

Multi-pollutant contribution of wood heating to emissions, concentrations and population exposure during wintertime down to the street levels

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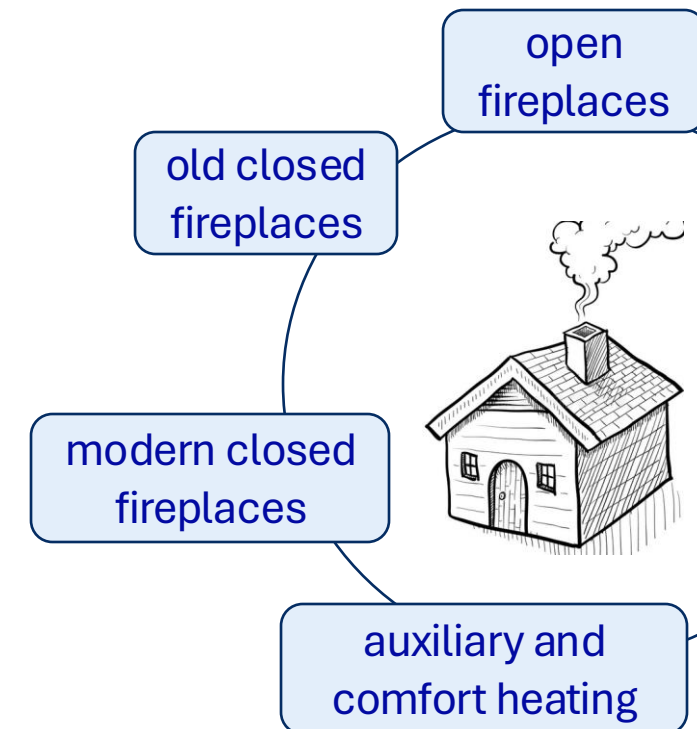
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Introduction

- Atmospheric pollution remains a **major health issue** in urban areas
 - responsible for 6.7 million premature deaths annually (WHO)
- Most hazardous health impacts are related to **fine particulate matter** (PM_{2.5})
 - Diverse composition and sizes (**emerging pollutants**)
 - black carbon (BC)
 - organics (OM)
 - ultra-fine particles (UFP – PM_{0.1})
 - **Importance to reduce population exposure**

Introduction

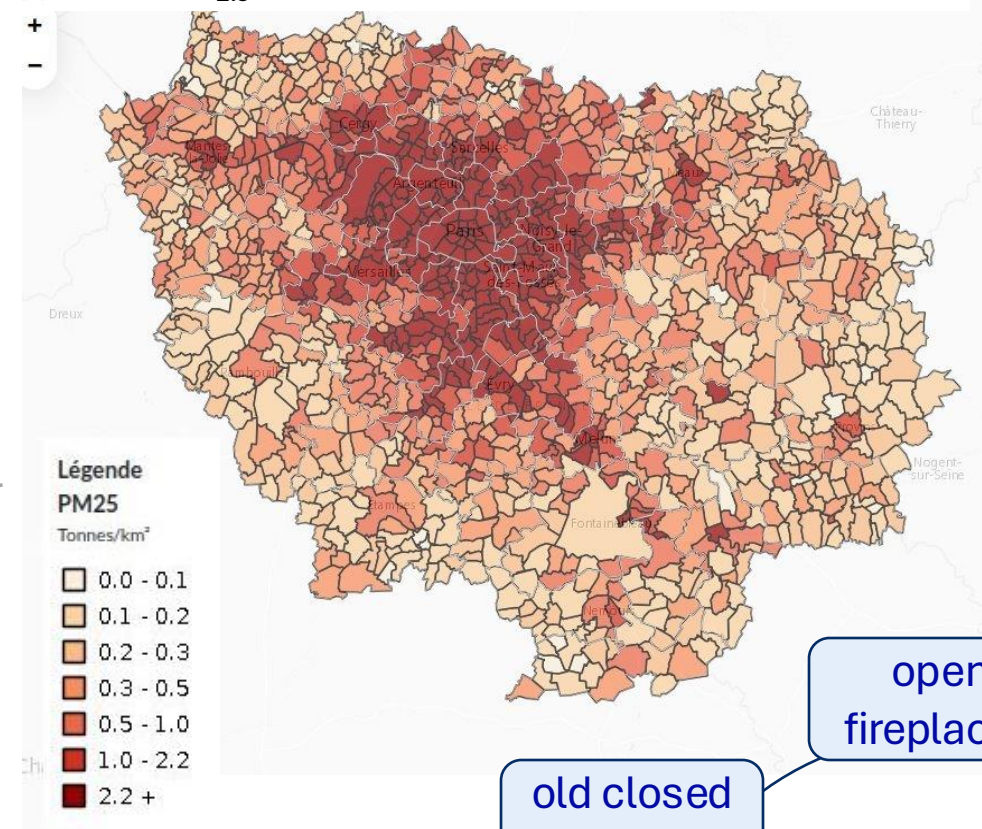
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 - Diverse composition and sizes (emerging pollutants)
 - black carbon (BC)
 - organics (OM)
 - ultra-fine particles (UFP – $PM_{0.1}$)
 - Importance to reduce population exposure
- Residential wood heating is a major source of $PM_{2.5}$ in different regions
 - different types and technologies of wood-burning heaters
 - different emission factors and practices



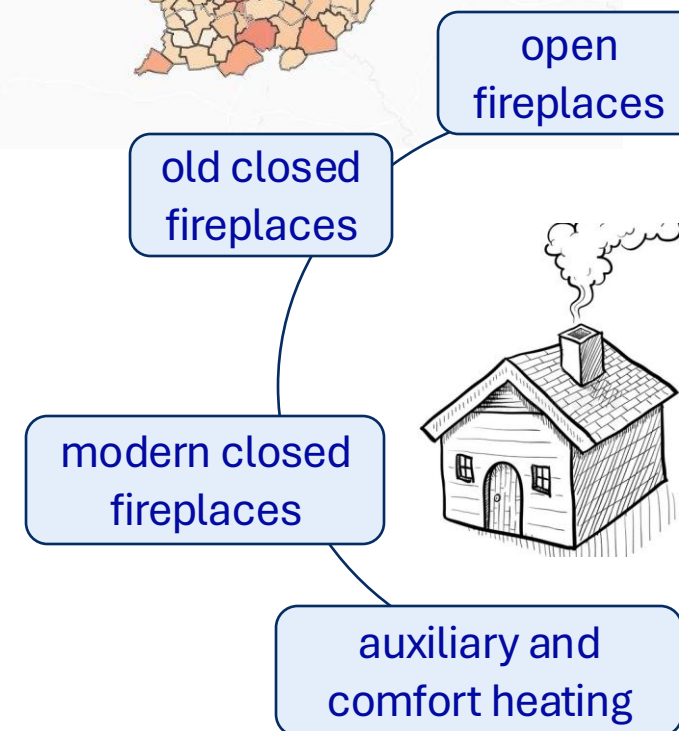
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 - black carbon (BC)
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 - ultra-fine particles (UFP – PM_{0.1})
 - Importance to reduce population exposure
- **Residential wood heating is a major source** of PM_{2.5} in different regions
 - different types and technologies of wood-burning heaters
 - different emission factors and practices
 - spatial variability
 - correlated to local population

PM_{2.5} emissions map in Greater Paris region



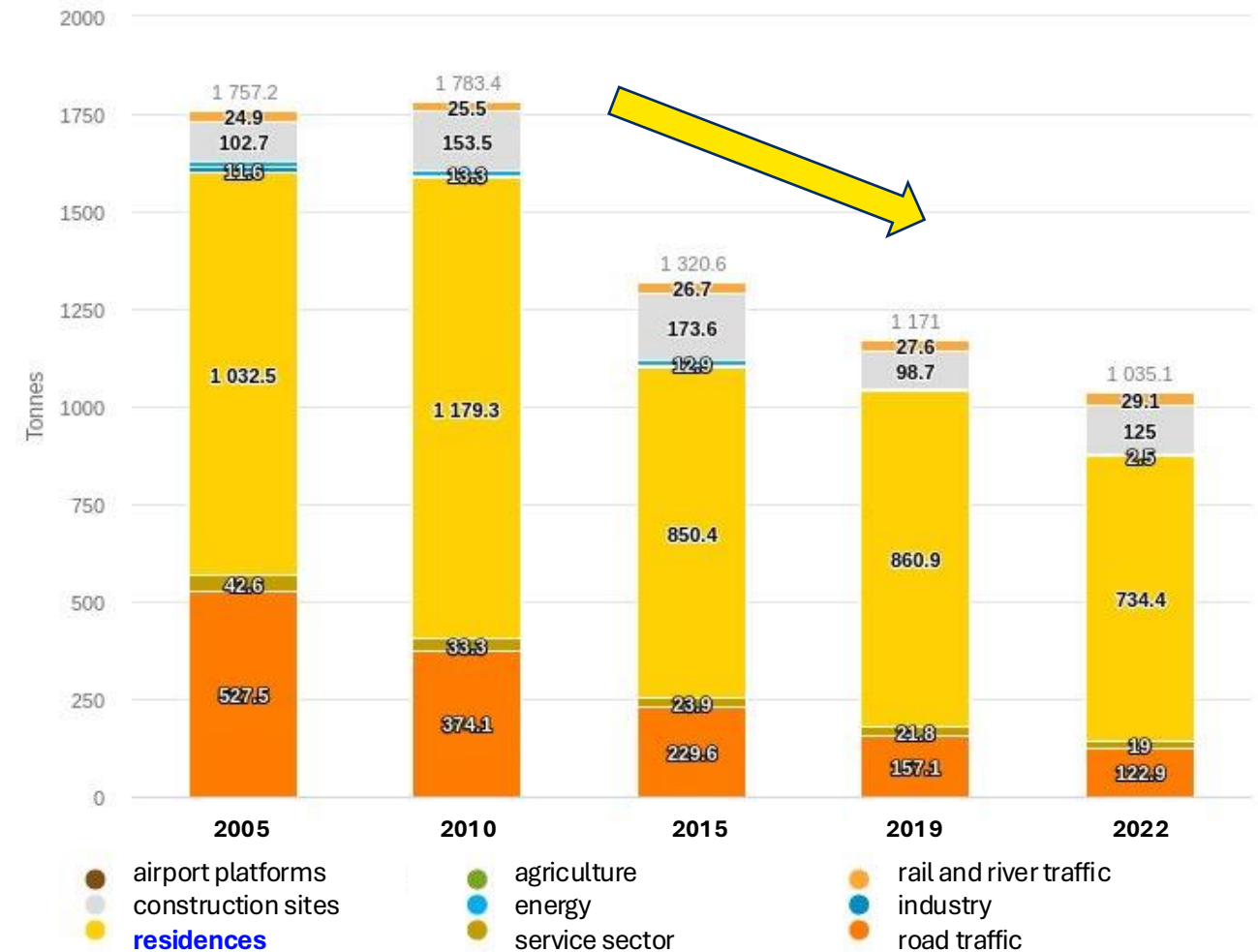
Source: <https://www.airparif.fr/>



Introduction

- Significant reductions of residential emissions over the last years

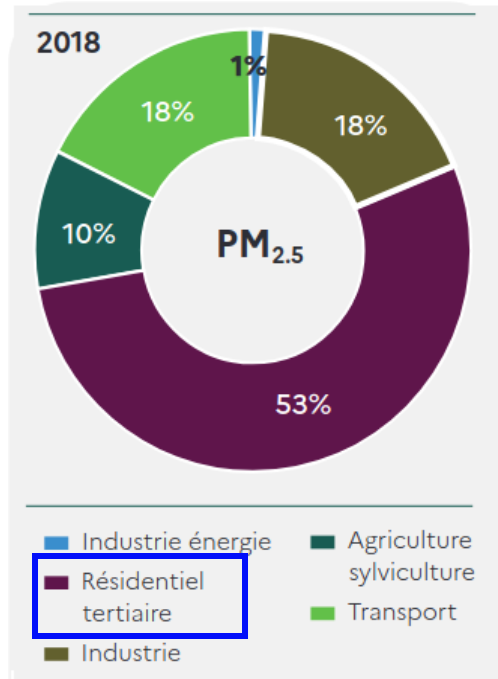
History of PM_{2.5} annual emissions in Paris



