites in Barcelona, Stockholm, Thessaloniki, and Milan), 3 airports (Barcelona, Milan and Thessaloniki), 1 harbour (Barcelona, as at the Thessaloniki harbour the instrument failed) and 2 railway sites (Stockholm and Valencia) and also by a factor analysis (PMF) based on SMPS/DMPS data for Barcelona (traffic, airport and harbour sites) and Stockholm (urban background site).

At all traffic, airport, harbour and subway sites, ELPI+ measurements showed a clear prevalence of ultrafine stage (<100nm) within the total Particle Number Concentration (PNC) and more specifically a mode within 6-20 nm, indicating the high prevalence of nucleation particles, both primary and secondary from transport-related gaseous precursors and SOx. The source apportionment method identified the specific PNSD of different sources at Barcelona traffic, airport and harbour sites:

- Road gasoline vehicles (unimodal at 30 nm) and Road diesel vehicles (unimodal at 90 nm) at the traffic site;

- Shipping emissions, unimodal at 30 nm;

- Aircraft emissions from taxing activity (movement from terminal to take-off runaway) with an unimodal PNSD peaking at 25 nm and Aircraft emissions of lower impact, from take-off activity with an unimodal PNSD peaking at 30 nm also attributed to secondary particles from SVOCs.


# Introduction

The goal of this report is to characterize the typical PNSD (from 6/10 nm up to the micrometre range) measured in the field in the proximity of different transport emission sources. Measurements were carried out during both warm and cold seasons at 4 urban background sites (Barcelona, Stockholm, Thessaloniki, and Milan), 4 road traffic sites (Barcelona, Stockholm, Thessaloniki, and Milan), 3 airports (Barcelona, Milan, Thessaloniki), 1 harbour (Barcelona as the instrument failed at the Thessaloniki harbour) and 2 railway sites (Stockholm and Valencia). Two different approaches were used: where only Low resolution ELPI+ measurements were available, PNSD refers to mean values of the ambient air measurements; where SMPS/DMPS measurements were available (only in Barcelona and Stockholm) source specific PNSD of different sources contributing to PNC where estimated by means of the Positive Matrix Factorization (PMF). In the case of High Resolution ELPI+ (Stockholm road tunnel and subway campaigns), PMF analysis did not deliver robust results, and therefore PMF results are not presented.

# Results

## ELPI+ PNSD

Figures 1-5 illustrate average PNSD obtained from the ELPI+ instrument at urban background sites and different transport modes hotspots. At urban background sites, we observed quite different PNSD depending on the climatic conditions but also on the season. In typically Mediterranean cities (Barcelona and Thessaloniki) a major peak occurs at the smallest size (6 nm) likely due to the high photochemical activity for the high solar radiation (Figure 1). Still a difference between them can be found between Thessaloniki and Barcelona, having a second, equally important peak at around 100 nm in Thessaloniki, probably due to the suburban location of the monitoring site, allowing to observe better secondary particle growth. Differently from the above, the city of Milan shows a quite coarser PNSD peaking at 260 nm in summer, due to the high incidence of secondary processes in Po Valley due to high precursors concentrations (e.g. NH3 from agriculture). In winter, instead the Milan site shows a very different PNSD peaking at 6nm, probably due to the role of residential heating emissions. Finally, in Stockholm, PNSD peaks around 60-80 nm, likely due to the lower impact of photonucleation (Figure 1).

All traffic sites (Figure 2) showed the largest mode of PNSD between 6 nm (at open roads) and 13 nm (at road tunnel), indicating the high prevalence of nucleation particles, both primary nanoparticles from internal combustion engines and secondary nanoparticles mostly from traffic-related gaseous precursors and SOx. In the case of Thessaloniki traffic site we observed also a second mode at 100 nm, possibly related to diesel primary emissions. In literature, most of studies reported a peak around 10-30 nm, (only a few studies report PNSD with a lower particle size detection limit ≤10 nm): 11 of them being unimodal distributions, 14 showing a bimodal size distribution with a second peak at 40-90 nm and 4 with a trimodal size distribution. In the studies carried out in Europe, a main mode occurs at 10-30 nm, and a secondary one at 60-90 nm. The finest and major mode occurring at 10-30 nm in most studies is attributable to i) the emissions of UFP from gasoline engines (Hopke et al., 2022 and references therein), and or ii) the nucleation of semi-volatile compounds (SVOCs) emitted by diesel engines and that escape from the filter traps (Damayanti et al. 2023, and references therein), while the modes at 40-90 nm are probably due to the primary emissions of diesel engines (Hopke et al., 2022, and references therein).

