

# AEROSOLS

Air Quality and Health Impact of Primary Semi-volatile  
and Secondary Particles and Their Abatement



## Atmos'Fair 2024 conference

*9-10<sup>th</sup> October 2024, Lyon (FRANCE)*

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## **Primary emissions from transportation**

- *Impact of transport emissions on air quality and health, relatively well known, as far as direct regulated pollutant emissions are concerned (i.e. particulate, NO<sub>x</sub>, hydrocarbons, etc.)*

## **Atmospheric chemistry & secondary emissions**

- *Some of the emissions from engines, and combustion processes in general, are also leading to further formation of health impacting compounds due to atmospheric aerosol chemistry*

## **Potential effects of secondary emissions**

- *Specific impact of these compounds, less understood*

## **Particle emissions vs regulations**

- *Current engine exhaust particle emission regulations historically consider Particulate Mass (PM) + more recently Solid Particle Number (PN) above 23 nm*
- *So-called volatile and semi-volatile particles excluded from PN*
  - *Main advantage: Robustness improvement of the automotive certification protocol in view of the market sale*
  - *Among the drawbacks: Underestimation of the impact on air quality and health*





## Programme “HORIZON Europe” call for proposal (2021)

- *HORIZON-CL5-2022-D5-01: Clean and competitive solutions for all transport modes*
- *Topic “HORIZON-CL5-2022-D5-01-07”: Prevent smog episodes in Europe: Air quality impact of engine-emitted volatile, semi volatile and secondary particles*

## Expected outcomes

- *Achieve better understanding of (semi)volatiles particles and secondary aerosol formation as well as their effects on health, air quality (in particular during winter season) and climate*
- *Assess the contribution to PM<sub>2.5</sub> of precursors present in exhaust from transport (i.e. volatile organic compounds, NO<sub>x</sub>, unburned hydrocarbons, nano-particles below 23nm, ammonia, etc.) through the formation of secondary aerosol (organic –SOA- and inorganic –SIA-)*
- *Find ways in which scientific evidences of the role of emissions in atmospheric processes could be an input to develop policies and mitigate SOA formation in urban areas of EU*
- *Improved quantification of transport externalities*
- *Support of future emissions legislation and of “polluter pays” legislation*



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- *Topic “HORIZON-CL5-2022-D5-01-07”: Prevent smog episodes in Europe: Air quality impact of engine-emitted volatile, semi volatile and secondary particles*

## 3 projects funded



(project ID n°101096133)  
[CORDIS - EU: PAREMPI](#)

