

# Experience in Lombardy in emission estimates from wood-fired pizza ovens

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Air and Support to Political Decision Maker

Air Emissions Inventories

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# Summary

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- Impact of wood-fired pizza ovens on emissions
- Measured emission factors
- Relevant issues in emissions and indicators
- Methodologies for indicators estimates, REG4IA

# Technology overview



**Internal measures: 130x130 cm**  
**External measures: 154x223 cm**  
**Weight: 1200 kg**  
**Chimney internal diameter: 20 cm**



**Internal measures: 120x120 cm**  
**External measures: 160x170 cm**  
**Weight: 1200 kg**  
**Chimney internal diameter: 20 cm**

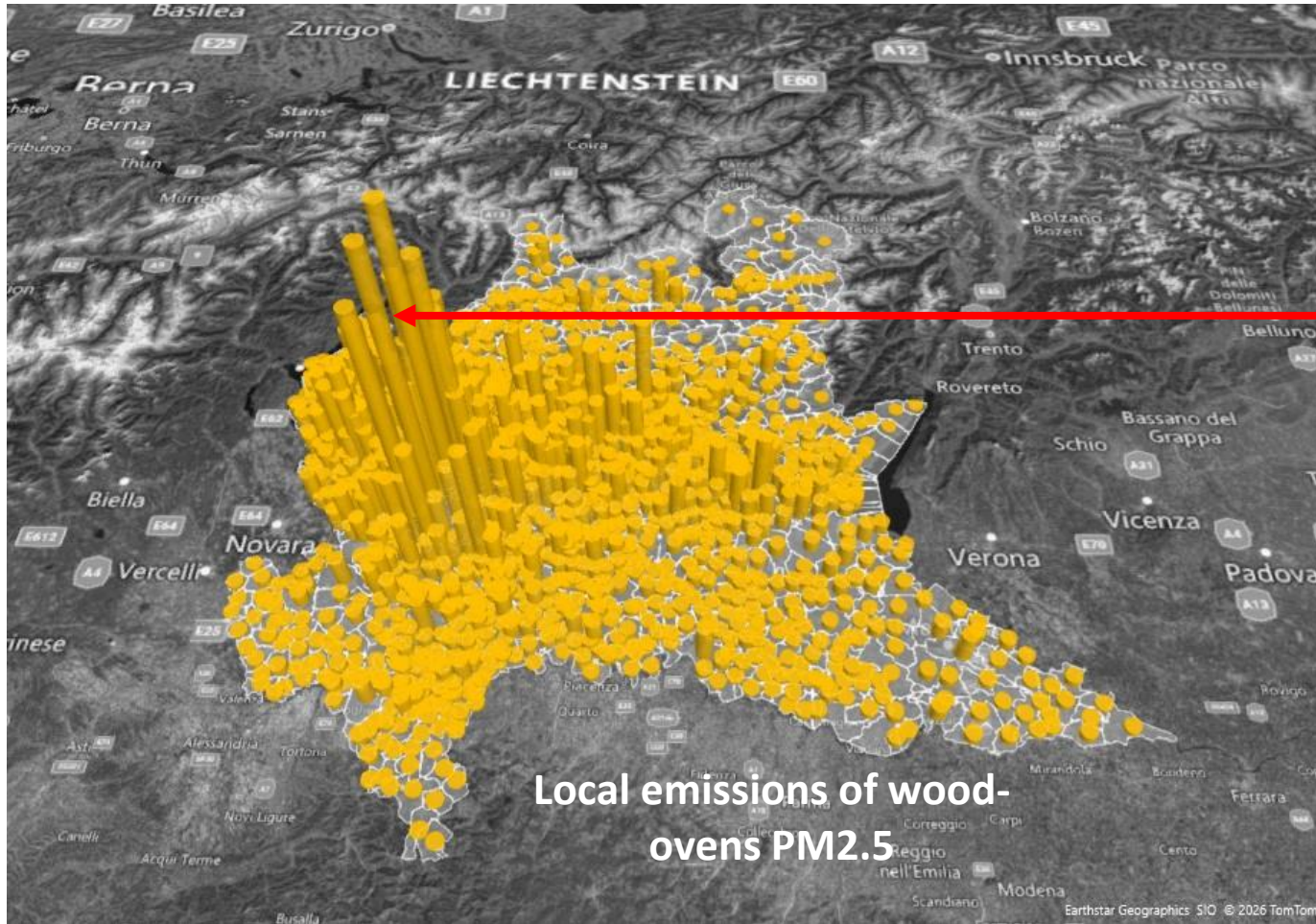


**Internal measures: 145x145 cm**  
**External measures: 186x234 cm**  
**Weight: 1600 kg**  
**Chimney internal diameter: 20 cm**