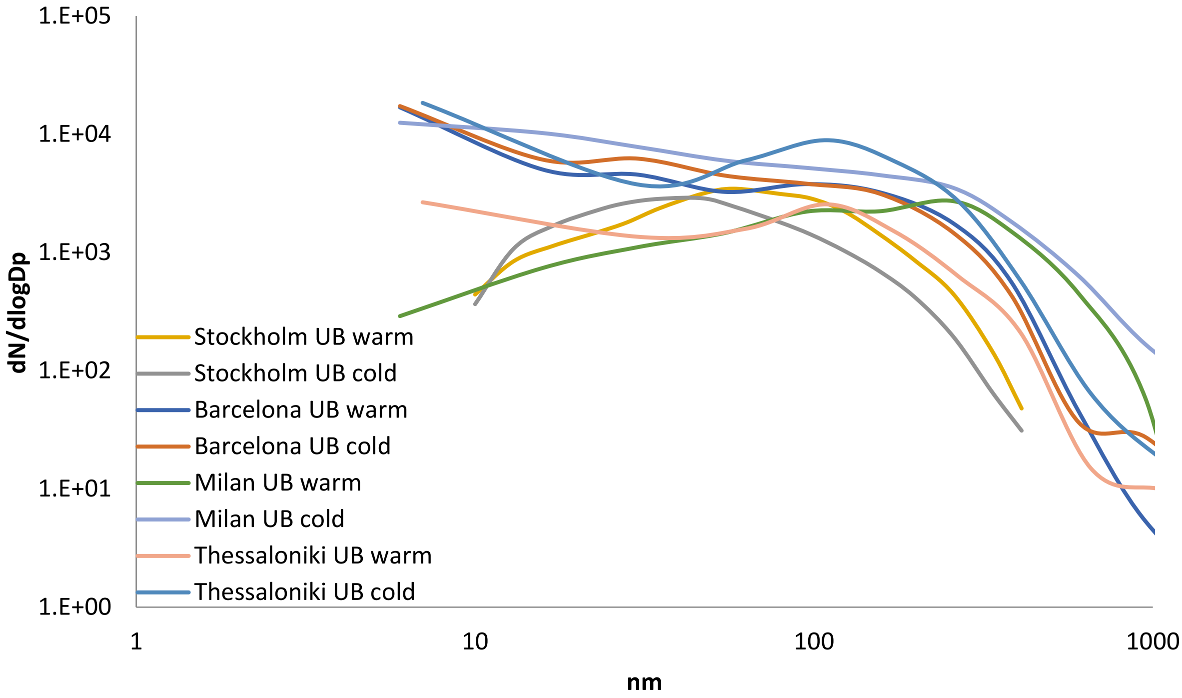


*Figure 1. Average PNSD at urban background sites*

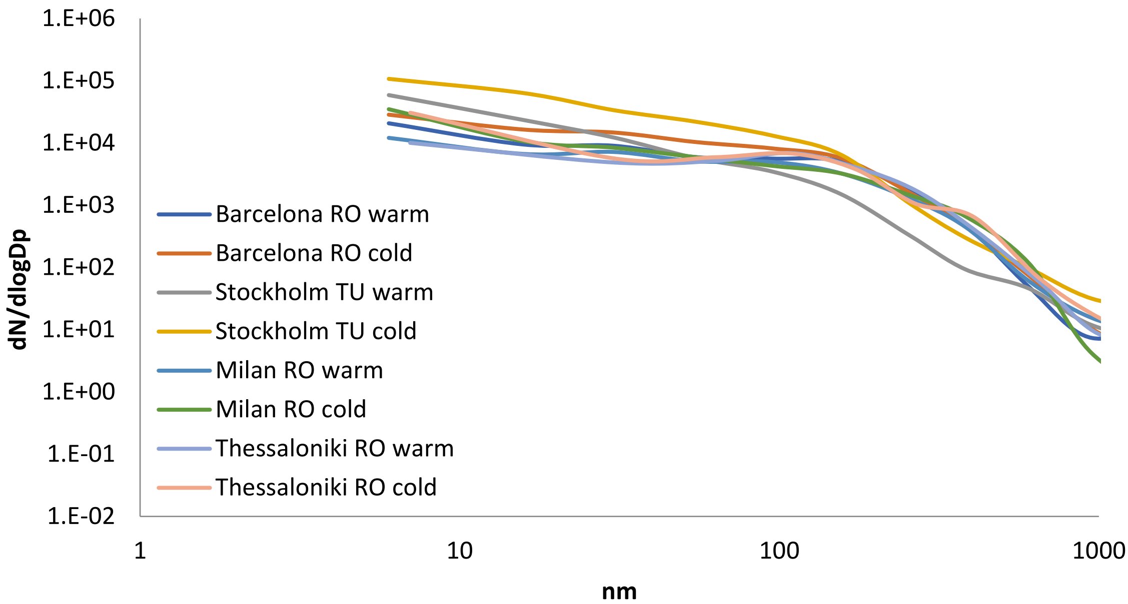


*Figure 2. Average PNSD at traffic sites*

At airports PNSD measured in the proximity of the take-off runaway showed a main mode at 6 nm indicating important nucleation events from gaseous precursors emitted by aircrafts (Figure 3). A second, less important mode was observed in the accumulation mode (100-1000 nm), probably of secondary origin but less related to aviation emissions.

In the harbour environment the PNSD resulted very similar to the airports, although concentrations are lower (Figure 4). There was a clear predominance of ultrafine particles (<100nm) with low concentrations of aged particles (100-500nm).

In the subway (Figure 5) the PNSD is more platykurtic than in other transport modes, being the ultrafine fraction 80% of total PNC, as compared to traffic sites (93-96%), airports (93-96%), and harbour (95%).