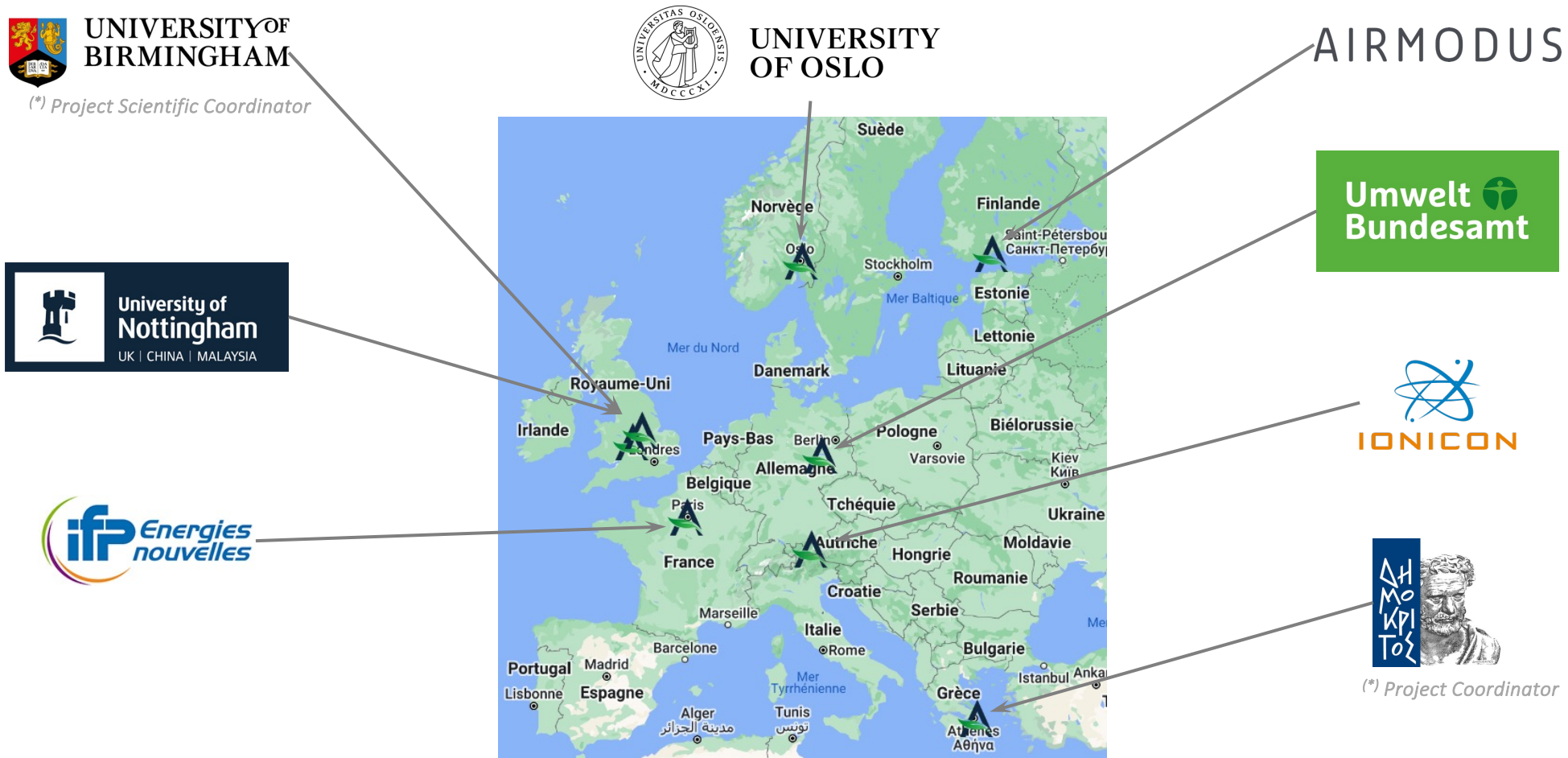


(project ID n°101095457)  
[CORDIS - EU: EASVLEE](#)



(project ID n°101096912)  
[CORDIS - EU: AEROSOLS](#)

# AEROSOLS project's consortium



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**Start date: 01<sup>st</sup> January 2024**