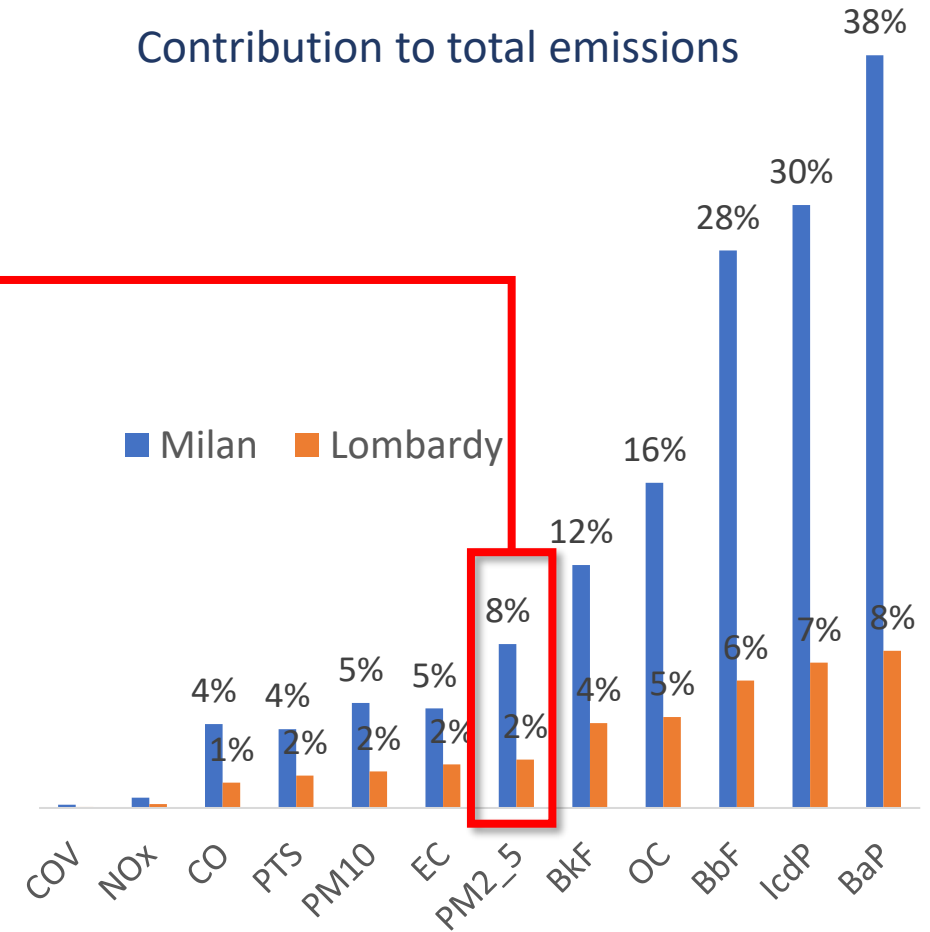


**Source:** Andrea Bergomi, Gabriele Migliavacca, Silvia Bertagna, Mattia Borelli, Salvatore Chiavarini, Valeria Comite, Ilaria D'Elia, Paola Fermo, Teresa M.G. La Torretta, Antonio Piersanti, Milena Stracquadanio, Air pollutant emission factors from wood-fired pizza ovens, Environmental Pollution, Volume 384, 2025, 126948, ISSN 0269-7491, <https://doi.org/10.1016/j.envpol.2025.126948>