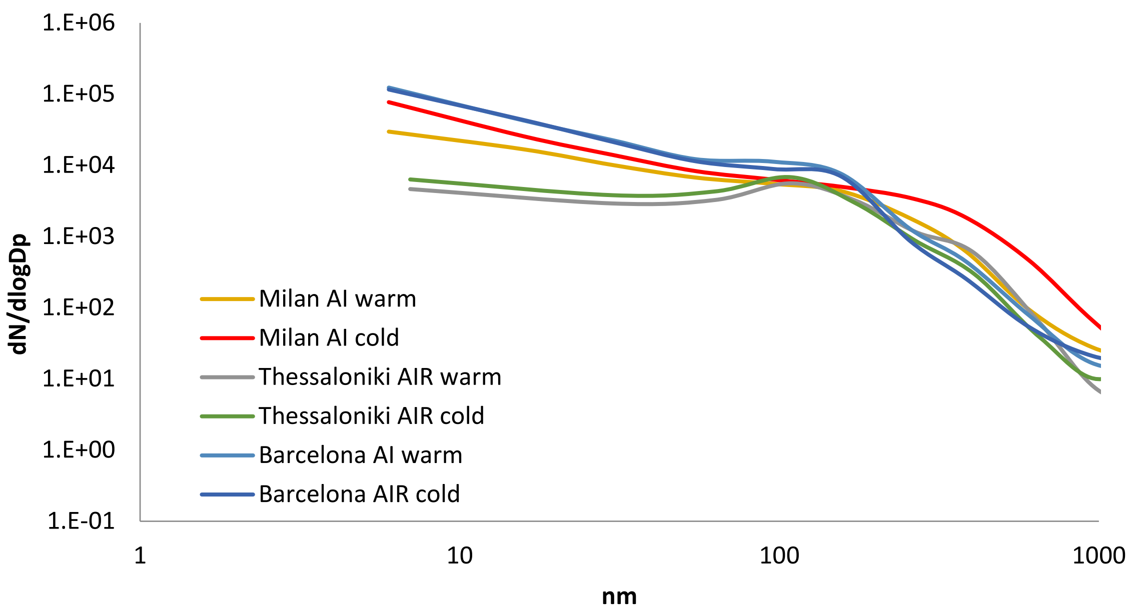


*Figure 3. Average PNSD at airport sites*

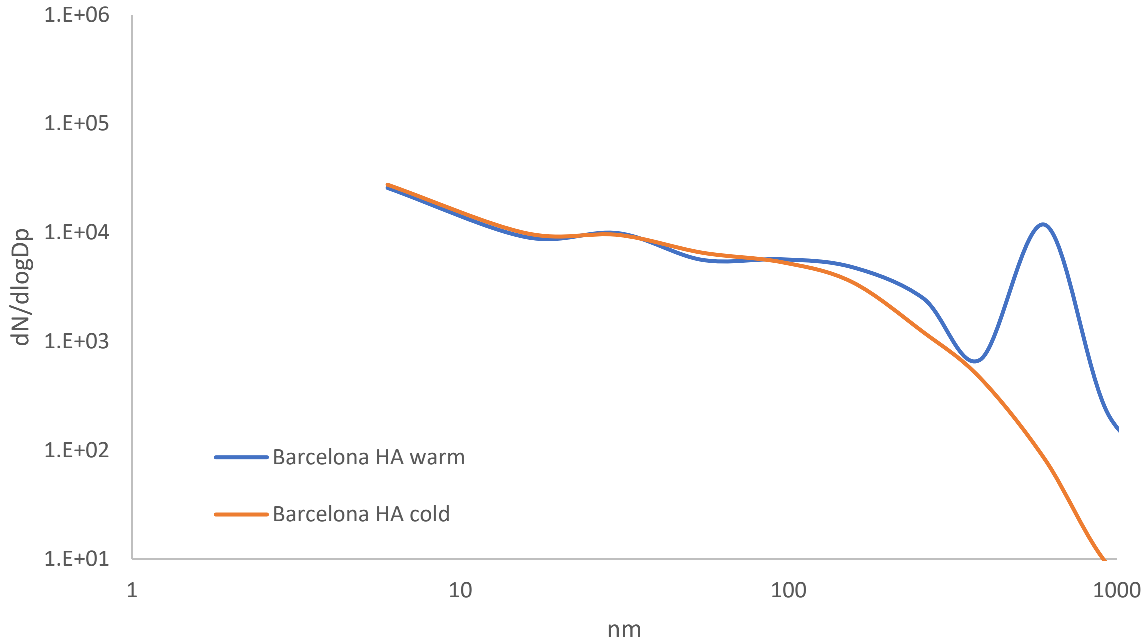


*Figure 4 Average PNSD at harbour*

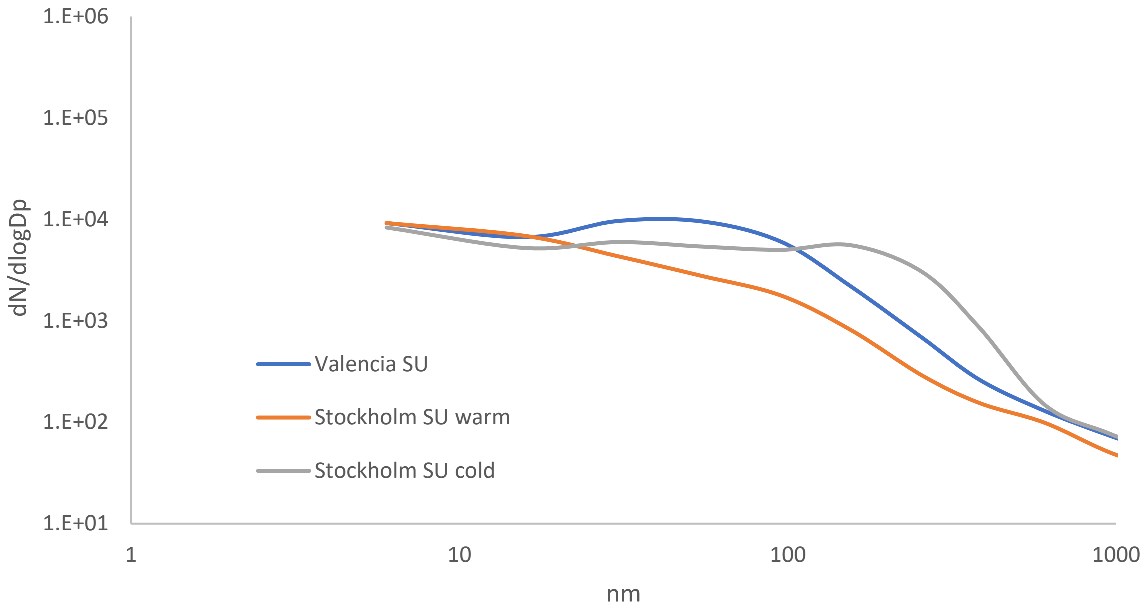


*Figure 5 Average PNSD at subway rail*

## Source specific PNSD

At the Barcelona Traffic site, the PMF multivariate method identified 4 different sources of nanoparticles (Figure 6):