**Duration: 36 months**



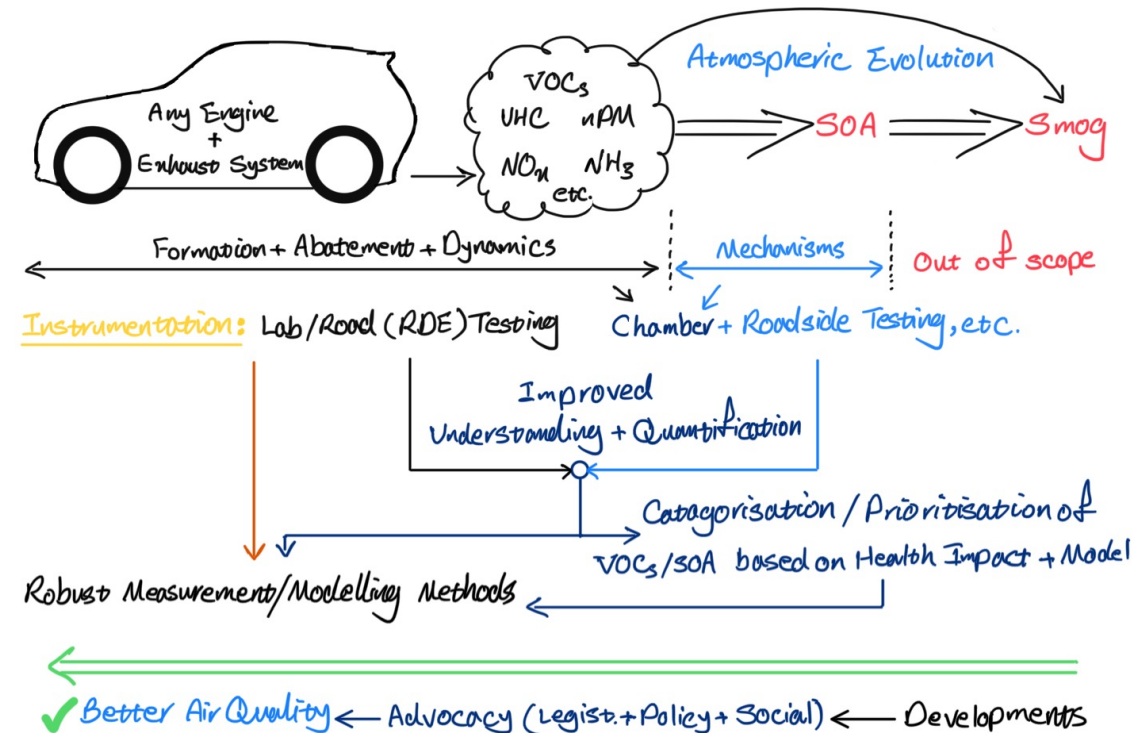
**N° of work packages: 7**



**Aim:**

*Define robust and transparent measurement and modelling methodologies to quantify the currently disregarded volatile/semi-volatile primary and secondary emissions*

*Assess their associated risks, and propose technological and legislative monitoring/abating mechanisms to help improve air quality and public health*







## **WP5:** Defining robust measurement, analysis & modelling methods for measurement/derivation of total emissions indices



Emissions taxonomisation assisted by AI  
Unified measurement programmes  
V/S-V + SA contribution to PM<sub>2.5</sub> & PM<sub>10</sub>  
Equivalent total particle emissions indices



## **WP4:** Investigation & quantification of the health, environmental & social impacts of V/S-V & secondary compounds



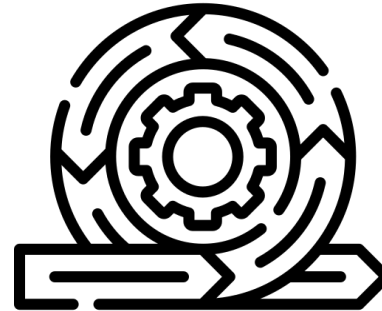
Health studies  
Environmental life cycle assessment  
Social life cycle assessment



## **WP6:** Dissemination of the advocacy information to the stakeholders & legislation/policy makers



## **WP7:** Project management & coordination



## **WP3:** Assessment of atmospheric processing of emissions



Aerosol aging  
Climatic effects on secondary aerosols



## **WP1:** Lab-based investigation & quantification of volatile/semi-volatile (V/S-V) compounds formation, abatement & dynamics within engine/exhaust systems



Compilation of relevant databases  
Engine-out emissions indices at RDE-compliant conditions  
Emissions abatement techniques  
Artefacts within the exhaust system and dilution impact



## **WP2:** Onboard vehicle RDE investigation and quantification of V/S-V emissions



Vehicles' setup  
On-board emissions equipment  
On-road and chassis-dyno RDE vehicle experiments



⇒ **From automotive "Euro" standards to secondary emissions, going through the particular role of VOCs**

