Coefficiente di assorbimento degli aerosol a Milano: evoluzione del ruolo della combustione di combustibili liquidi e solidi (2019–2025)

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Scientific Context & Motivation

Light-absorbing aerosols in urban environments

•Black carbon, brown carbon (BrC), mineral dust strongly affect:

- Air quality and visibility
- Climate radiative forcing

•Po Valley = European pollution hotspot, highly impacted by combustion processes

•Black carbon recognised as an emerging pollutant in EU directive

•Brown carbon: enhanced absorption at short wavelengths

•Need for:

- Long-term observations
- Robust source apportionment methods

Measurement Site & Dataset

Where?

•Urban traffic site: **Milano–Marche (ARPA Lombardia)**

When?

•Period: **July 2019 – June 2025**

- Missing year: 2022
- Hourly data

Available measurements?

•Instrument: **AE33 Aethalometer**

- Light absorption coefficient (b_{abs}), 7 wavelengths (370–950 nm)
- PM2.5 inlet

Source apportionment: traditional Aethalometer model

Aethalometer model (traditional)

- Source apportionment (2 sources): liquid fuels/solid fuel combustion

- Input: 2 wavelengths. Possible choice (Aethalometer data):

  - short wavelength: 370 or 470 nm

  - long wavelength: 880 or 950 nm

- Hypotheses:

  - babs due to LF and SF only

  - LF and SF: power-law λ-dependence

    with α_{LF} and α_{SF}

$$b_{abs}(\lambda_1) = b^{LF}_{abs}(\lambda_1) + b^{SF}_{abs}(\lambda_1) \qquad b_{abs}(\lambda_2) = b^{LF}_{abs}(\lambda_2) + b^{SF}_{abs}(\lambda_2)$$

$$\frac{b_{abs,LF}(\lambda_2)}{b_{abs,LF}(\lambda_1)} = \left(\frac{\lambda_2}{\lambda_1}\right)^{-\alpha_{LF}} \qquad \frac{b_{abs,SF}(\lambda_2)}{b_{abs,SF}(\lambda_1)} = \left(\frac{\lambda_2}{\lambda_1}\right)^{-\alpha_{SF}}$$

Source apportionment: traditional Aethalometer model

Aethalometer m

- Source app… …ombustion
- Input: 2 wave…
  - short wavelength: 370 or 470 nm
  - long wave… …nm

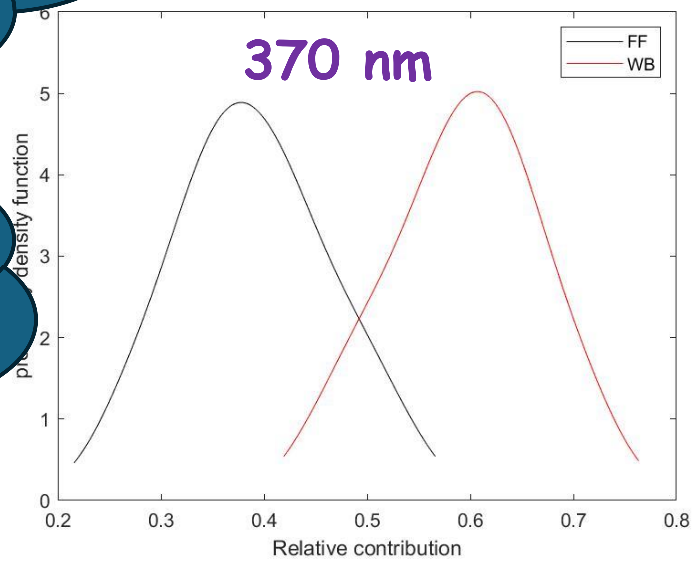
How to choose the input wavelengths? (note: choice can impact about 7%)

WHY do I not exploit all available information?

How do I choose α_{LF} & α_{WB}?