Introduction

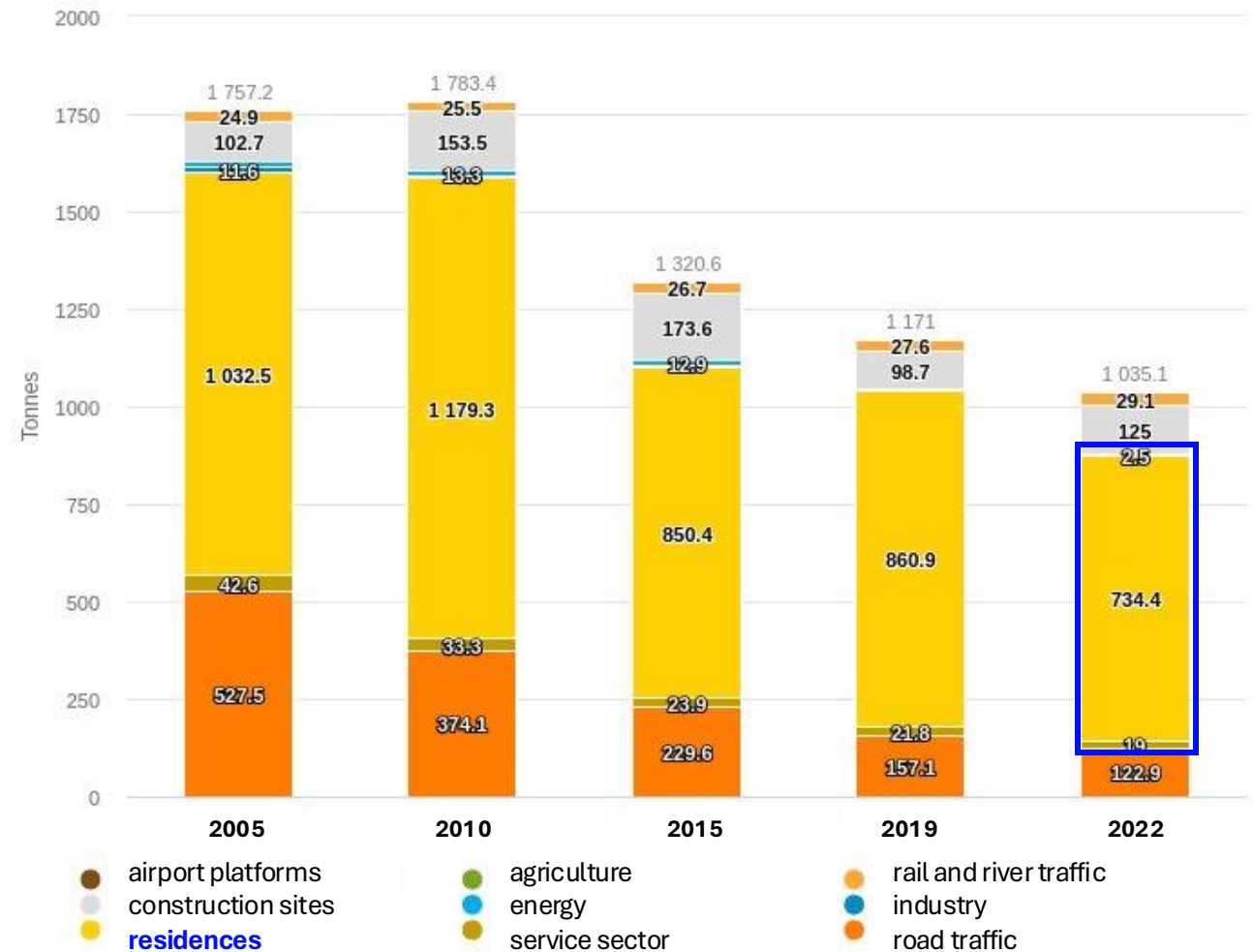
- Still, residential sector contributes with **most of PM_{2.5} emissions**
 - most of particles emitted by residential wood heating

PM_{2.5} emission sources in France



Source: CITEPA

History of PM_{2.5} annual emissions in Paris



Source: <https://www.airparif.fr/>

Introduction

- Significant reductions of residential emissions over the last years
 - most of particles emitted by residential wood heating
- **French national objective** – reduction of 50% of particles emitted by residential heating up to 2030

PLAN D'ACTION

Réduction des émissions issues du chauffage au bois en France

Chauffage domestique au bois performant

ÉTAT DES LIEUX



Objective

- ***Estimate the **contribution of wood heating** to the population exposure of regulated and emerging pollutants with a street-level resolution***

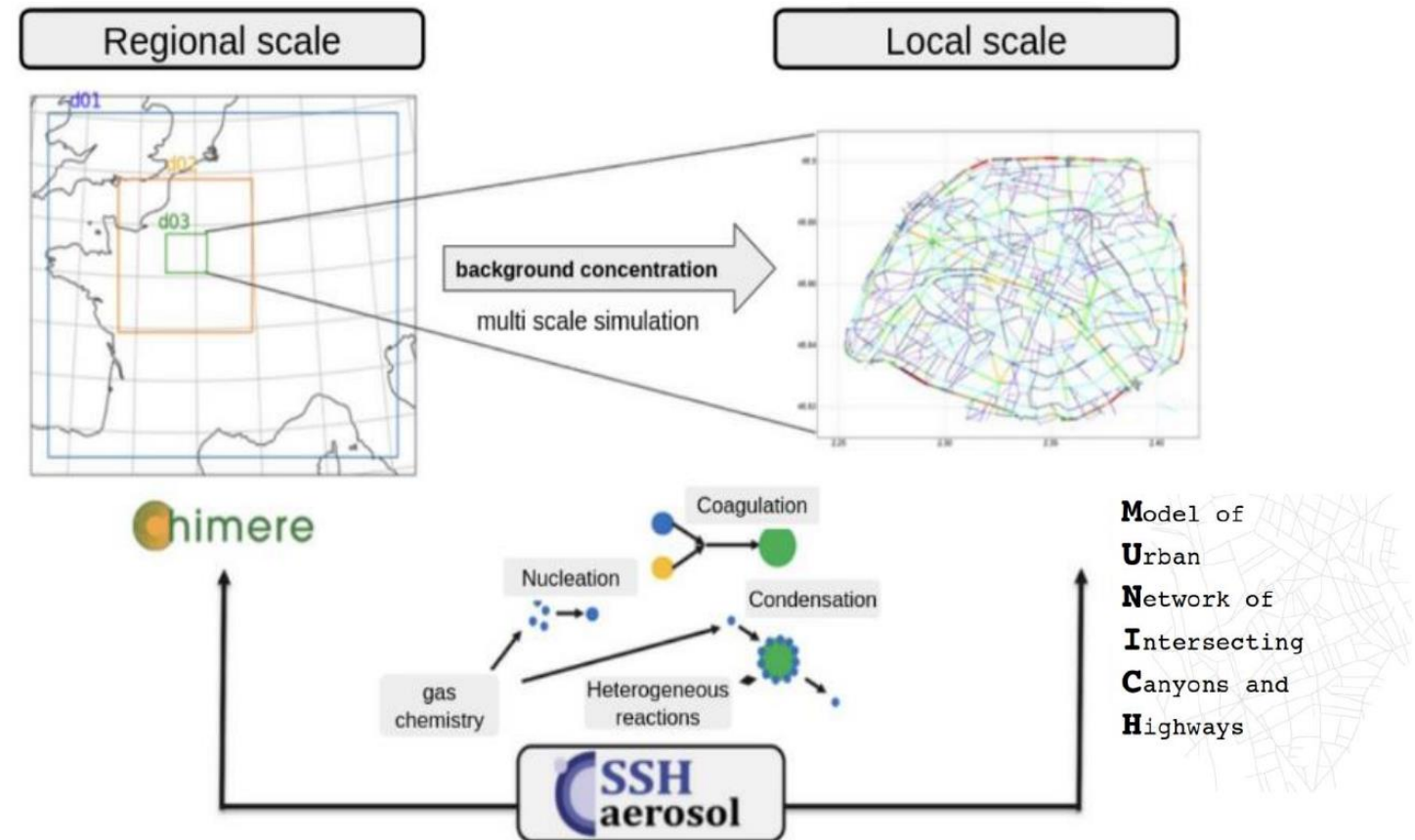
Objective

- ***Estimate the **contribution of wood heating** to the population exposure of regulated and emerging pollutants with a street-level resolution***
 - ***Two 2030 scenarios were evaluated:***
 - ***business-as-usual (BAU)***
 - ***national emission-reduction objective***
 - Analysis over Metropolitan France and Paris region during winter 2020/2021
 - Regulated (PM₁₀, PM_{2.5}, NO₂) and emerging pollutants (BC, OM, UFP)

Multi-scale model chain

- Innovative multi-scale modelling chain **CHIMERE/MUNICH/SSH-aerosol**

- Concentrations at regional scale (~ 1 km)
 - **CHIMERE** model (Menut et al., 2021)
- Concentrations at street level (~ 10 m)
 - **MUNICH** model (Kim et al., 2022)
- Chemical interactions and transformations of particles in the atmosphere
 - **SSH-aerosol** model (Sartelet et al., 2020)
- Meteorological fields
 - **WRF** model (Powers et al., 2017)

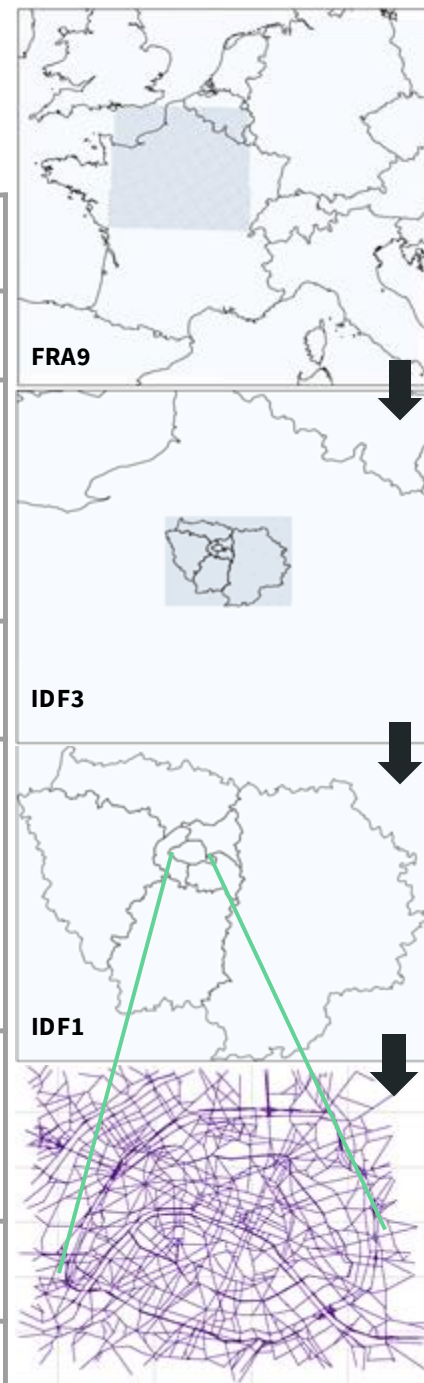


Consistent representation of multi-scale concentrations, taking into account the main phenomena related to atmospheric dispersion.