1. a photo-nucleation factor with secondary particles (<30 nm) oxidized both from the hot exhaust gases and SOx.
2. a gasoline emissions source with the peak around 30 nm, indicating secondary particles oxidized from SVOCs.
3. a diesel exhaust factor with the predominance of primary particles (black carbon) with mode at 90 nm.
4. a regional/secondary source representing aged and secondary particles transported at the traffic site from other areas.

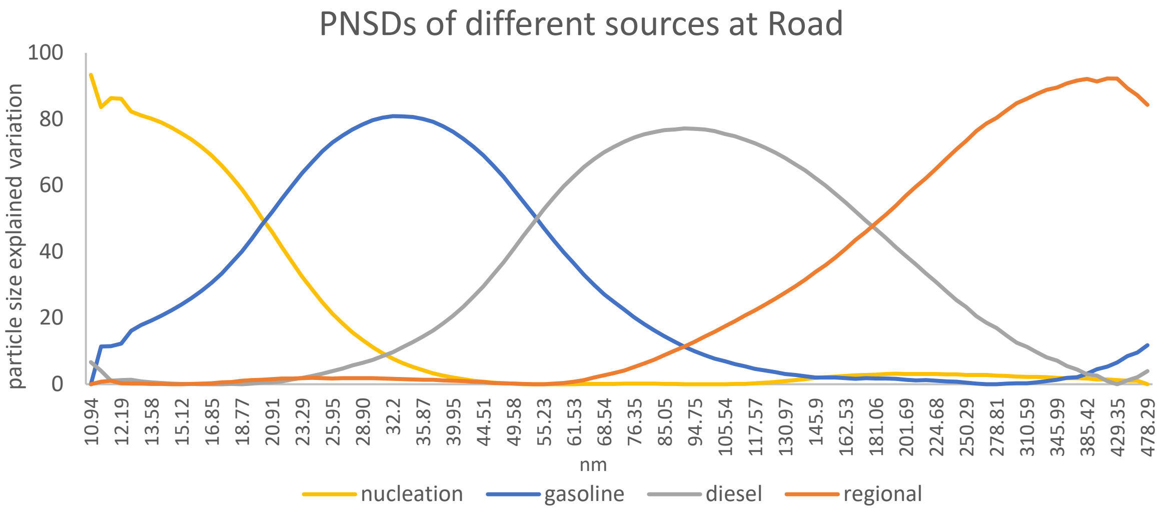


*Figure 6. Source profile of PNSD in Barcelona traffic site*

At the Barcelona harbour site 4 sources were also identified by PMF (Figure 7):

The first source, identified as Urban Background, shows a bimodal size distribution with major size mode of 100 nm and a secondary peak at 35 nm (Figure 5). Previous source apportionment studies in an urban background site in Barcelona have identified a regional contribution to PNC with a peak > 100 nm, contributing to 19% of total PNC (Dall'Osto et al., 2012). In our study, this source contributes to 9% of total PNC and constitutes a significant portion (30.4%) of accumulation mode particles. Additionally, this source accounts for nearly all O3 concentrations (94%), 50% of SO2, 28% of BC, and 20% of NO. Polar plots (Figure 6) indicate that this source prevails from the NW to the E sector, downwind from the city of Barcelona, with concentrations peaking during the night and early morning, before the onset of the sea breeze.

The second source, labeled as Nucleation, exhibits a narrow size distribution with a size mode of 18 nm. It accounts for 30% of total PNC and 62% of particles in the Nucleation mode, while showing minor contributions to both Aitken (9%) and Accumulation (5%) modes (Figure 5). This source also explains 13% of BC, 18% of NO, 30% of NO2, 9% of SO2 and 6% of O3. Photonucleation appears to be of limited relevance for this source, as indicated by a minor peak around 12:00 and a more pronounced peak occurring between 19:00 and 21:00 h, a time of minimal photochemical activity. The low correlation with O3 further supports this observation. In fact, photonucleation is favored in cleaner atmospheres (Reche et al., 2011).