# Impact of pollutant emissions from wood-ovens



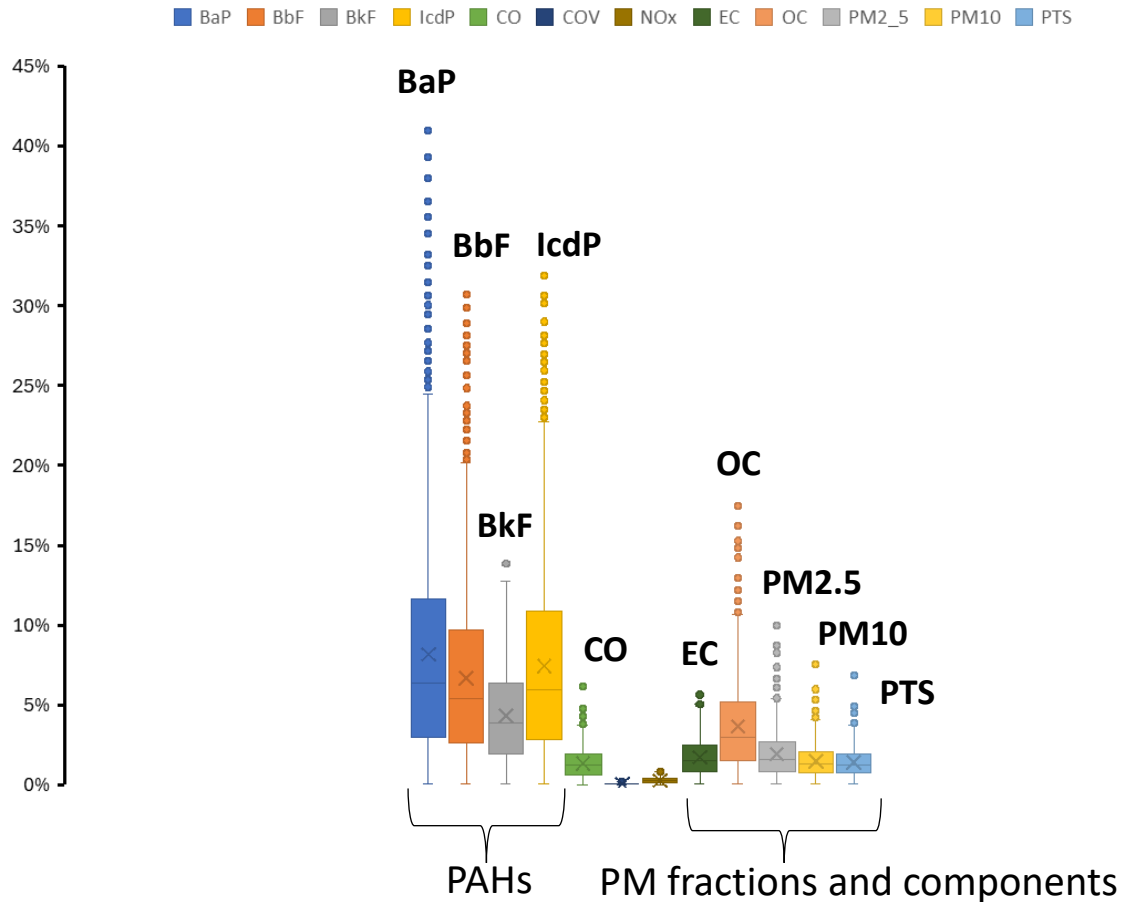
Contribution to total emissions



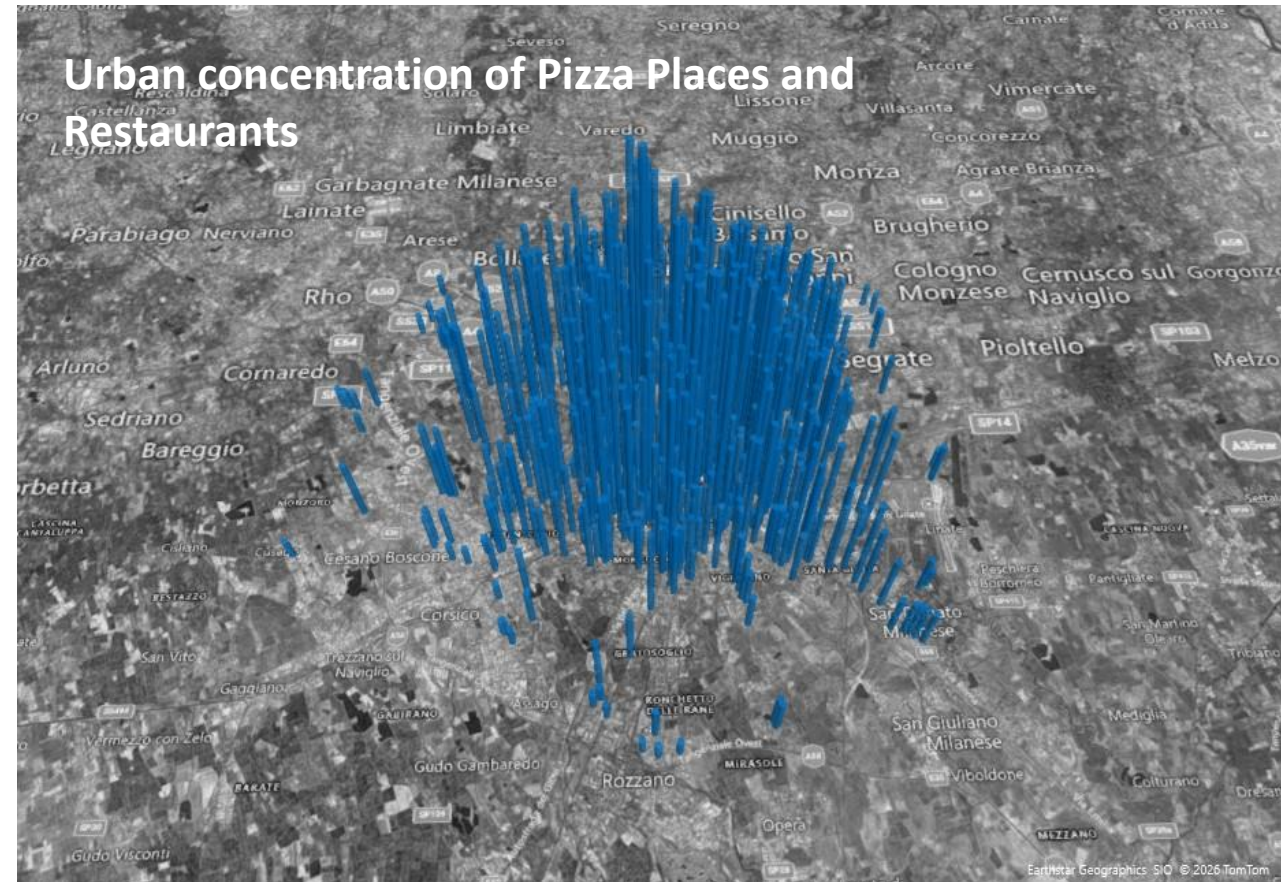
For years, the estimates on this emission source are accounted for in the Lombardy Emission Inventory.