Outdoor population exposure in Paris:
Population -weighted concentrations (PWC)

Multi-scale model chain

	CHIMERE (échelle régionale)	MUNICH (échelle locale)
Domain	Île-de-France (spatial resolution: 1 km x 1 km)	Paris (4655 rues)
Boundary/initial conditions	Boundary conditions : CAMS Nested simulations : France (9 x 9 km) et IdF (3 x 3 km) Meteorology : données horaires WRF avec UCM	Urban background concentrations: hourly data from CHIMERE Meteorology : hourly data from WRF using UCM
Biogenic emissions	MEGAN v2.04 (Guenther et al., 2006) dans CHIMERE	Not included
Emissions used in the Île-de-France region	Emissions : Airparif (local air quality agency) - Non-traffic : Emissions with 1km resolution. Detailed survey for residential heating - Traffic : Emissions per street corrected with counting loops	Emissions : Airparif (local air quality agency) Traffic : Emissions per street corrected with counting loops
Emissions used outside the Île-de-France region	EMEP inventory Condensables estimated following Couvidat et al., 2013 (ACP)	Not included
UFP emissions	Methodology implemented and validated based on the literature (Park, et al., 2025 , Sartelet et al., 2022)	
Population data	MAJIC database (Letinois, L., 2014) with the number of inhabitants per building	



Emission inventory over Greater Paris

- Combination of emission inventories with detailed spatial resolution and residential emission data
 - computed by the local air-quality agency (Airparif)

Residential emissions

- based on the most **recent survey** in the region
 - detailed heating fleet (technologies, types and practices)
- inclusion of **condensable emissions** with emission factors adapted per heating type

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Road-traffic emissions

- emissions per street and vehicle type corrected with traffic counting loops
- condensable emissions estimated based on the literature

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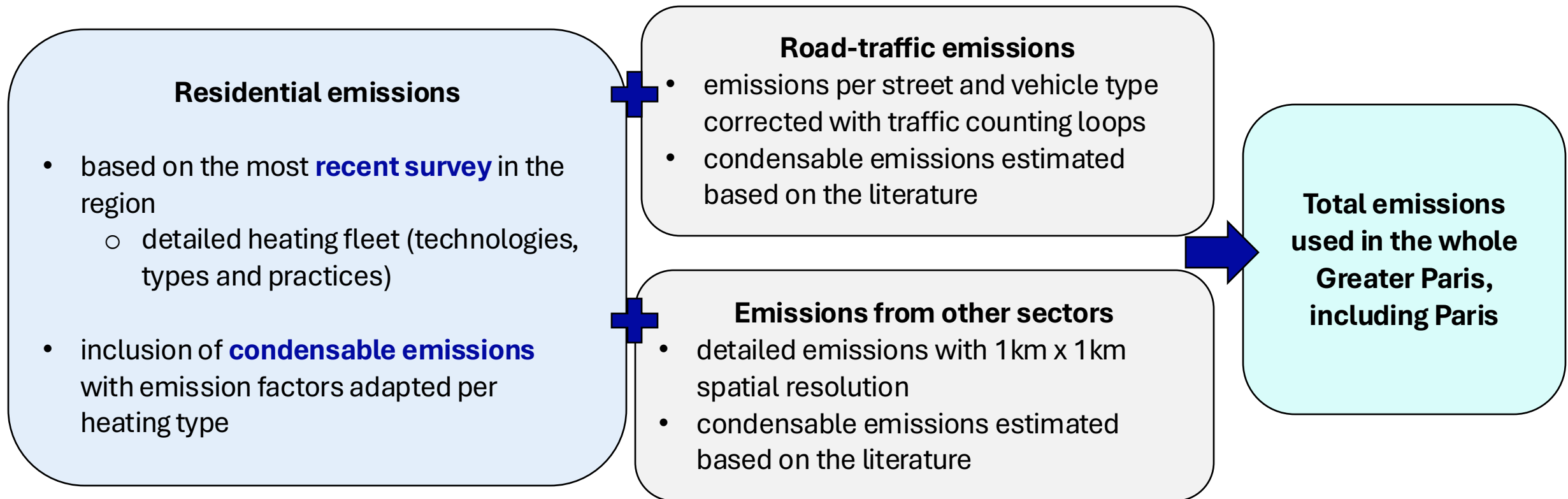
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Emissions from other sectors

- detailed emissions with 1km x 1km spatial resolution
- condensable emissions estimated based on the literature

Emission inventory over Greater Paris

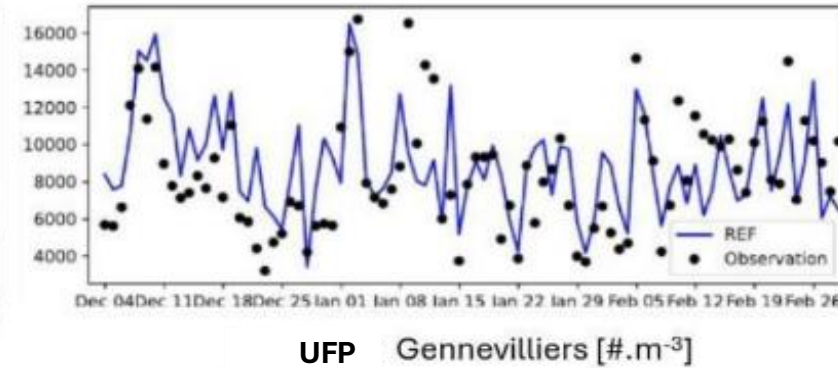
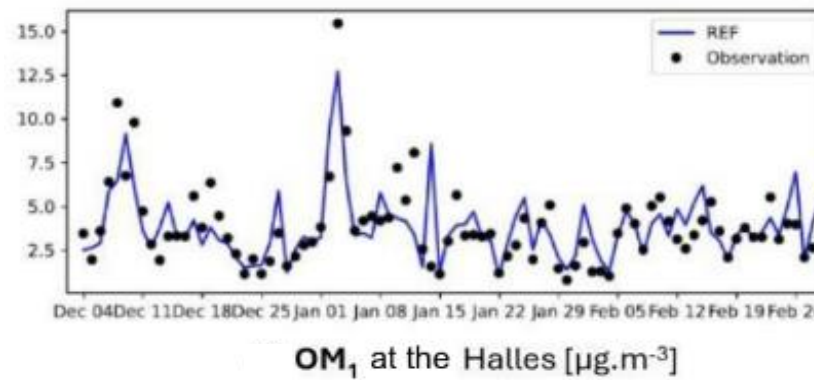
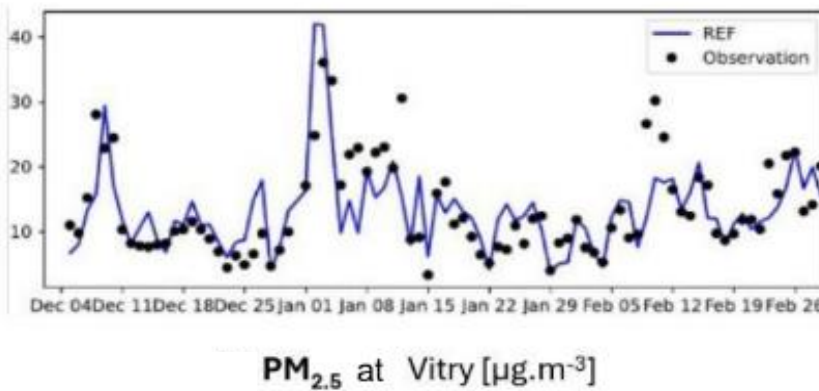
- Combination of emission inventories with detailed spatial resolution and residential emission data
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- Future BAU 2030 emissions based on residential emissions 2010-2022 trend

Model validation

- Good representations of all analyzed pollutants during the winter period
 - representation of temporal evolution
 - performance criteria defined in the literature ([Boylan and Russell, 2006](#), [Hanna and Chang, 2012](#))



Average concentrations observed and simulated in different stations

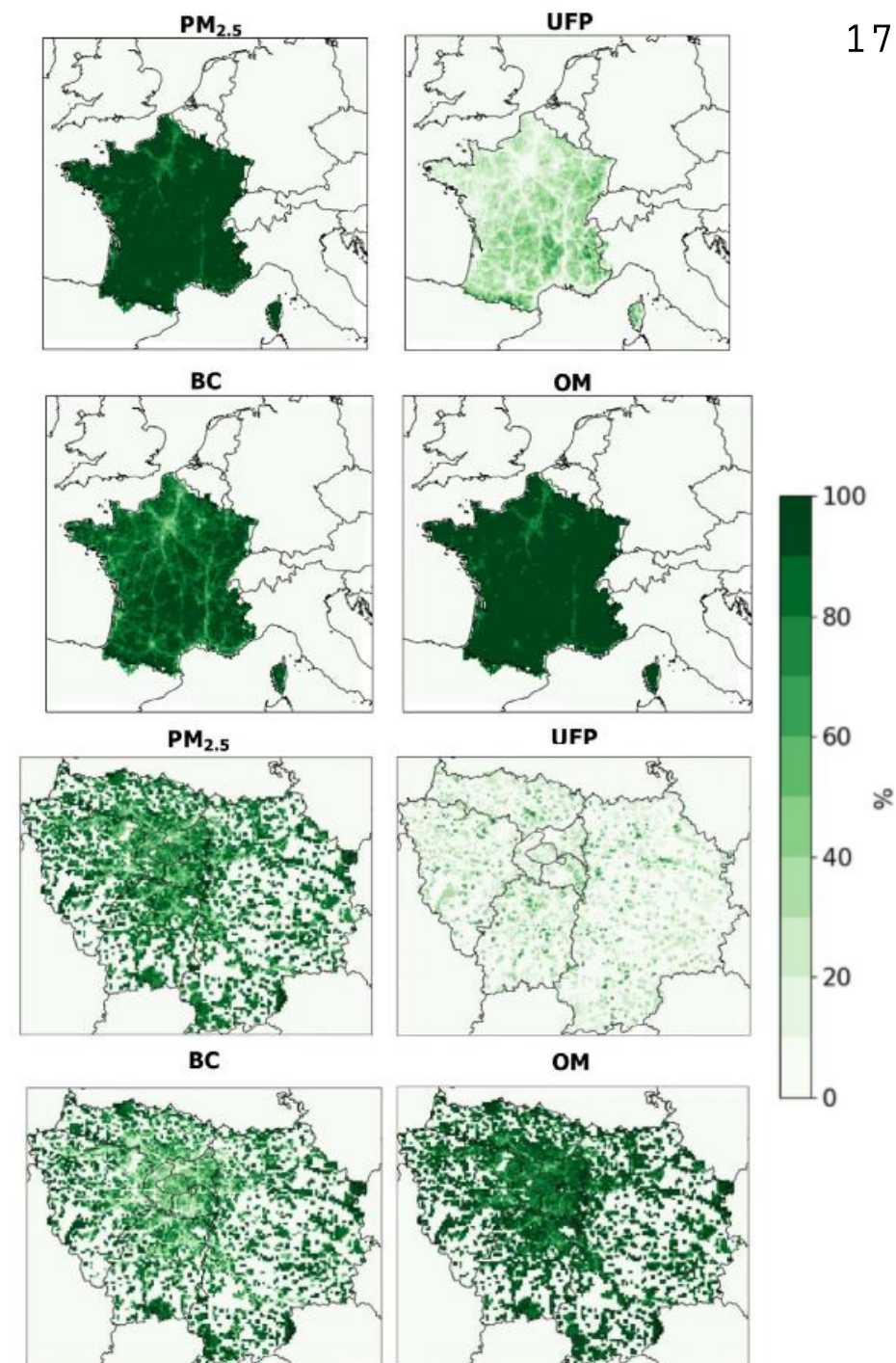
	PM ₁₀			PM _{2.5}			BC			OM			UFP		
Region/ station type	Nst	obs. [µg.m ⁻³]	sim. [µg.m ⁻³]	Nst	obs. [µg.m ⁻³]	sim. [µg.m ⁻³]	Nst	obs. [µg.m ⁻³]	sim. [µg.m ⁻³]	Nst	obs. [µg.m ⁻³]	sim. [µg.m ⁻³]	Nst	obs. [#.m ⁻³]	sim. [#.m ⁻³]
Met. France	139	16.5	14.1	86	11.3	13.0	5	0.7	1.1	1	3.8	5.4	5	7196	9697
Greater Paris	14	16.7	14.6	8	11.9	13.1	5	0.7	0.7	1	3.8	3.9	4	7086	6902
Paris streets	5	26.1	23.2	2	16.5	23.4	2	3.2	3.5	1	4.0	7.7	0	-	-