The third source, identified as Coastal background, showed a unimodal size distribution with a size mode at 75 nm (Figure 5). This source contributed to 22% of total PNC, 27% of Aitken mode, 55% of accumulation mode and was negligible in Nucleation mode particles (<1%). Furthermore, this source explained almost 38% of BC concentrations, 43% of NO, 32% of NO2, and approximately 30% of SO2. The term Coastal Background reflects the blend of pollutant from both urban and maritime sources. It represents the combined influence of emissions from the city of Barcelona and from maritime activities in the Mediterranean. The city's pollution plume is carried towards the Mediterranean, where it merges with emissions from cargo ships waiting to access the harbor. During the sea breeze conditions, this mix of urban and maritime pollutants is transported back to the measurement site, resulting in the observed particle size distribution and pollutant concentrations.

The last factor, identified as Ship transit, displayed a PNSD with a predominant size mode at 35 nm, contributing to 33% of total PNC, 20% of Nucleation mode, 45% of Aitken mode, and <1% of Accumulation mode particles (Figure 5). This factor primarily reflects emissions from vessels actively entering or leaving the harbor, rather than those docked. This distinction is supported by the polar plots from the Ship transit and Nucleation factors. The polar plot for the Ship transit reveals a significant source from the SSW direction (Figure 6), which corresponds precisely with the harbor entrance. This indicates that the emissions captured by this factor are predominantly associated with ships transiting through the harbor.

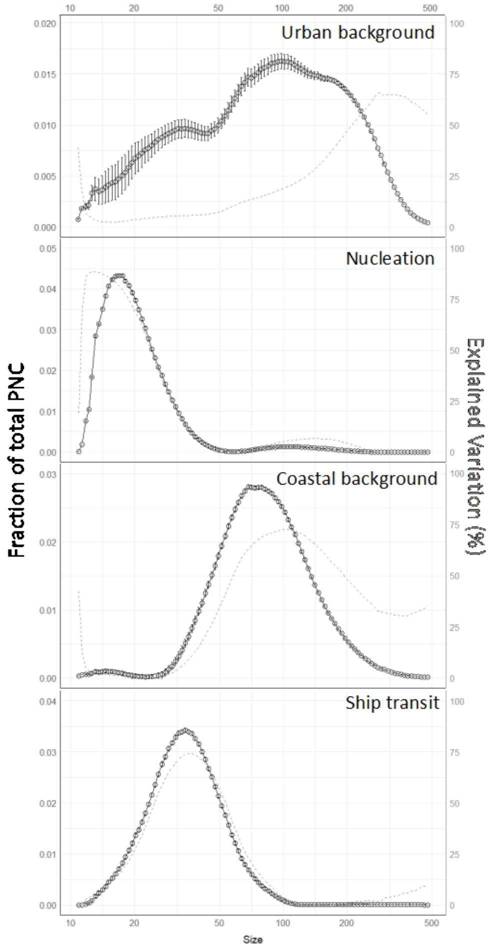


*Figure 7 Source profiles of PNSD in Barcelona harbour site*

At the Barcelona airport site, PMF identified 6 sources of PNC (Figure 8):

1. Aircraft emissions from taxing activity (movement from terminal to take-off runaway) with an unimodal PNSD peaking at 25 nm and attributed to secondary particles from SVOCs .
2. Aircraft emissions of lower impact, from take-off activity with an unimodal PNSD peaking at 30 nm also attributed to secondary particles from SVOCs .
3. a photo-nucleation factor with secondary particles (<30 nm) from gaseous precursors of various origin.
4. a diesel related factor, peaking at 60 nm, probably linked to the airport service machinery.
5. a regional source representing urban-industrial emissions transported to the airport site comprising of larger, aged particles peaking at around 260 nm.
6. a long-range transport source of particles in the upper range (mode at 400 nm).

In literature, most of studies reported a unimodal PNSD with major mode < 20 nm, while few studies reported a bimodal PNSD with a major mode < 14 nm and a second mode at 30-50 (Masiol et al. 2017) or 80 nm (Masiol et al. 2016).