# Impact of pollutant emissions from wood-ovens

Contribution to total emissions in each municipality of Lombardy



The local impact on City emission can be relevant, confirming also the local nature of these sources.



# Methodology

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- Indicators and emission factors adopted for the estimation of 2023 emissions from pizzerias are obtained from the results of a research carried out at the University of Milan
- Average emission factors are obtained through measurements carried out on three types of oven: a new medium-sized wood-fired oven (5/6 pizzas), a new hybrid oven (wood or gas), also medium-sized, and a larger 10-year-old wood-fired oven (8/10 pizzas). The ovens were fed with logs or beech briquettes, reproducing real operating conditions.
- Measurements considered the condensable fraction of PM
- The average emission factors are determined considering that ovens were used regularly for two daily periods of four hours each, weighing the contribution of each operational phase.

$$EF_x = \frac{1}{8}EF_{HR} + \frac{5}{8}EF_{COOK} + \frac{2}{8}EF_{STAT}$$

HR = Hot Reignition phase

COOK = Cooking phase

STAT = Stationary phase

# Operational Phase: Combustion Cycle

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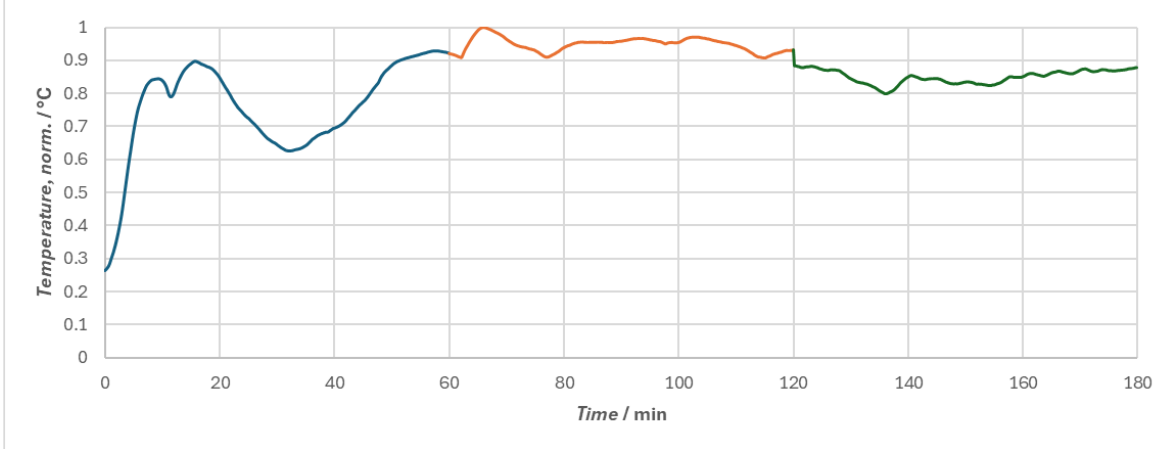
- *Hot re-ignition*: After being inactive for several hours (16–18 h), the furnace is re-ignited the following day, starting from an internal temperature typically between 80 and 180 °C. A load of commercially available kindling wood (2.0–2.5 kg) is first introduced into the oven. Subsequently, a series of fuelwood loads<sup>1</sup> are fed sequentially, taking advantage of the bed of embers formed during ignition, until the furnace reaches the target operating temperature (approximately 350 °C). Once this temperature is achieved, the burning fuelwood and embers are pushed to one side of the oven, creating a clear cooking area on the opposite side for the subsequent cooking phase.
- *Cooking*: the hot oven is periodically fed with fuelwood loads to keep a constant operating temperature and, at the same time, the pizzas are introduced. Specifically, 8 pizzas are introduced during each fuel load in two successive rounds of 4 pizzas. The normal operations of cleaning and moving the ashes and embers that are necessary for effective management of the oven under operating conditions are also carried out.
- *Stationary*: the hot oven is periodically fed with fuelwood loads to maintain a constant operating temperature without the introduction of pizzas. The normal operations of cleaning and moving the ashes and embers that are necessary for effective management of the oven under operating conditions are also carried out.