Contribution of wood heating on emissions

- Small contributions on NO_2 emissions (< 2% in Greater Paris)

Contribution of wood heating to pollutant emissions during the winter period studied (in %)

	NO_2	PM_{10}	$\text{PM}_{2.5}$	BC	OM	UFP
Met. France	26.1	89.1	93.9	83.1	94.5	21.5
Greater Paris	1.4	40.2	50.5	33.7	66.0	7.9
Paris city	1.5	53.0	64.7	44.7	81.6	9.3

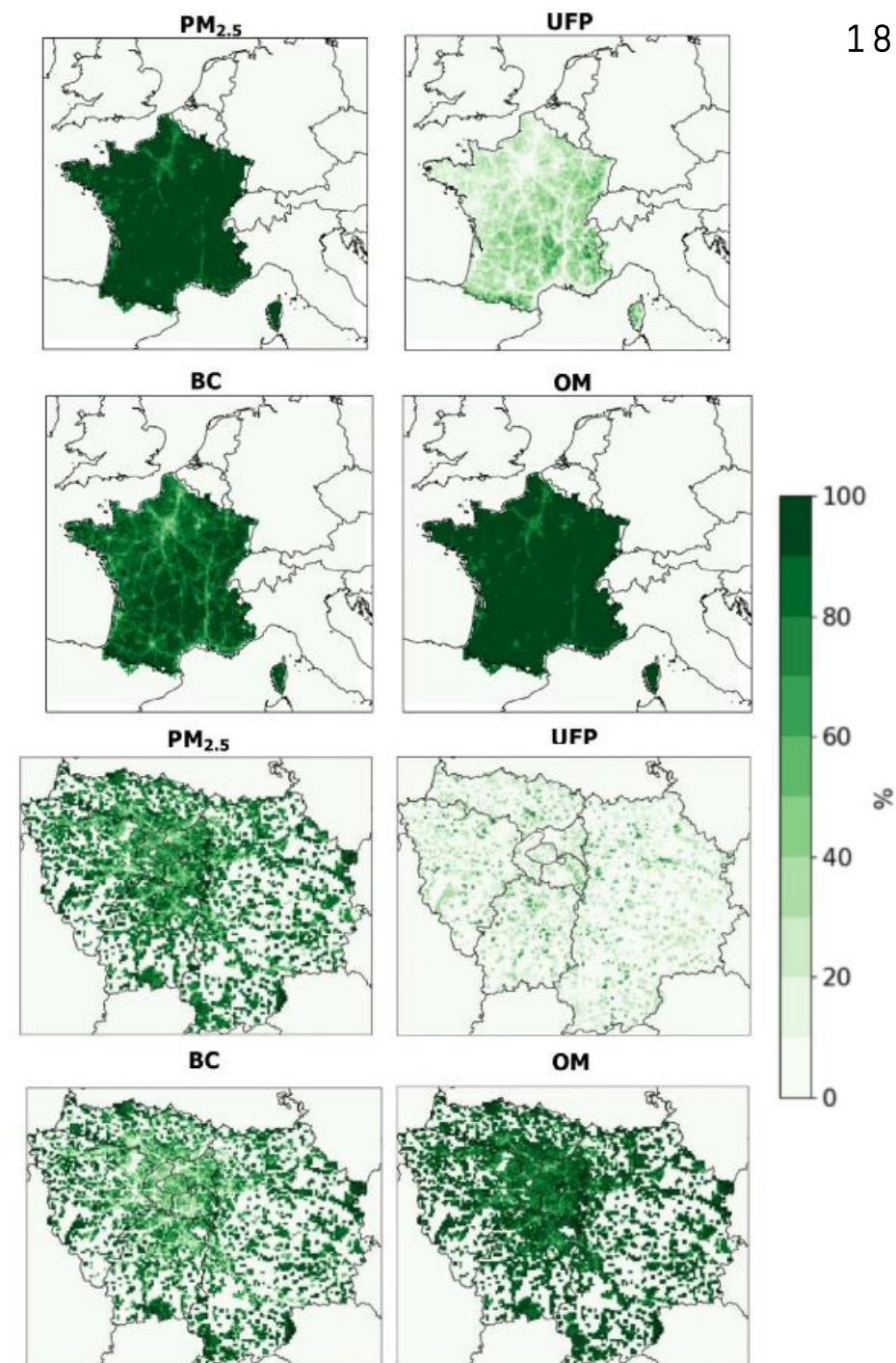


Contribution of wood heating on emissions

- Small contributions on NO_2 emissions (< 2%)
- Strong contributions on particulate mass emissions
 - up to 82% in OM emissions over Paris
 - smaller contributions to BC emissions – strong traffic signature

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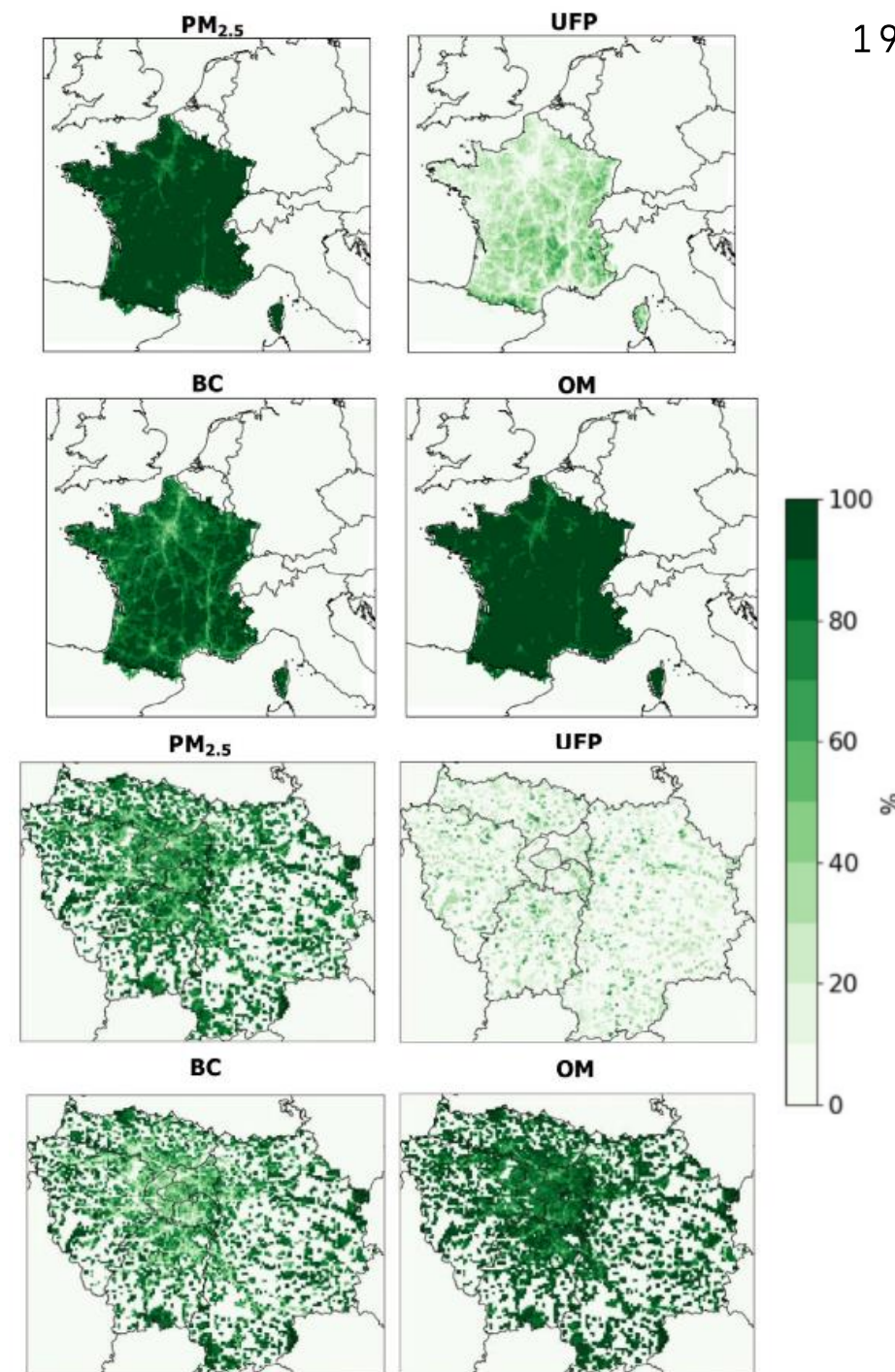


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- Small contributions on NO_2 emissions (< 2%)
- Strong contributions on particulate mass emissions
 - up to 82% in OM emissions over Paris
 - smaller contributions to BC emissions – strong traffic signature
- Small contributions on UFP emissions
 - minimal particle diameter of 80nm for residential sector based on PMF ([Garcia-Marles et al., 2024](#))

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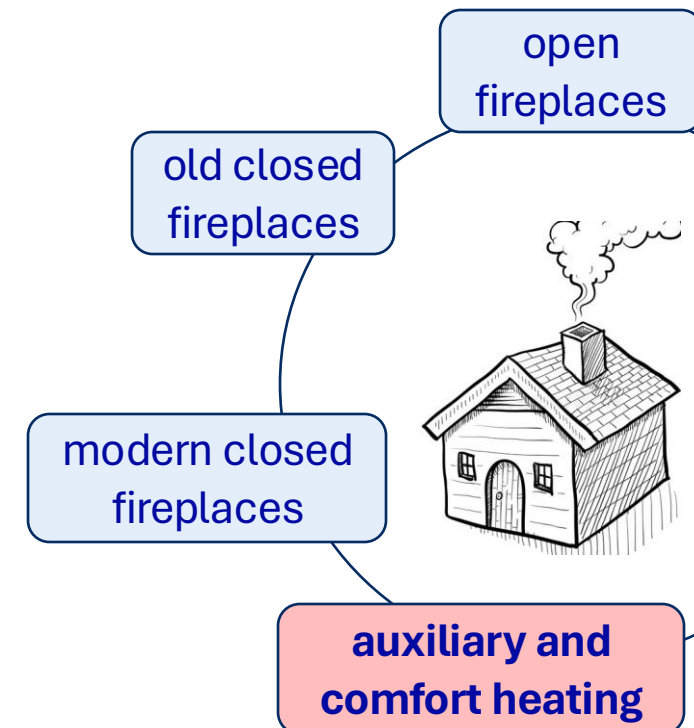


Contribution of wood heating on emissions

- Auxiliary and comfort heating is the most important source of wood burning emissions in Paris