# Evolution of Passenger Cars (PC) & Light-Duty (LD) vehicle's Euro standards



## Extended scope of approval

- Euro 1-6
  - *Introduction of additional limits*
    - *Particulate Mass (gasoline)*
    - *Particle Number (Diesel, then gasoline)*
  - *Extended aftertreatment devices sustainability*
  - *More representative testing conditions*
    - *On lab. first (from NEDC to WLTP)*
    - *Then on road (Real Driving Emissions protocol)*
    - *From Type Approval to In-Service Conformity*

⇒ **Exhaust primary emission limits only**

⇒ **Some gases**

⇒ **Total Particulate Mass + solid Particle Number**

EURO		1	2	3	4	5a	5b	6b	6d	7
Date	(NT)	07/92	01/96	01/00	01/05	01/09	09/11	09/14	01/20	11/26
Test cycle	(-)	Urban +EUDC	Urban +EUDC	NEDC	NEDC	NEDC	NEDC	NEDC	WLTP + RDE	WLTP + RDE
PI		1	2	3	4	5a	5b	6b	6d	7
CO	(mg/km)	2720	2200	2300	1000	1000	1000	1000	1000	1000
HC	(mg/km)	-	-	200	100	100	100	100	100	100
HCnM	(mg/km)	-	-	-	-	68	68	68	68	68
NOx	(mg/km)	-	-	150	80	60	60	60	60	60
HC+NO <sub>x</sub>	(mg/km)	970	500	-	-	-	-	-	-	-
PM	(mg/km)	-	-	-	-	5,0	4,5	4,5	4,5	4,5
PN <sub>23</sub>	(#/km)	-	-	-	-	-	-	6.10 <sup>11</sup>	6.10 <sup>11</sup>	-
PN <sub>10</sub>	(#/km)	-	-	-	-	-	-	-	-	6.10 <sup>11</sup>
CI		1	2	3	4	5a	5b	6b	6d	7
CO	(mg/km)	2720	1000	640	500	500	500	500	500	500
HC	(mg/km)	-	-	-	-	-	-	-	-	-
NOx	(mg/km)	-	-	500	250	180	180	80	80	80
HC+NO <sub>x</sub>	(mg/km)	970	700	560	300	230	230	170	170	170
PM	(mg/km)	140	80	50	25	5,0	4,5	4,5	4,5	4,5
PN <sub>23</sub>	(#/km)	-	-	-	-	-	6.10 <sup>11</sup>	6.10 <sup>11</sup>	6.10 <sup>11</sup>	-
PN <sub>10</sub>	(#/km)	-	-	-	-	-	-	-	-	6.10 <sup>11</sup>



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# Evolution of Passenger Cars (PC) & Light-Duty (LD) vehicle's Euro standards



## Extended scope of approval

### • Euro 7

#### • A long adoption process

- From EC proposal (11/22)
- ... CEU general approach (09/23)
- ... EP position (11/23)
- To OJ of the EU publication (05/24)

#### • Restricted Exhaust emission limits evolution

- ⇒ NH<sub>3</sub> limit finally removed (PCs + LDV)
- ⇒ Reduction of particle cut-off  $\phi$  (23 ⇒ 10 nm)

#### • Introduction of Non-Exhaust Emissions (NEE)

- ⇒ Brake wear Particles [BWP]
- ⇒ Tire Abrasion rate [TA]