<sup>1</sup>0.5-1.5 kg for beechwood logs; 1.7 kg for beechwood briquettes.

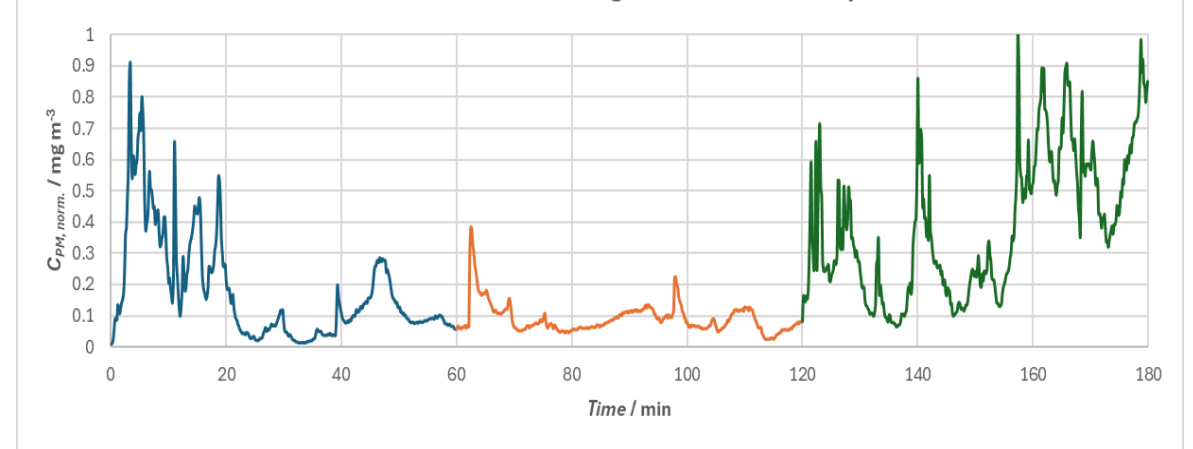
<sup>2</sup>Every 15 minutes for beechwood logs; every 20 minutes for beechwood briquettes.

# Operational Phase: Combustion Cycle

Hot Flue Gas Temperature Profile During Wood-Fired Oven Operation



Particulate Matter Profile During Wood-Fired Oven Operation



- HOT REIGNITION
- STATIONARY
- COOKING

# Proposed emission factors

## “Non-residential cooking Cooking using solid fuel

The extent of solid fuel use in commercial cooking is not known, but is likely to be in specialised areas such as artisan bakeries and traditional wood-fired pizza ovens in restaurants. In addition, there is growing use of charcoal barbecues/grills by restaurants and catering/event hospitality organisations.

Emission factor tables for these sources are covered by Table 3-20 and Table 3-46 which detail emission factors for coal and wood, respectively, for the <1MWth sized appliances. Additionally, Table 3-22, and Table 3-23 (coal), Table 3-47 and Table 3-48 (wood) provide further disaggregation for <1MWth appliances between those that are manual feed and automatic feed respectively.”