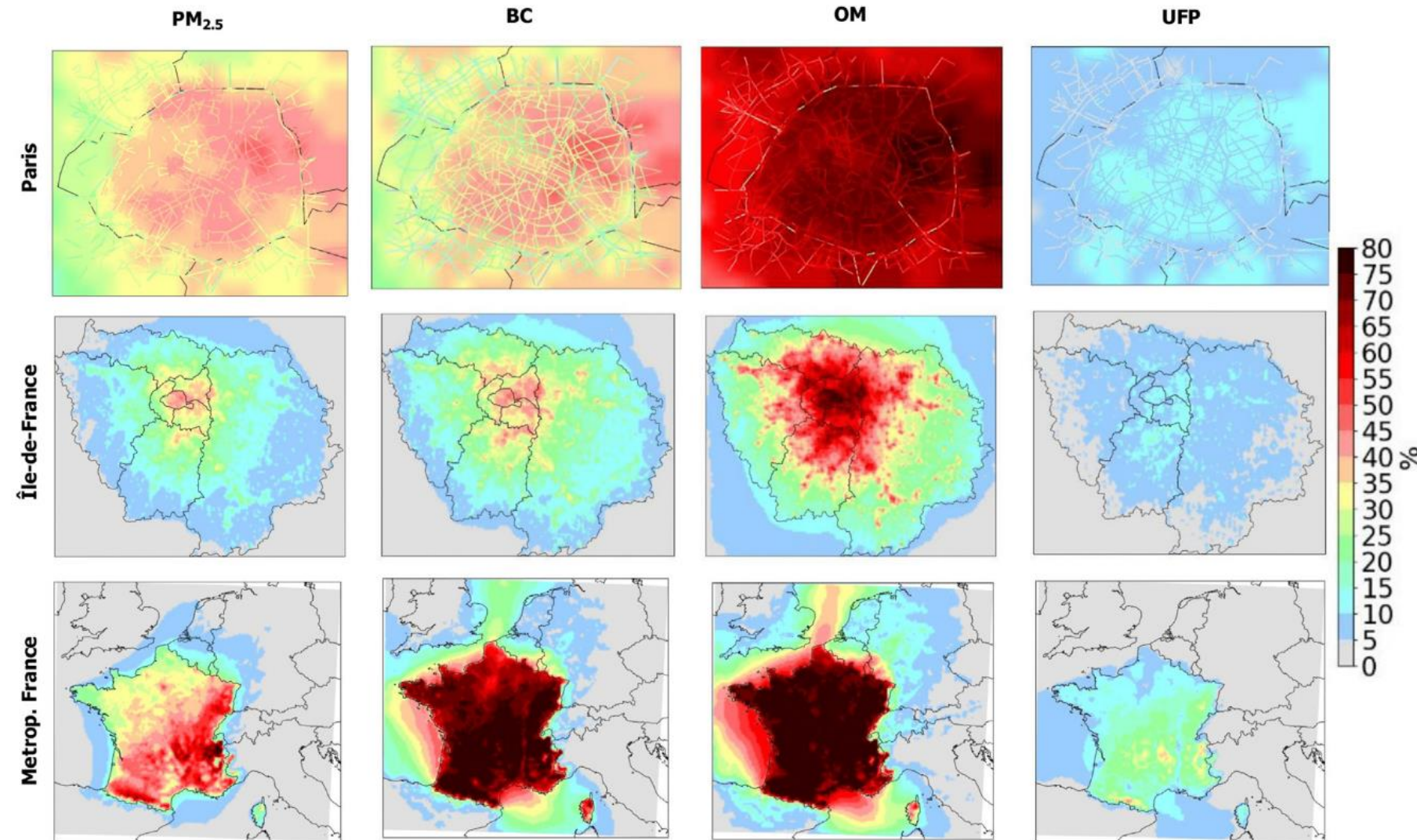
Contribution of wood heating to pollutant emissions per type of equipment (in %)

Region	Pol.	No WB	Open FP	Old closed FP	Aux. and comf.
Paris city	NO ₂	1.5	0.6	0.8	1.5
	PM ₁₀	53.0	30.8	40.3	52.0
	PM _{2.5}	64.7	37.5	49.2	63.4
	BC	44.7	25.9	34.0	43.8
	OM	81.6	47.4	62.1	80.0
	UFP	9.3	5.4	7.1	9.1
Greater Paris	NO ₂	1.4	0.8	0.6	1.1
	PM ₁₀	40.2	19.0	29.9	33.2
	PM _{2.5}	50.5	13.9	37.5	41.7
	BC	33.7	15.9	25.1	27.8
	OM	66.0	31.2	49.0	54.5
	UFP	7.9	3.8	5.9	6.6



Contribution of wood burning on concentrations during winter

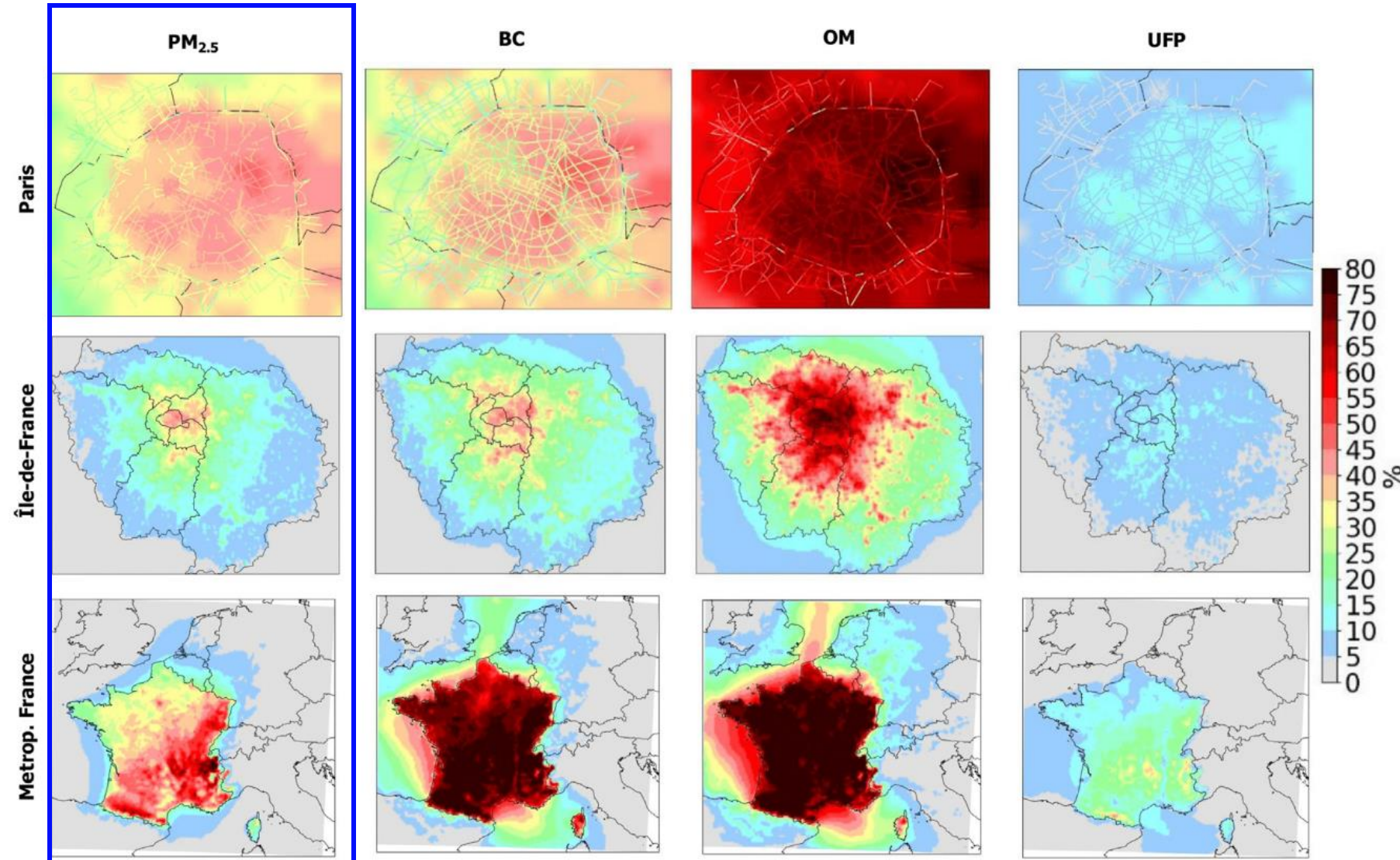
Average contribution of wood heating on particle concentrations during winter (in %)



Contribution of wood burning on concentrations during winter

- Higher contributions of wood heating on $PM_{2.5}$ concentrations with dense population and/or mountain areas

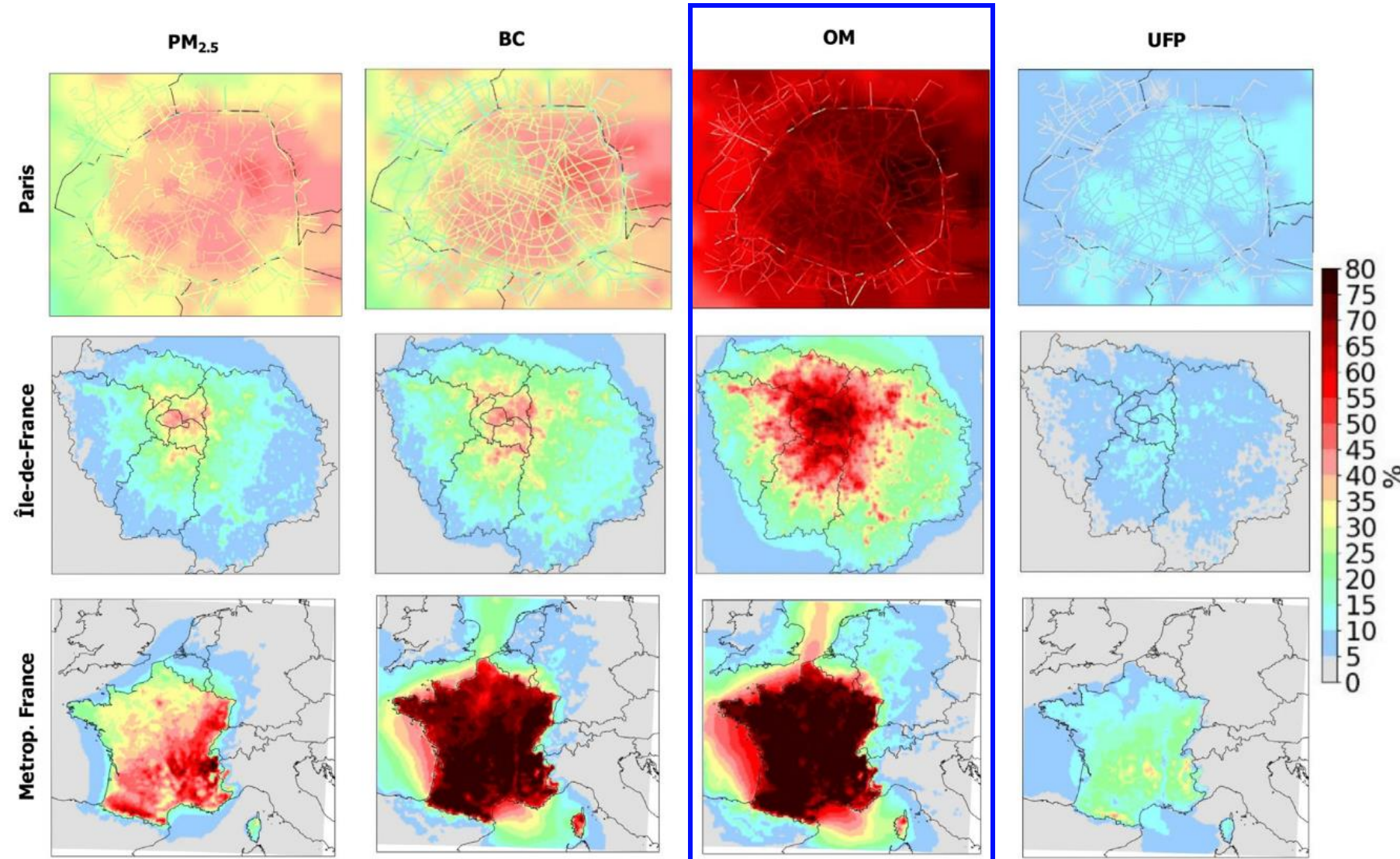
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Contribution of wood burning on concentrations during winter

- Higher contributions of wood heating on PM_{2.5} concentrations with dense population and/or mountain areas
- Higher contribution obtained for OM, up to 73.2% in the urban background and 62.5% in the street level