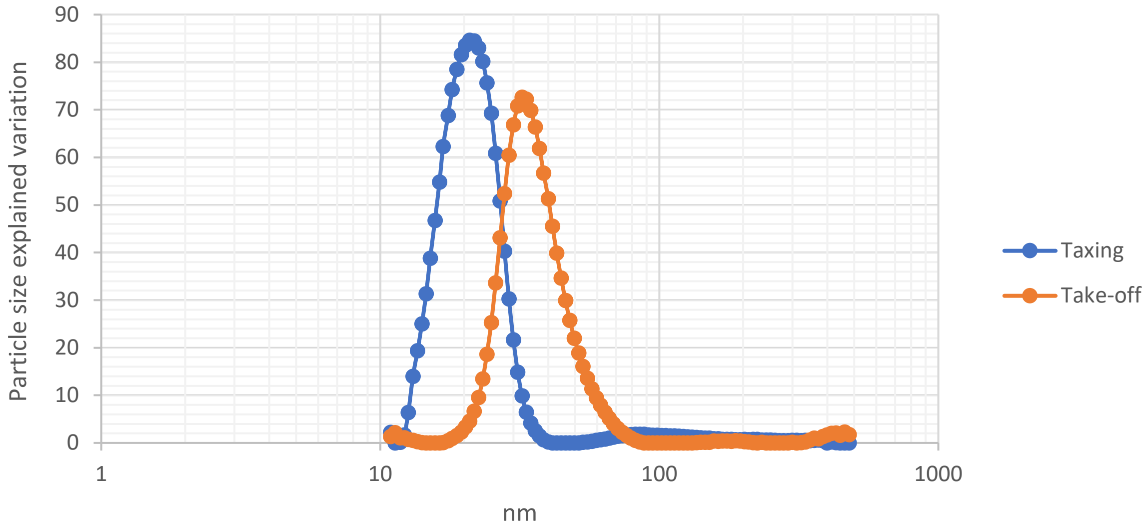


*Figure 8 Aircraft emissions profiles of PNSD in the airport site*

At the Stockholm urban background site, PMF identified 4 sources of PNC (Figure 9):

1. Aircraft emissions from the Bromma airport, peaking at 10 nm and attributed to secondary particles from SVOCs
2. Road traffic emissions, peaking at 30 nm
3. Shipping emissions, peaking at 80-90 nm
4. A regional/dust source representing urban-industrial emissions peaking at the highest particle range (400 nm).

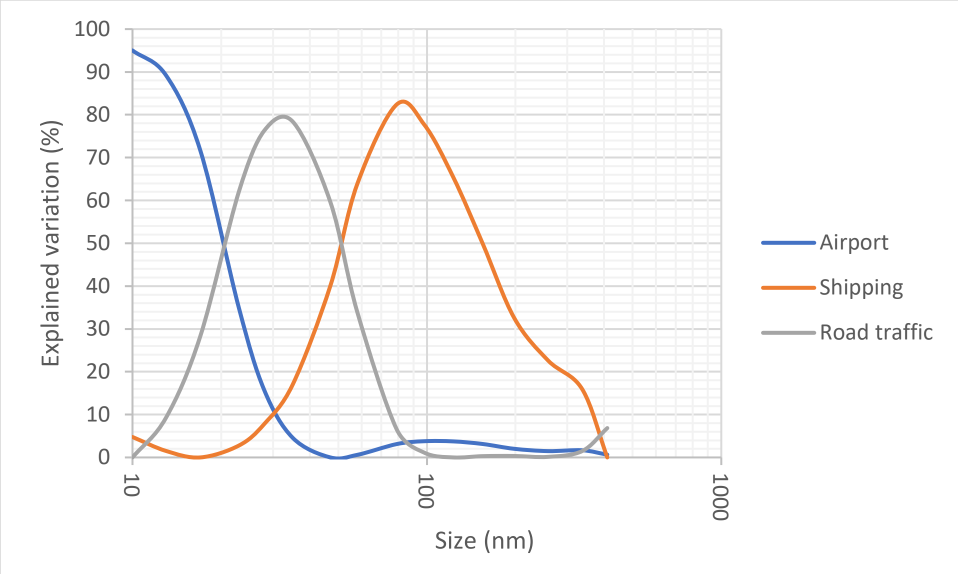


*Figure 9 Different transport emissions profiles of PNSD at the Stockholm urban background site*

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