Pollutant	Value	Unit	95 % confidence interval	
			Lower	Upper
NO <sub>x</sub>	85	g/GJ	80	90
CO	1038	g/GJ	987	1089
OGC	71	g/GJ	57	85
TSP	233	g/GJ	216	250
PM10	162	g/GJ	153	171
PM2.5	157	g/GJ	148	166
Total PAH-sum	1482	mg/GJ	946	2018

Pollutant	Value	Unit	95 % confidence interval	
			Lower	Upper
Napthalene	852	mg/GJ	570	1134
Acenaphthylene	153	mg/GJ	86	220
Acenaphthene	4	mg/GJ	2	6
Fluorene	24	mg/GJ	13	35
Phenanthrene	194	mg/GJ	129	259
Anthracene	24	mg/GJ	14	34
Fluoranthene	84	mg/GJ	53	115
Pyrene	68	mg/GJ	41	95
Benz[a]anthracene	13	mg/GJ	7	19
Chrysene	13	mg/GJ	7	19
Benzo[b]fluoranthene	20	mg/GJ	10	30
Benzo[k]fluoranthene	5	mg/GJ	2	8
Benzo[a]pyrene	12	mg/GJ	5	19
Indeno[1,2,3-c,d]pyrene	10	mg/GJ	5	15
Dibenz[a,h]anthracene	1	mg/GJ	0.5	2
Benzo[ghi]perylene	7	mg/GJ	3	11

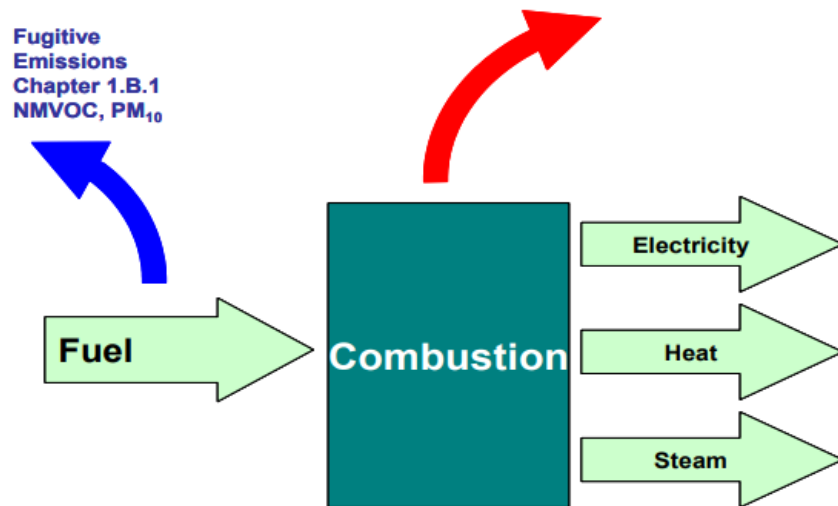


Andrea Bergomi, Gabriele Migliavacca, Silvia Bertagna, Mattia Borelli, Salvatore Chiavarini, Valeria Comite, Ilaria D'Elia, Paola Fermo, Teresa M.G. La Torretta, Antonio Piersanti, Milena Stracquadanio, Air pollutant emission factors from wood-fired pizza ovens, Environmental Pollution, Volume 384, 2025, 126948, ISSN 0269-7491, <https://doi.org/10.1016/j.envpol.2025.126948>

# Some relevant issues

## 1.A.4.a.i, 1.A.4.b.i, 1.A.4.c.i, 1.A.5.a Small combustion

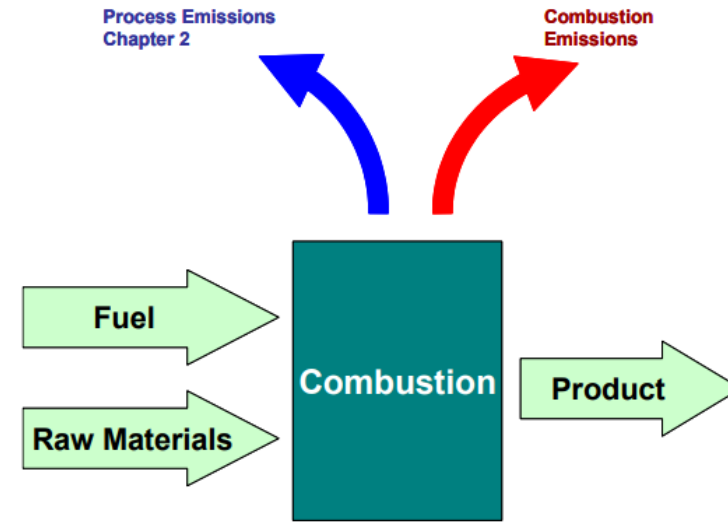
Figure 2-1 Illustration of the main process in small combustion installations; figure adapted from 2006 IPCC Guidelines for National Greenhouse Gas Inventories



OR

## 1.A.2 Manufacturing industries and construction (combustion)

Figure 2-1 Illustration of the main process in industrial combustion installations.