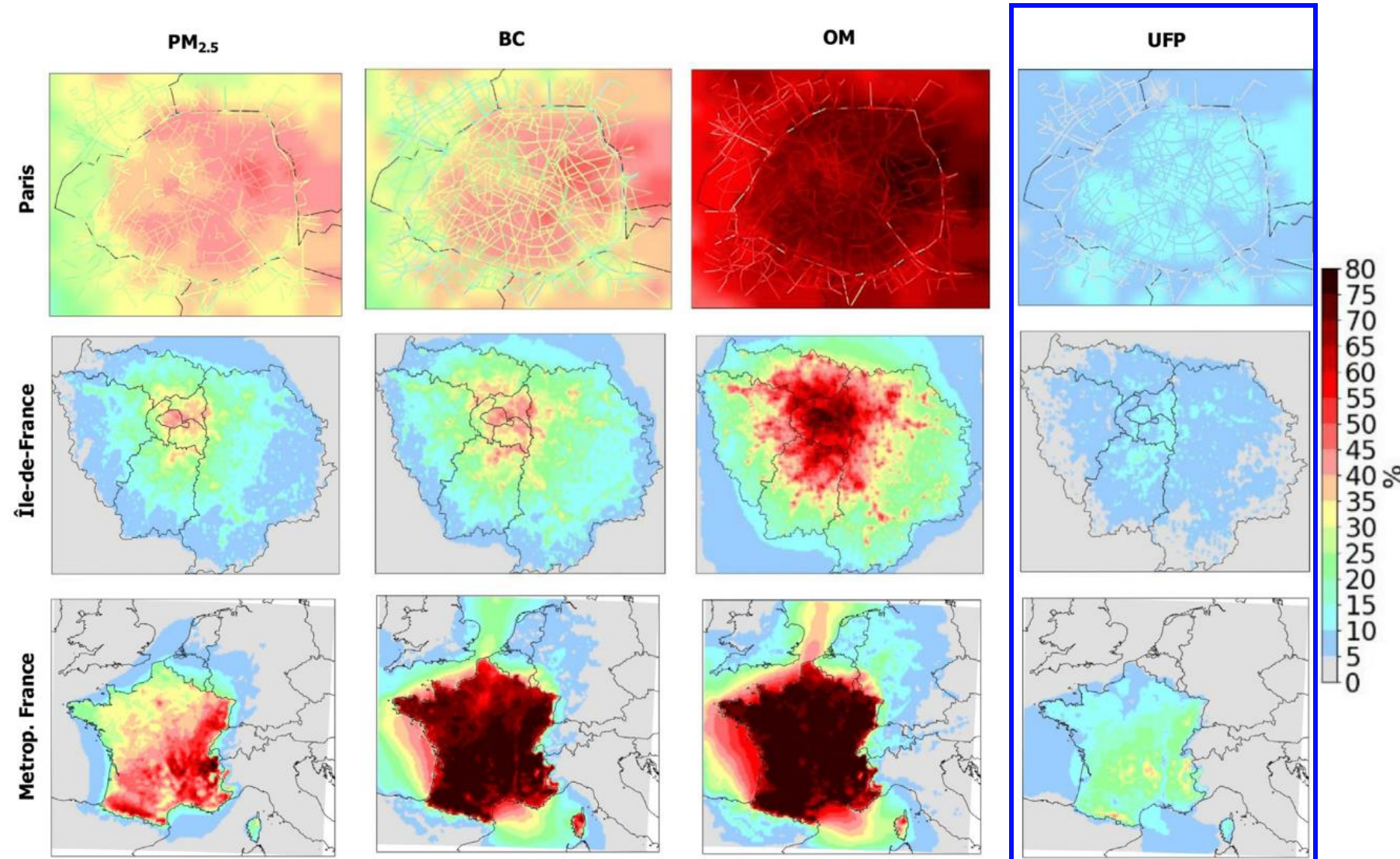
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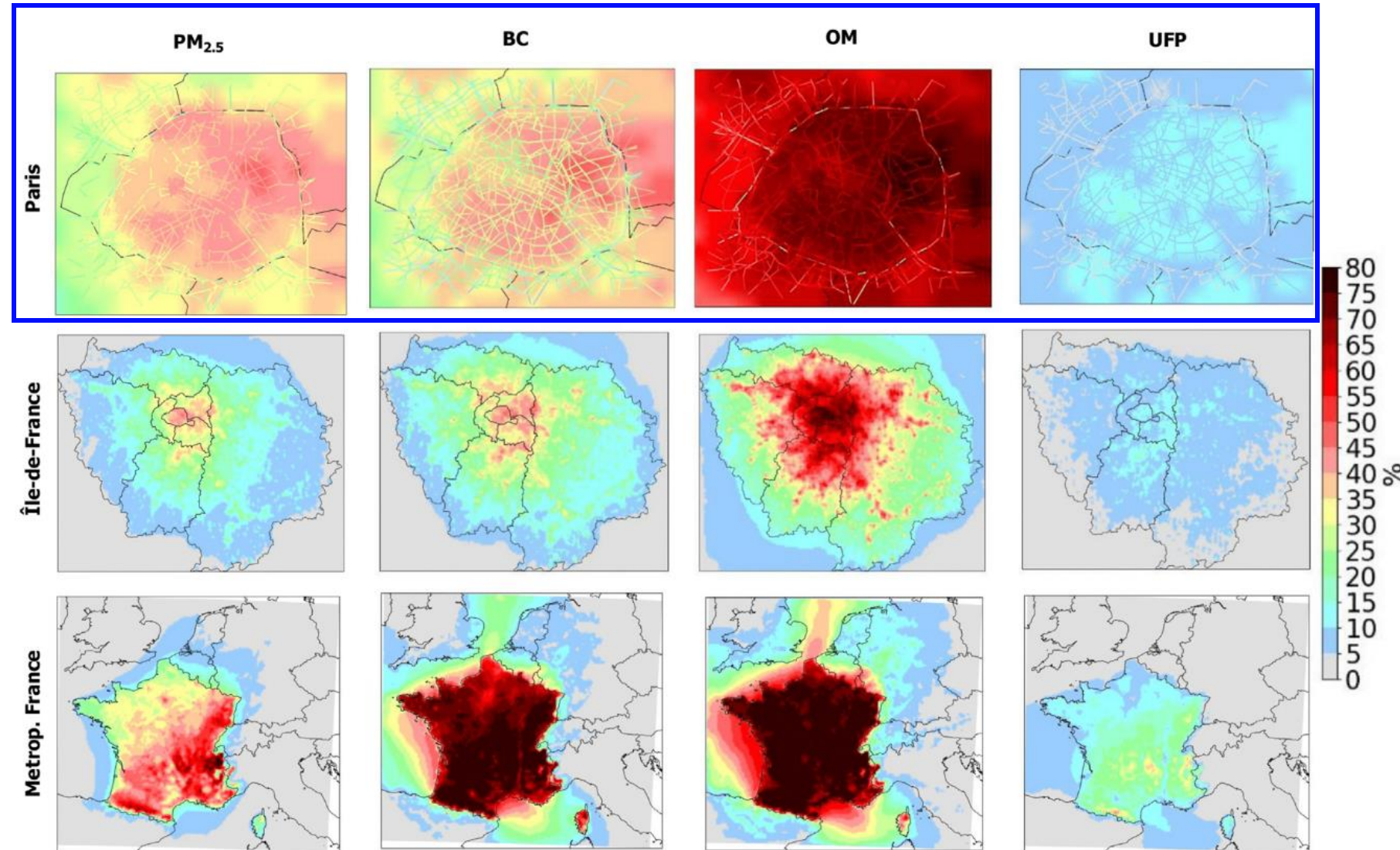
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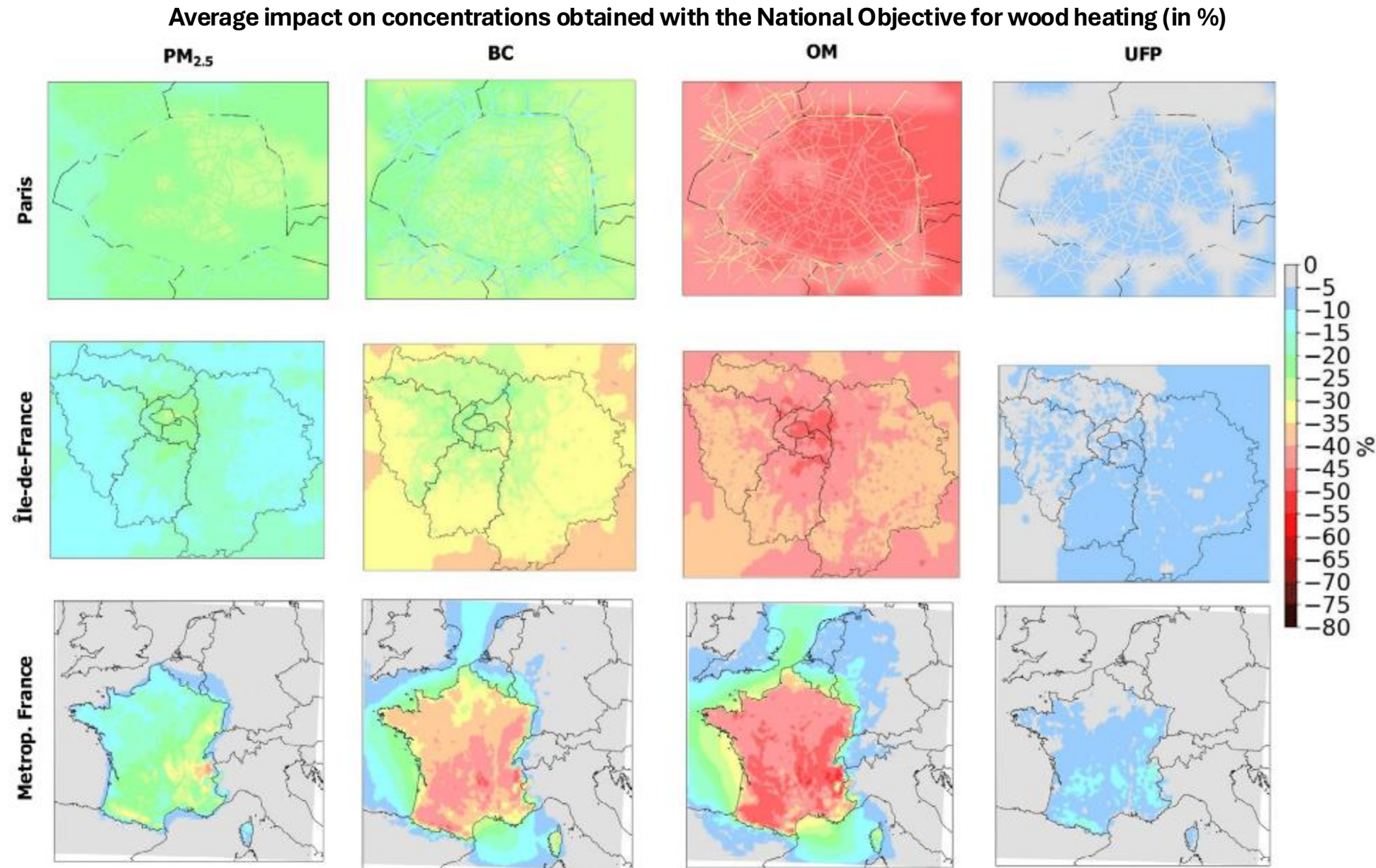
- Higher contributions of wood heating on PM_{2.5} concentrations with dense population and/or mountain areas
- Higher contribution obtained for OM, up to 73.2% in the urban background and 62.5% in the street level
- Small contribution of wood heating in UFP concentrations (< 10% in the street level)
- For all pollutants, the contribution of wood heating is smaller in the street level than in the urban background
 - influence of road traffic, mainly for BC

Average contribution of wood heating on particle concentrations during winter (in %)



Impact on concentrations of future scenarios on residential heating

- Significant reductions on particles mass concentrations
 - Higher impact on OM concentrations