- Hypotheses
  - babs due tc…
  - LF and SF: power-law λ-depend…

    with α_{LF} and α_{SF}



Methodology Overview

Aerosol absorption coefficient at 7-λ ($b_{abs}(\lambda)$):
Derived from Aethalometer output (loading corrected eBC) using ACTRIS recommendations

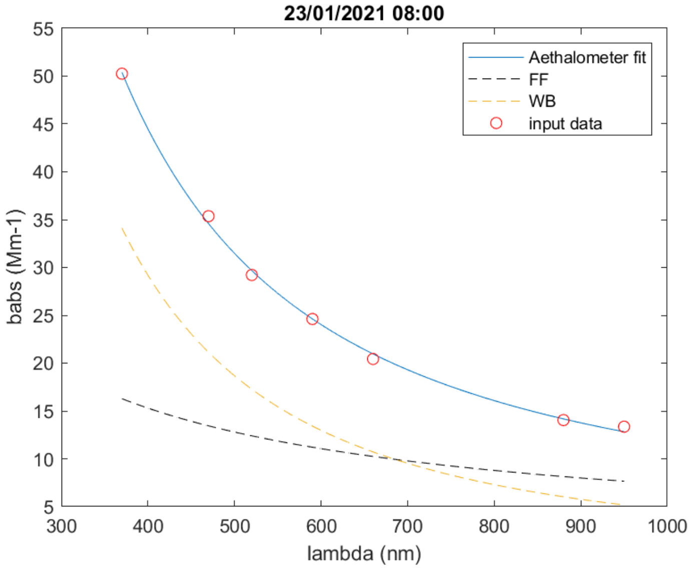
•Source apportionment:

Massabò et al, 2015;
Bernardoni et al, 2017

- **Multi-wavelength Aethalometer model**
- Liquid Fuel (LF) vs Solid Fuel (SF) combustion

$$b_{abs}(\lambda) = \underbrace{A'\lambda^{-\alpha_{LF}} + B'}\lambda^{-\alpha_{SF}}$$

Determinare
con fit multi-λ



Free parameters of the model (to be chosen a-priori)

- α_{LF}
- α_{SF}

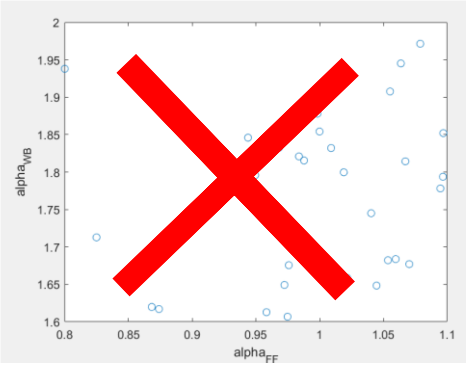
Development of a new optimisation methodology

Internal optimisation of Aethalometer parameters

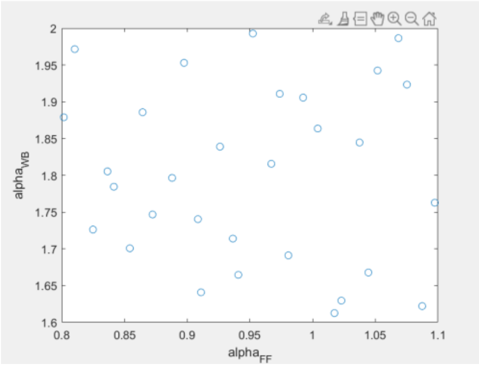
- Key innovation of the study: optimisation of α_{LF} and α_{SF}

$$b_{abs}(\lambda) = A' \lambda^{-\alpha_{LF}} + B' \lambda^{-\alpha_{SF}}$$

Random sampling



LHS sampling



Methodology:

- Test values: Latin Hypercube Sampling of random (α_{LF} and α_{SF} couples) are used to run the model.
- Innovation: maximising internal consistency of the fit: **no need of external tracers**

- The best choice:
  - Minimises negative source contributions (i.e., **minimise the number of** time-slots with **A'<0 & B'<0**)
  - **Minimise the number** of samples with **relative uncertainties** on fit parameters **beyond threshold**