Source: Adapted from Figure 2.4 2006 IPCC Guidelines for Stationary Combustion for National Greenhouse Gas Inventories

- Experimental measurements confirm that the cooking phase contributes to the emissions.
- Evidences on gas ovens seem showing the increase in emissions of PM, OC and Laevoglucosan (LG) due to the transformation of raw ingredients.
- The contribution on emissions of the gas-fired ovens is not negligible (how define the emission factors, energy based or product based?)

# Quantification and position of the ovens


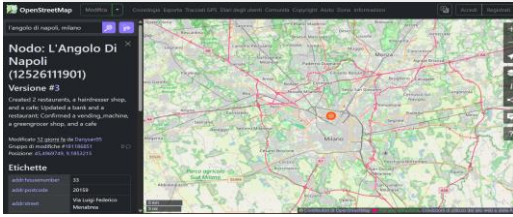
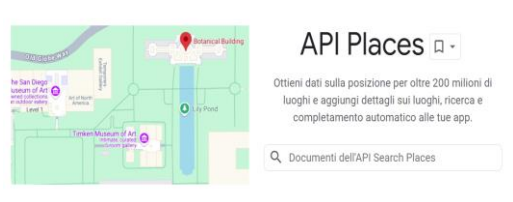
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- Average biomass consumption is **6.82 kg/hour** which, considering the operation of 48 hours/week for 48 weeks/year, provides an annual consumption indicator of **15.713 t/year per oven**.
- It has been determined that **28%** of the activities surveyed in Milan at the Chamber of Commerce such as catering and take-away services are equipped with a pizza oven.
- A national estimate carried out by CNA Agroalimentare in 2024 also determined that 50% of these ovens are wood-fired and 8% are hybrids (approx. **54% are wood ovens**)
- The number of wood-fired ovens has been determined in **9.4. per 10 000 residents**.

# Multimodal Machine Learning for micro-localisation of wood-fired ovens

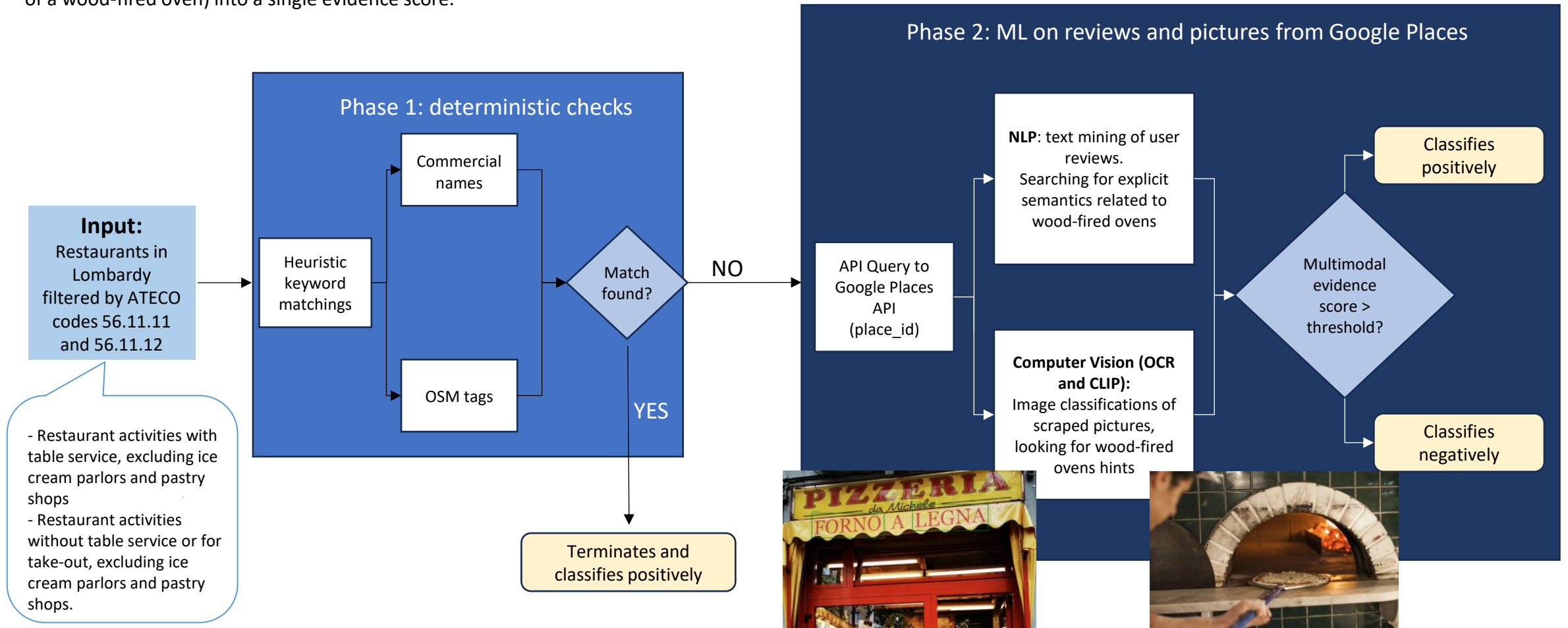
A bottom-up data fusion methodology for high-resolution emission inventories