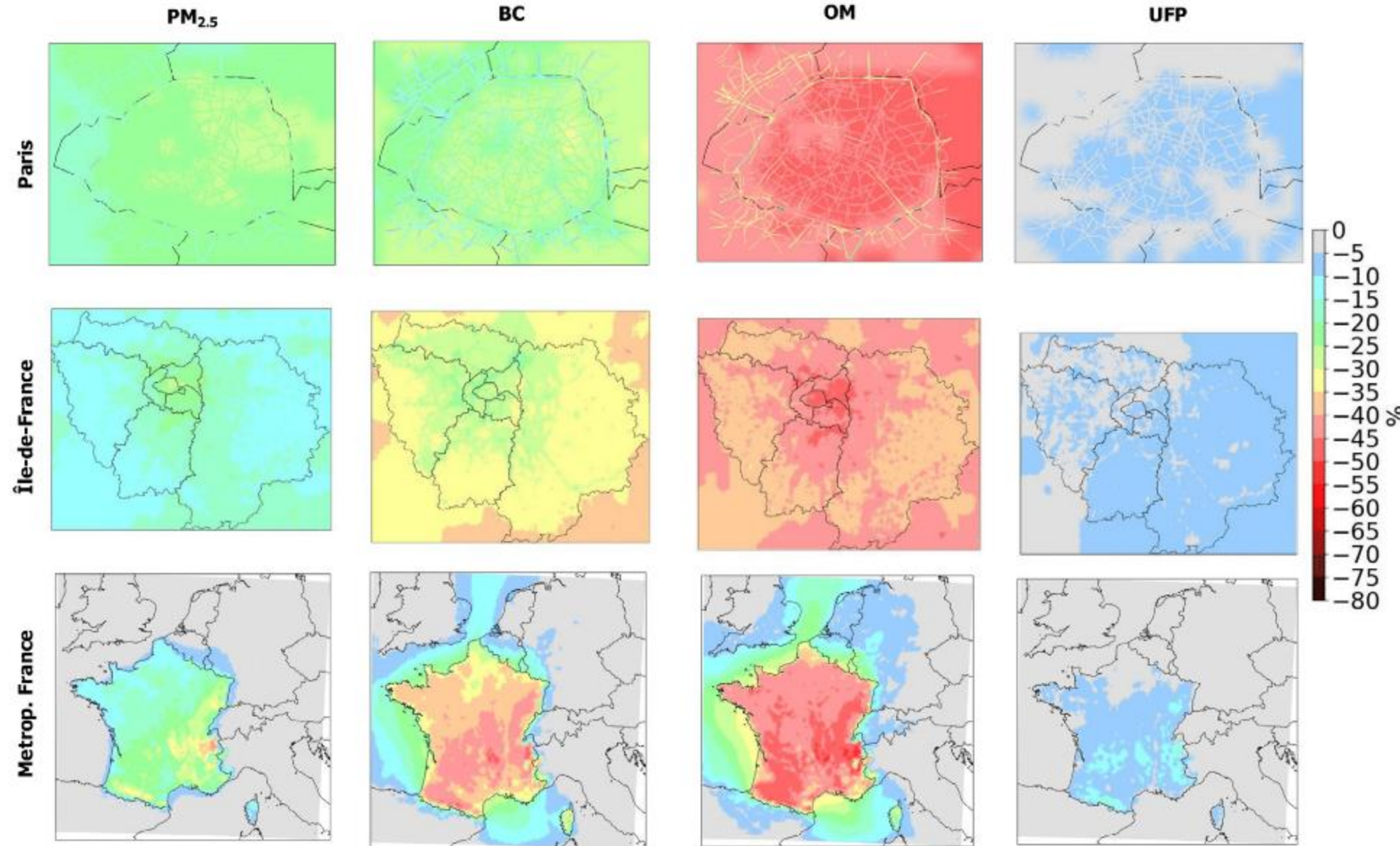
Impact on concentrations of future scenarios on residential heating

- Significant reductions on particles mass concentrations
 - Higher impact on OM concentrations
- Both BAU and Nat. Obj. reduce concentrations of particle mass
 - Up to 43% of OM with the Nat. Obj scenario

Average reductions on concentrations over France

Scenario/ Pollutant	Nat. Obj	BAU
PM _{2.5}	-19.8%	-13.4%
BC	-37.7%	-25.2%
OM	-42.9%	-29.4%
UFP	-6.5%	-4.3%

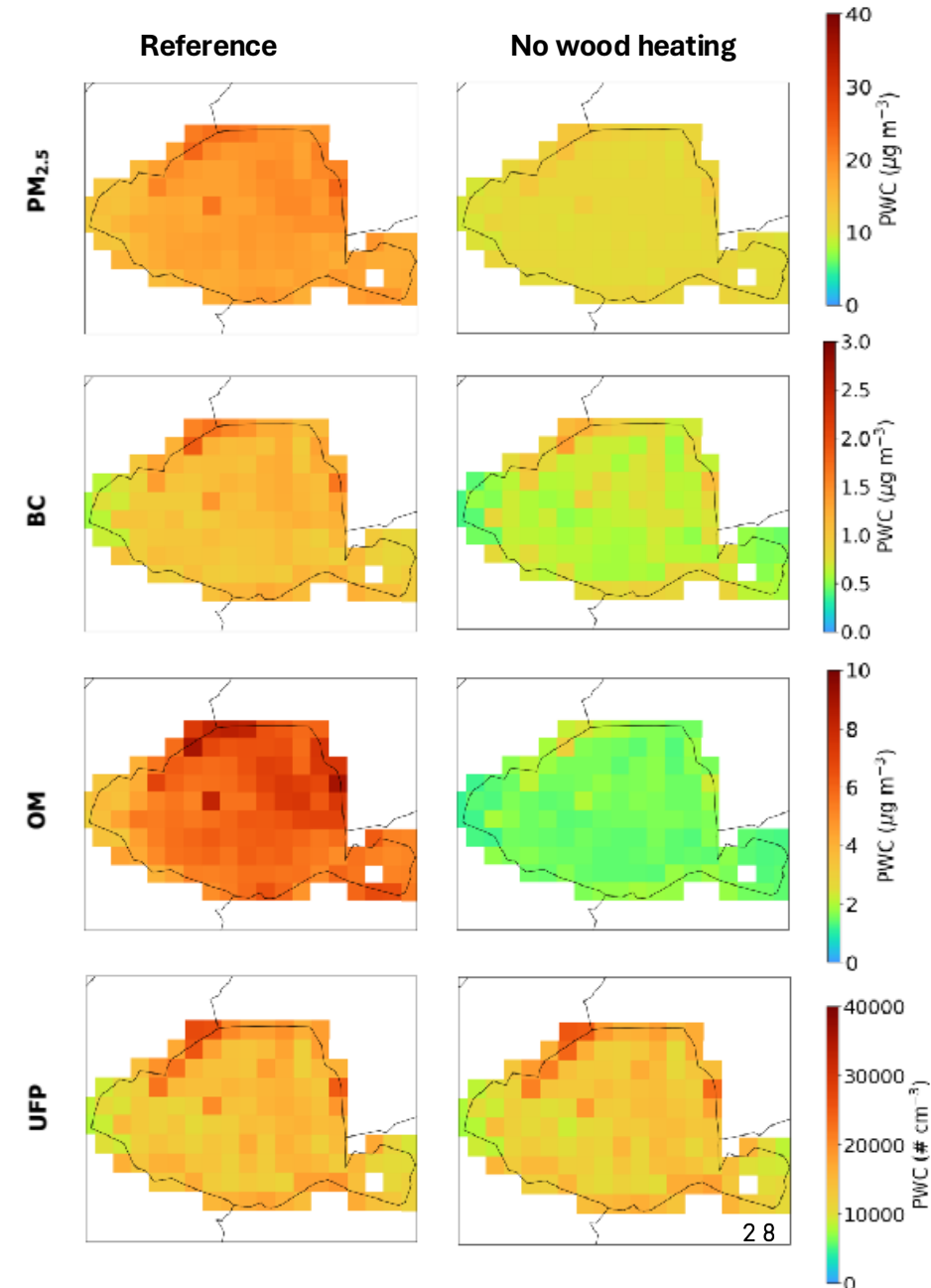
Average impact on concentrations obtained with the National Objective for wood heating (in %)



Contribution of wood heating on population exposure during winter

- Population exposure estimated over Paris based on multi-scale population weighted concentrations (PWC)

PWC obtained for particle concentrations



PWC obtained for different pollutants during the winter period studied (in %)

	PM _{2.5} [$\mu\text{g.m}^{-3}$]	BC [$\mu\text{g.m}^{-3}$]	OM [$\mu\text{g.m}^{-3}$]	UFP [$\#.\text{m}^{-3}$]
Reference	14.7	0.7	4.2	10,441
No wood heating	9.8	0.4	1.2	9,665
Wood heating contrib.	33.3%	42.8%	71.4%	7.4%

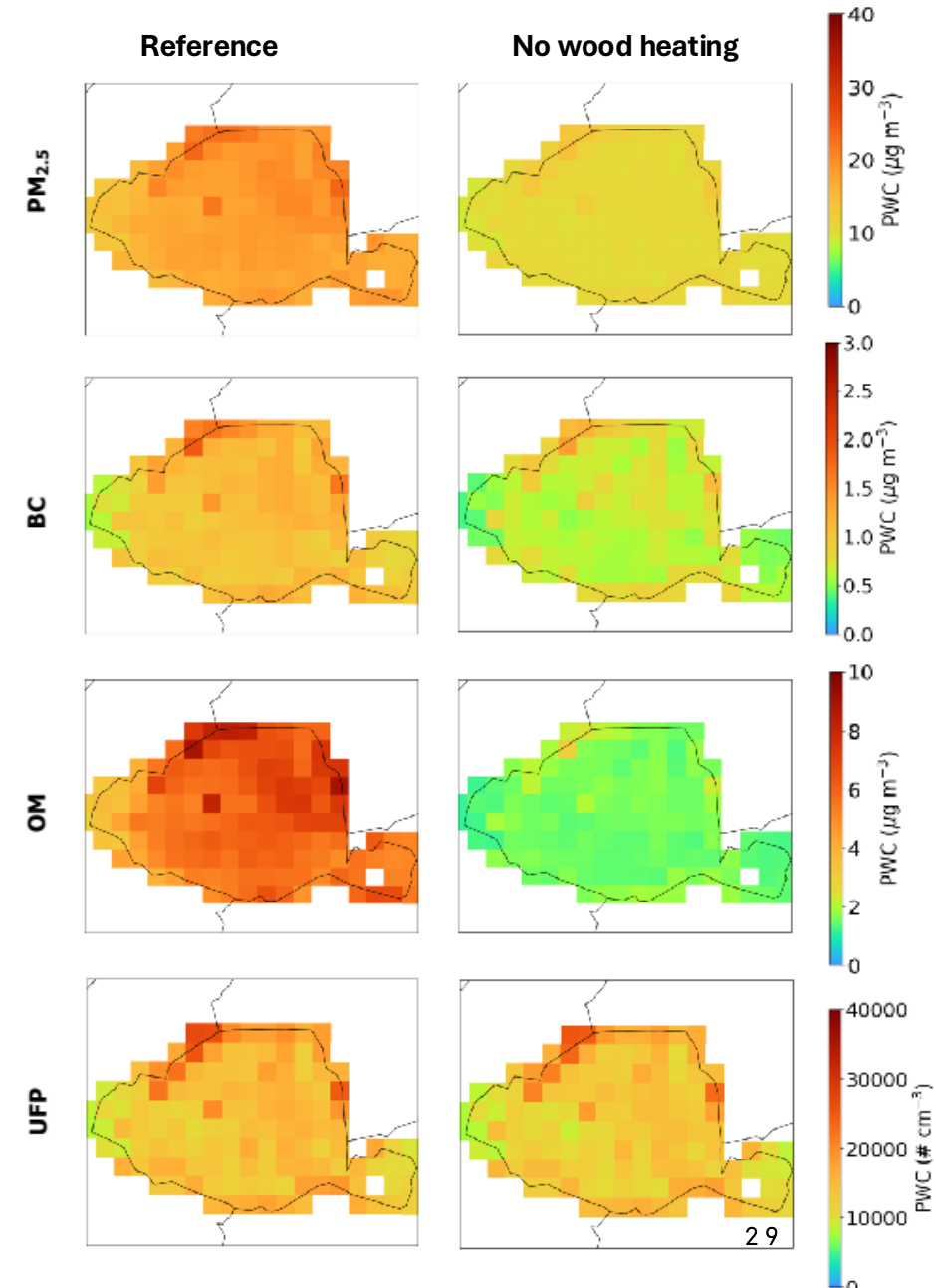
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- Population exposure estimated over Paris based on multi-scale population weighted concentrations (PWC)
- Wood heating contributes with, at least 33% population exposure to particle concentrations
 - up to 70% for OM
 - up to 43% for BC