\# of A' <0 & B'<0

\# of errRel(A') & errRel(B') beyond threshold

Final optimised choice: α_{LF} **= 0.80,** α_{SF} **= 2.0**

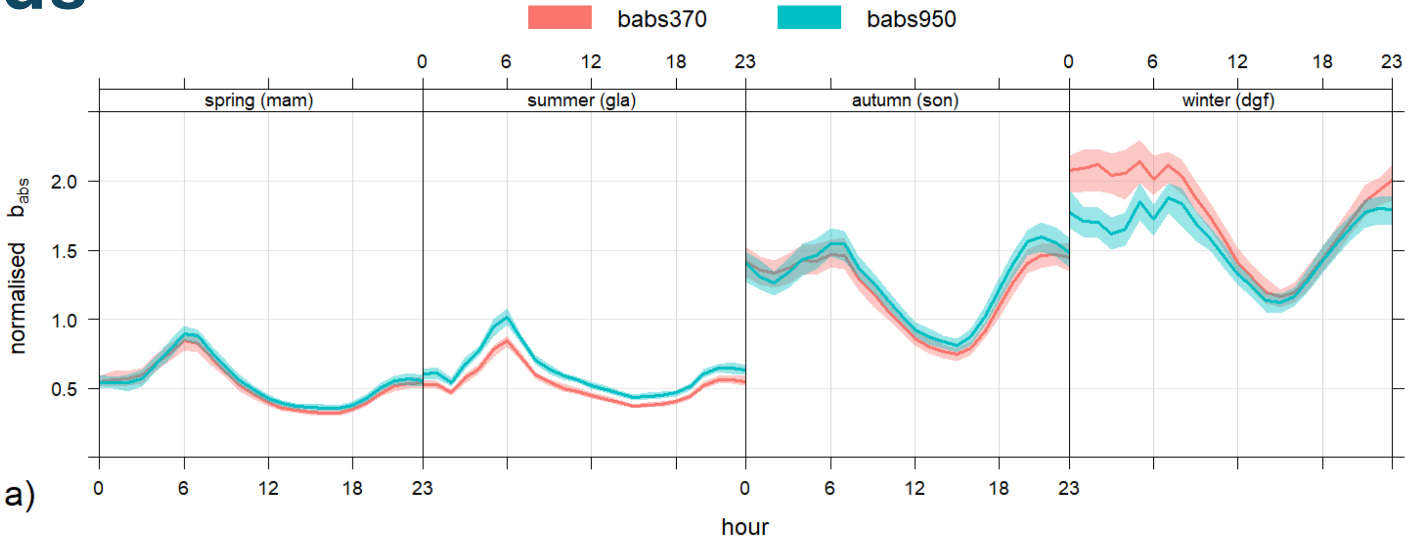
Absorption Coefficient Trends

Temporal evolution of aerosol absorption

•Clear seasonal cycle with winter maxima

•Clear rush-hour in spring/summer

•Highest relative winter vs summer increase of babs(370nm) compared to babs(950 nm)



Spring		Summer		Autumn		Winter	
b_{abs370}	b_{abs950}	b_{abs370}	b_{abs950}	b_{abs370}	b_{abs950}	b_{abs370}	b_{abs950}
-16%	-17%	-32%	-37%	-34%	-39%	-19%	-26%

•Comparison **2019–2021 vs 2023–2025**

•Observed reductions:

- At all wavelengths
- Stronger at **950 nm** than at **370 nm**

•Indicative of:

- Generally decreasing trend
- Stronger BC decrease than BrC

Source Apportionment Results

LF vs SF combustion contributions

•LF dominates absorption in most of the year, also at 370 nm

•Seasonal behaviour:

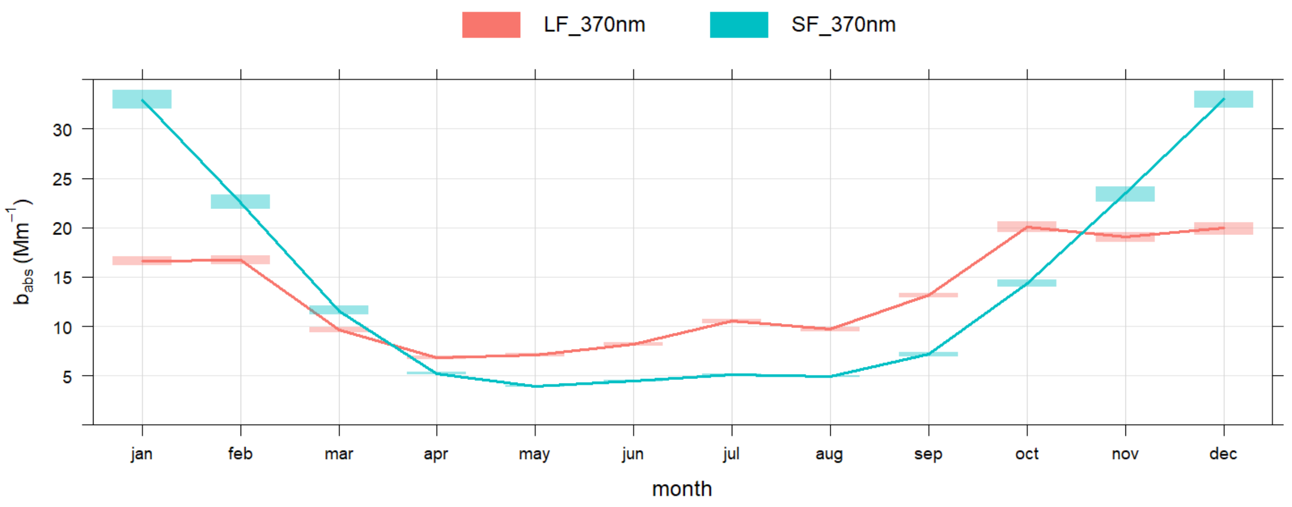
- LF: stable, traffic-driven
- SF: strong winter enhancement

•Winter at 370 nm:

- SF becomes dominant contributor

•Diurnal patterns:

- LF peaks during rush hours
- SF higher at night



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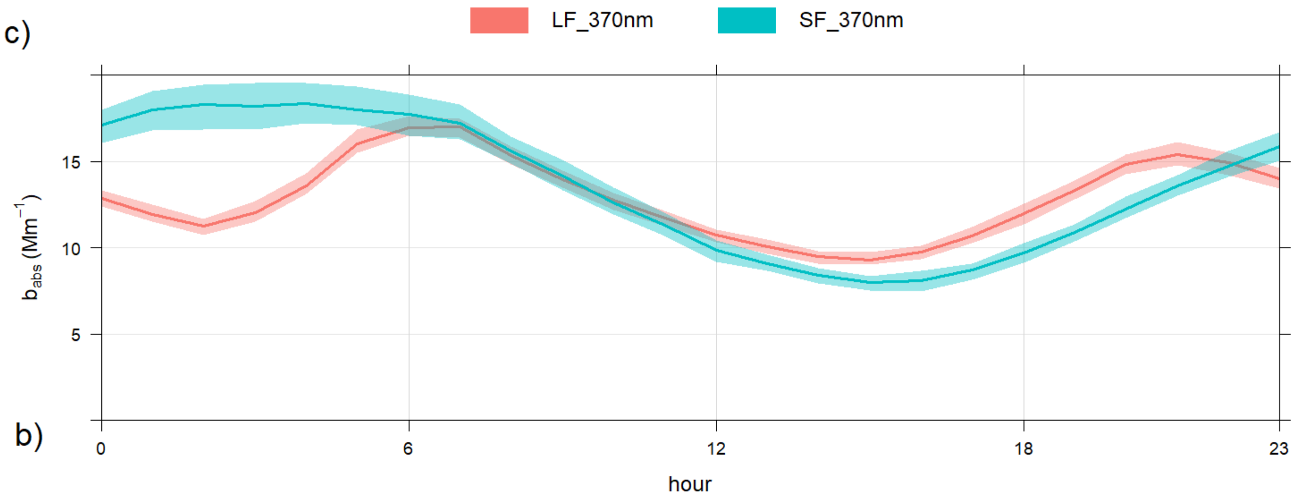

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Drivers of Long-Term Change

Linking absorption trends to emission sources

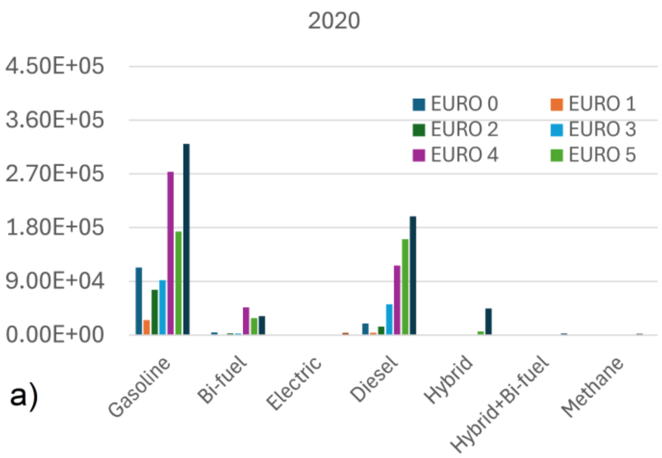
•Total b_{abs} reduction mainly due to:

- **Declining LF** contribution
- **Much weaker SF** combustion reduction

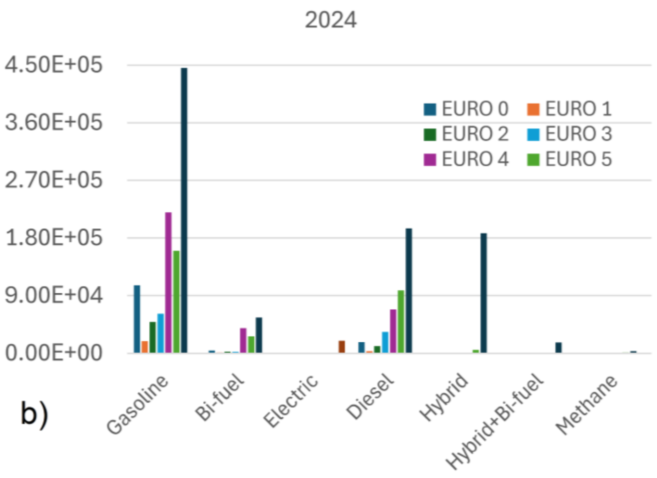
	Season	LF	SF
Relative reduction (23-25 vs. 19-21)	summer	-41%	-9%
	autumn	-44%	-22%
	winter	-36%	-12%
	spring	-17%	-14%

•Vehicle fleet analysis (2020 → 2024):

- Pre-EURO 6 diesel vehicles reduction compensated by EURO 6 gasoline and hybrid cars
- Heavy-duty fleet renewal equally relevant



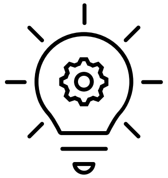
a)



b)

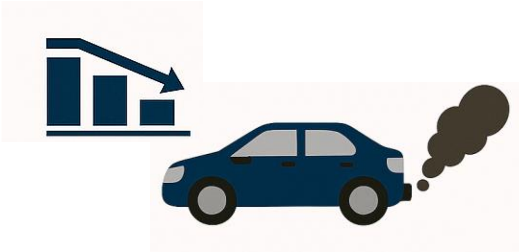
Conclusions & Policy Relevance

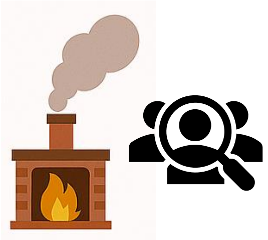
•Robust 5-year evidence of declining aerosol absorption coefficient



•New internal optimisation of the Aethalometer model with no need of external tracers

•Traffic emission reduction policies (EURO 6) was proven to be effective for BC mitigation

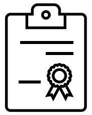




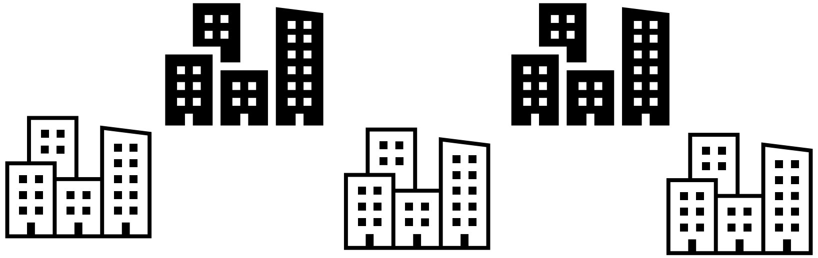
•Solid fuel combustion remains critical in winter and needs to be more targeted by reduction policies

•Method scalable to other urban monitoring sites

•High relevance for:



- EU Air Quality Directive (2024/2881)
- Future BC emission regulations



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