#### • Extended lifetime & traction battery durability requirements

### ⇒ Exhaust primary emission limits

#### ⇒ Same gases and limits

#### ⇒ From Solid PN<sub>23</sub> to SPN<sub>10</sub>

EURO		1	2	3	4	5a	5b	6b	6d	7
Date	(NT)	07/92	01/96	01/00	01/05	01/09	09/11	09/14	01/20	11/26
Test cycle	(-)	Urban +EUDC	Urban +EUDC	NEDC	NEDC	NEDC	NEDC	NEDC	WLTP + RDE	WLTP + RDE
PI		1	2	3	4	5a	5b	6b	6d	7
CO	(mg/km)	2720	2200	2300	1000	1000	1000	1000	1000	1000
HC	(mg/km)	-	-	200	100	100	100	100	100	100
HCnM	(mg/km)	-	-	-	-	68	68	68	68	68
NOx	(mg/km)	-	-	150	80	60	60	60	60	60
HC+NO <sub>x</sub>	(mg/km)	970	500	-	-	-	-	-	-	-
PM	(mg/km)	-	-	-	-	5,0	4,5	4,5	4,5	4,5
PN <sub>23</sub>	(#/km)	-	-	-	-	-	-	6.10 <sup>11</sup>	6.10 <sup>11</sup>	-
PN <sub>10</sub>	(#/km)	-	-	-	-	-	-	-	-	6.10 <sup>11</sup>
CI		1	2	3	4	5a	5b	6b	6d	7
CO	(mg/km)	2720	1000	640	500	500	500	500	500	500
HC	(mg/km)	-	-	-	-	-	-	-	-	-
NOx	(mg/km)	-	-	500	250	180	180	80	80	80
HC+NO <sub>x</sub>	(mg/km)	970	700	560	300	230	230	170	170	170
PM	(mg/km)	140	80	50	25	5,0	4,5	4,5	4,5	4,5
PN <sub>23</sub>	(#/km)	-	-	-	-	-	6.10 <sup>11</sup>	6.10 <sup>11</sup>	6.10 <sup>11</sup>	-
PN <sub>10</sub>	(#/km)	-	-	-	-	-	-	-	-	6.10 <sup>11</sup>

Sources:

- European Commission [EC] proposal (10/11/2022)
- Council of the European Union [CEU] general approach (25/09/2023)
- European Parliament [EP] position (09/11/2023)
- Official Journal of the European Union (08/05/2024)
- Passenger-Cars-and-Light-Duty-Vehicles-Emissions-Standards-Booklet (22/23)



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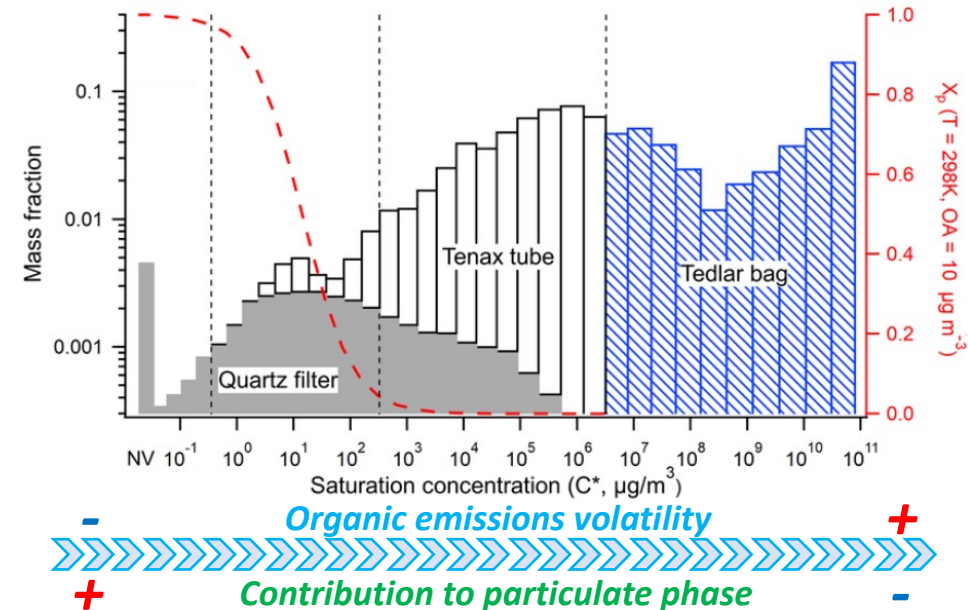