PWC obtained for different pollutants during the winter period studied (in %)

	PM _{2.5} [$\mu\text{g}\cdot\text{m}^{-3}$]	BC [$\mu\text{g}\cdot\text{m}^{-3}$]	OM [$\mu\text{g}\cdot\text{m}^{-3}$]	UFP [$\#\cdot\text{m}^{-3}$]
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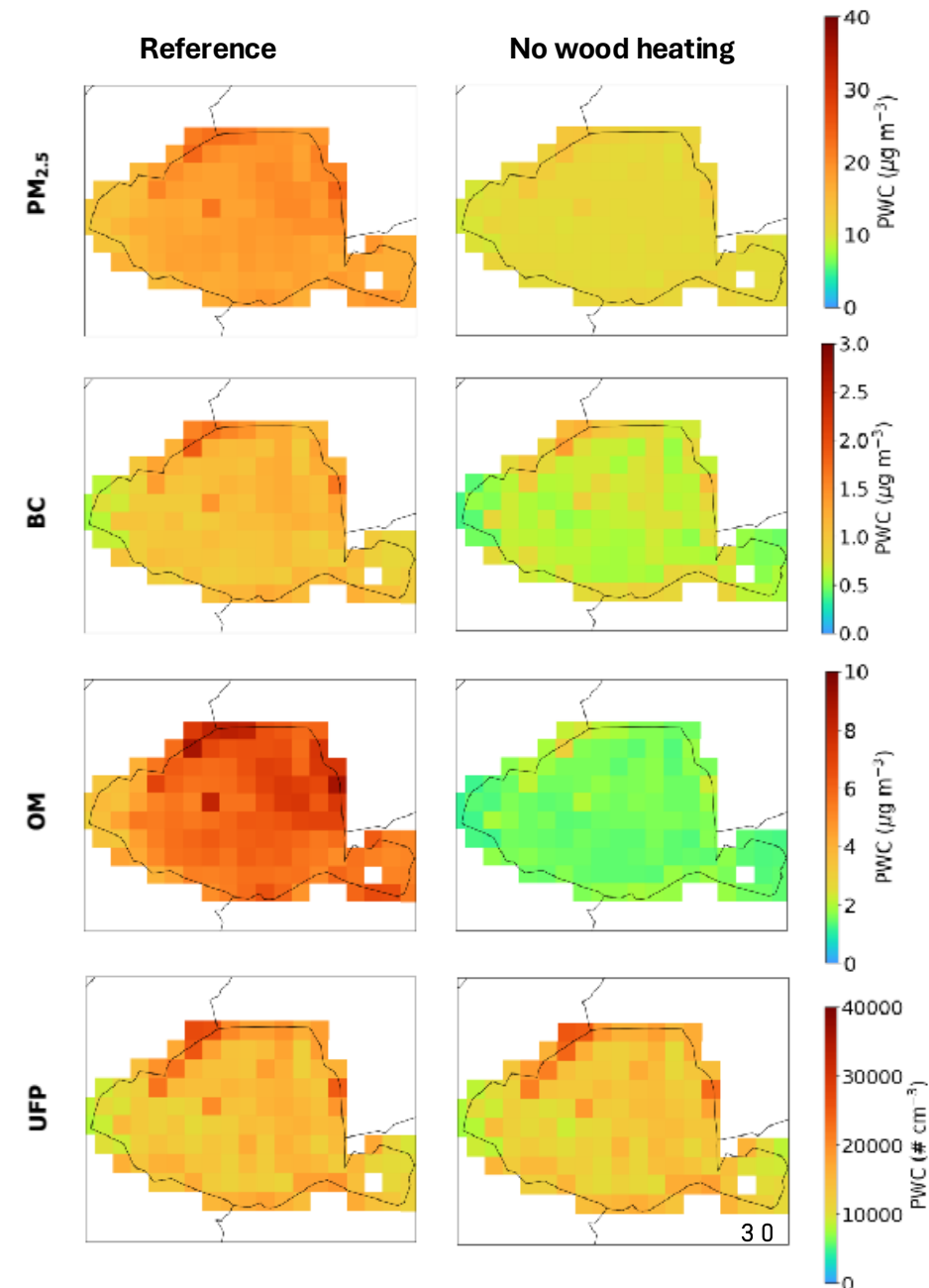
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- Population exposure estimated over Paris based on multi-scale population weighted concentrations (PWC)
- Wood heating contributes with, at least 33% population exposure to particle concentrations
 - up to 70% for OM
 - up to 43% for BC
- Smaller contributions are obtained for UFP (< 10%)

PWC obtained for different pollutants during the winter period studied (in %)

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PWC obtained for particle concentrations



Conclusions

- Estimation of wood heating contribution in urban air quality and outdoor population exposure, based on:
 - detailed residential emission inventory in Greater Paris, including a recent survey and condensable emission factors, computed by the local air-quality agency
 - innovative multi-scale modelling chain (CHIMERE/MUNICH/SSH-aerosol)
 - detailed residential population database (MAJIC)
 - analysis of two 2030 future scenarios for residential emissions

Conclusions

- Wood heating significantly contributes to particle mass emissions and concentrations
 - emissions: up to 65% for $\text{PM}_{2.5}$, going up to 82% for OM in Paris
 - auxiliary and comfort heating is the most important source of wood burning emissions in Paris

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- Wood heating significantly contributes to particle mass emissions and concentrations
 - emissions: up to 65% for $\text{PM}_{2.5}$, going up to 82% for OM
 - auxiliary and comfort heating is the most important source of wood burning emissions in Paris
 - concentrations: up to 40% for $\text{PM}_{2.5}$, going up to 73.2% for OM
 - smaller contributions of wood heating at the street level than in the urban background
 - Influence of road traffic

Conclusions

- Wood heating significantly contributes to particle mass emissions and concentrations
 - emissions: up to 65% for $PM_{2.5}$, going up to 82% for OM
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 - concentrations: up to 40% for $PM_{2.5}$, going up to 73.2% for OM
 - smaller contributions of wood heating at the street level than in the urban background
 - Influence of road traffic
 - Small contribution of wood heating for UFP emissions and concentrations
 - particles emitted by wood heating $\geq 80nm$

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 - smaller contributions of wood heating at the street level than in the urban background
 - Influence of road traffic
 - Small contribution of wood heating for UFP emissions and concentrations
 - particles emitted by wood heating $\geq 80\text{nm}$
 - Both BAU and National Objective reduces particle concentrations
 - higher reductions obtained with the National objective – around 50% higher than with BAU

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 - emissions: up to 65% for $PM_{2.5}$, going up to 82% for OM
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 - smaller contributions of wood heating at the street level than in the urban background
 - Influence of road traffic
 - Small contribution of wood heating for UFP emissions and concentrations
 - particles emitted by wood heating $\geq 80nm$
 - Both BAU and National Objective reduces particle concentrations
 - higher reductions obtained with the National objective – around 50% higher than with BAU
- Important contribution of wood heating on population exposure to particles in Paris
 - 33.3% for $PM_{2.5}$, going up to 71.4% for OM

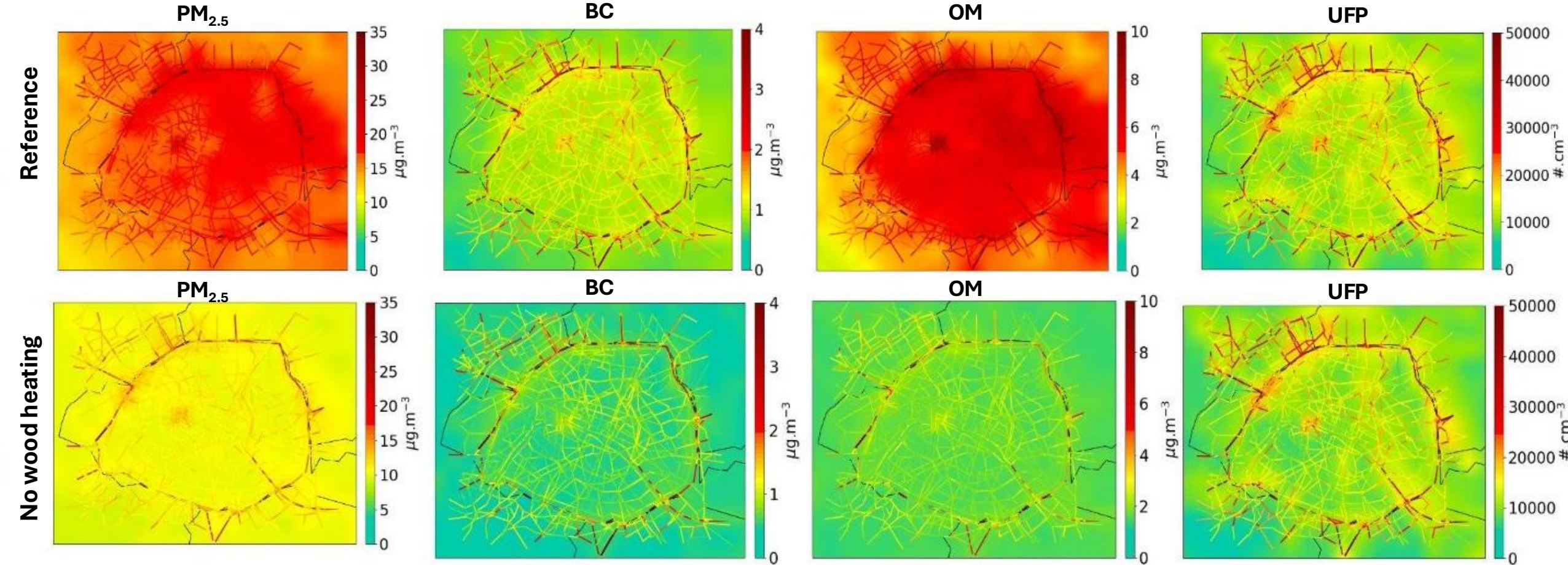
Thank you very much for your attention !

For more details, please find here our publication



Contribution of wood burning on concentrations during winter

Concentration maps obtained in the reference case and without wood heating emissions



- Strong contribution of wood heating for $PM_{2.5}$, BC and OM, as observed in the emissions
- Higher concentrations in streets than in the urban background in both cases – influence of road traffic

Model validation

- Good representations of all analyzed pollutants during the winter period
 - performance criteria defined in the literature ([Boylan and Russell, 2006](#), [Hanna and Chang, 2012](#))
 - Strict: $MFE < 50\%$, $|MFB| < 30\%$, Less strict: $MFE < 75\%$, $|MFB| < 50\%$

Model performance to represent **regulated** pollutants over Paris in different stations

	NO ₂					PM ₁₀					PM _{2.5}				
station type	Nst	obs. [µg.m ⁻³]	sim. [µg.m ⁻³]	MFB [%]	MFE [%]	Nst	obs. [µg.m ⁻³]	sim. [µg.m ⁻³]	MFB [%]	MFE [%]	Nst	obs. [µg.m ⁻³]	sim. [µg.m ⁻³]	MFB [%]	MFE [%]
urban	24	24.9	25.0	-3	29	14	16.7	14.6	-7	33	8	11.9	13.1	18	39
traffic (streets)	9	43.1	51.6	18	28	5	26.1	23.2	-8	30	2	16.5	23.4	37	41

Model performance to represent **emerging** pollutants over Paris in different stations

	BC					OM					UFP				
station type	Nst	obs. [µg.m ⁻³]	sim. [µg.m ⁻³]	MFB [%]	MFE [%]	Nst	obs. [µg.m ⁻³]	sim. [µg.m ⁻³]	MFB [%]	MFE [%]	Nst	obs. [µg.m ⁻³]	sim. [µg.m ⁻³]	MFB [%]	MFE [%]
urban	5	0.7	0.7	7	41	1	3.8	3.9	5	28	4	7086	6902	-6	36
traffic (streets)	2	3.2	3.5	23	45	1	4.0	7.7	66	68	0	-	-	-	-