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- *With various definitions (based on chemical composition, boiling  $T^\circ$ , saturation vapor concentration)*
- *Exhibiting a wide volatility range*
- *Distributed between gaseous & particulate phase emissions, depending on conditions ( $T^\circ$ ,  $P$ ,  $RH$ ,  $[x]$ )*

### Diesel engine

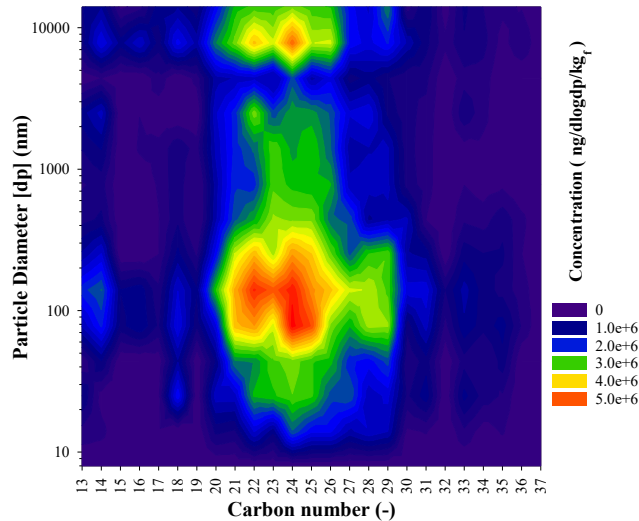


⇒ ***Needing an extended sampling + analytical protocol to evaluate the whole range of compounds in both gaseous/particulate phases***

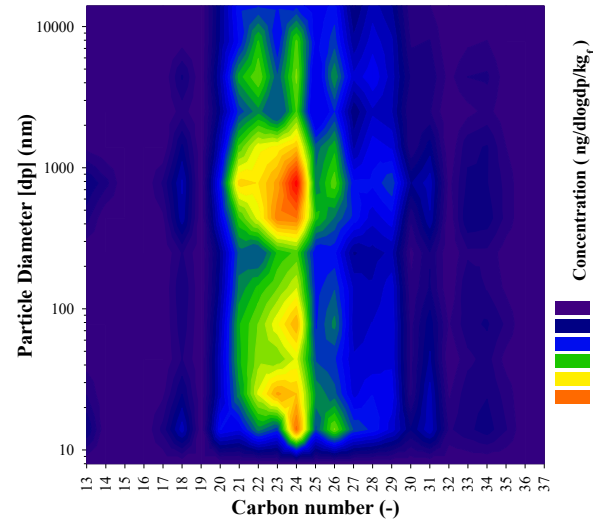
## Originating from extremely complex reactions and numerous compounds

- Can derive from thousands of  $\neq$  hydrocarbons (carbon number C1 to  $\approx$  C40) in unburnt fuel & engine lubricating oil
- Contains compounds resulting from partial combustion & pyrolysis

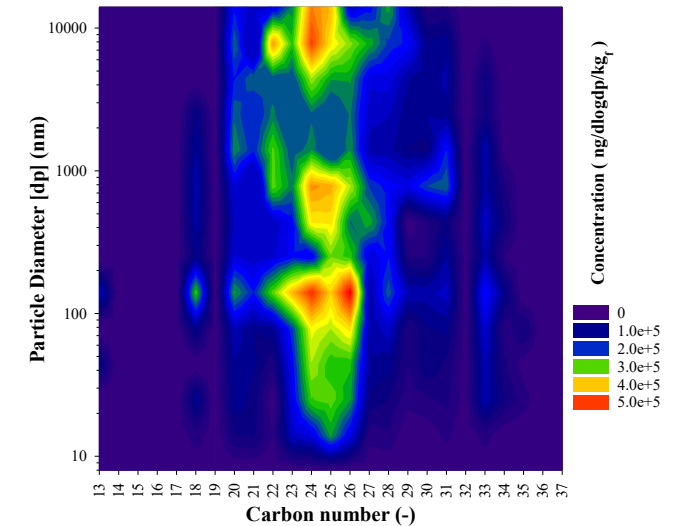
Alkanes (Before DOC)



Alkanes (After DOC)



Alkanes (After DOC+DPF)



## Presence of $\approx$ C>11 intermediate-/semi-volatile organic compounds (I/SVOC) can result in uncertainty in physico-chemical characterisation of particle emissions, mainly due to:

- Active gas-particle partitioning & interaction with other species under the exhaust conditions
  - Contribution to the formation of secondary aerosols
- ⇒ **An extended characterization and better knowledge of VOCs partitioning & richness, to accurately evaluate the potential contribution of these particular precursors to the formation of Secondary Organic Aerosols**

# Overview of the “AEROSOLS” protocol to evaluate, primary/secondary emissions + ageing



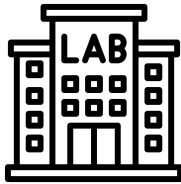
WP2

WP3

## Vehicle's evaluation



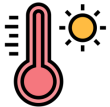
On-road



In-lab.

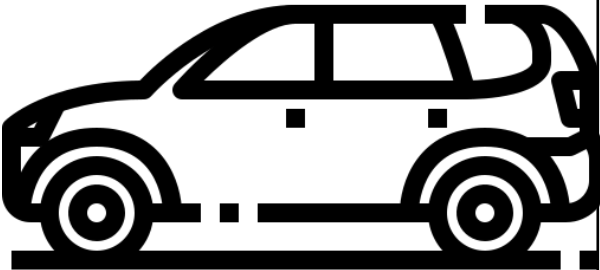


Ambient...



...hot start

\*2



## Vehicle's primary emissions

### Euro 6

**Gaseous phase** ⇨

CO, CO<sub>2</sub>, NO<sub>x</sub>, HC<sub>total</sub>, nMHC

**Particulate phase** ⇨

Particulate Mass (PM)

Particle Number (SPN<sub>23</sub>)

### Euro 7

**Gaseous phase** ⇨

CO, CO<sub>2</sub>, NO<sub>x</sub>, HC<sub>total</sub>, nMHC

**Particulate phase** ⇨

Particulate Mass (PM)

Particle Number (SPN<sub>10</sub>)

### Unregulated, Aerosols & SOA precursors

**Gaseous phase** ⇨

N<sub>2</sub>O, NH<sub>3</sub>, SO<sub>2</sub>, CH<sub>2</sub>O, CH<sub>4</sub>O, individual HCs, HONO, VOCs, iVOCs, sVOCs...

**Particulate phase** ⇨

Particulate Mass (PM<sub>1</sub>, PM<sub>2.5</sub>, PM<sub>10</sub>)

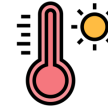
Particle Number (Solid/volatile; from PN<sub>1</sub>)

Size distribution & composition (organic, metals,...)

## Ageing



RH



RH



3 ≠ ageing devices

## Secondary emissions

### Euro 6

Not applicable

### Euro 7

Not applicable

### Unregulated & Secondary Aerosols

**Gaseous phase** ⇨

Potential gaseous precursors of SOA in particular (VOCs, iVOCs, sVOCs,...)

**Particulate phase** ⇨

Particulate Mass (PM<sub>1</sub>, PM<sub>2.5</sub>, PM<sub>10</sub>)

Particle Number (Total; from PN<sub>1</sub>)

Size distribution

Composition (BC, organic, nitrate, sulfates,...)

⇒ **To WP4: Health, Environmental & Social impacts**  
 ⇒ **& WP5: Robust measurement & modelling methods**



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# AEROSOLS

Air Quality and Health Impact of Primary Semi-volatile  
and Secondary Particles and Their Abatement



**Thank you for  
your attention!**

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