The detection pipeline integrates heterogeneous data sources at different levels of granularity: from administrative registries to user-generated content. These are to produce a composite signal for each business unit

	Source	Structure	Extracted features	Use	Limitations
	<b>PARIX</b> (InfoCamere / Registro Imprese Lombardia)	Structured tabular	Business name, address, industry classification code, activity status, employees, province/municipality	Define the analysis perimeter (active food service businesses in Lombardy); seed the geolocation pipeline	Registry covers all restaurants - no info about wood-fired ovens, or actual operations; address quality varies
	<b>OpenStreetMap</b>	Geospatial vector with key-value tag system	POI coordinates; tags: amenity=restaurant/fast_food, cuisine=pizza	Identify and geolocate pizza places using structured tags; first-pass filter before heavier AI analysis	Tag completeness depends on volunteer contributors, lots of missing
	<b>Google Places API</b>	Semi-structured API (JSON)	Place photos, user reviews, opening hours, ratings	Visual analysis via CLIP, OCR on signage/menus, keyword	Photo/review availability varies, depending on volunteer contributors; not a proper verified ground truth

# Progressive enrichment of the pipeline

The pipeline combines a deterministic filter based on commercial names and OSM tags with a multimodal ML layer that draws on Google Places reviews and images when the deterministic check returns no match, integrating NLP-based text mining (on reviews) and computer vision (CLIP for wood-fired oven pictures and OCR for signs indicating the presence of a wood-fired oven) into a single evidence score.



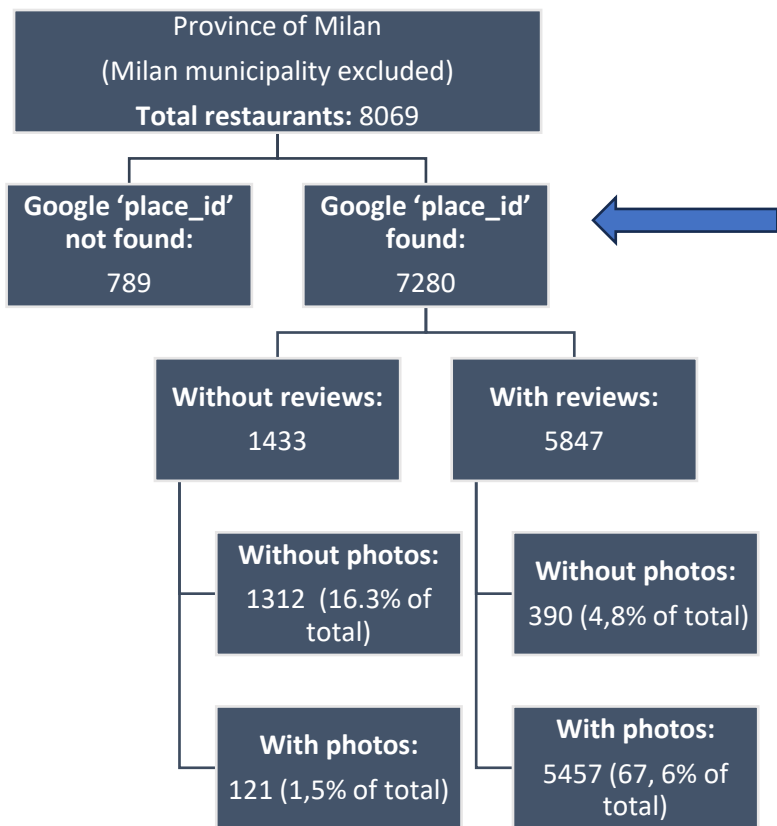
- Restaurant activities with table service, excluding ice cream parlors and pastry shops
- Restaurant activities without table service or for take-out, excluding ice cream parlors and pastry shops.

# Preliminary results

In this first *demonstrator*, the pipeline was kept deliberately lightweight to validate the methodological approach prior to scaling. In particular:

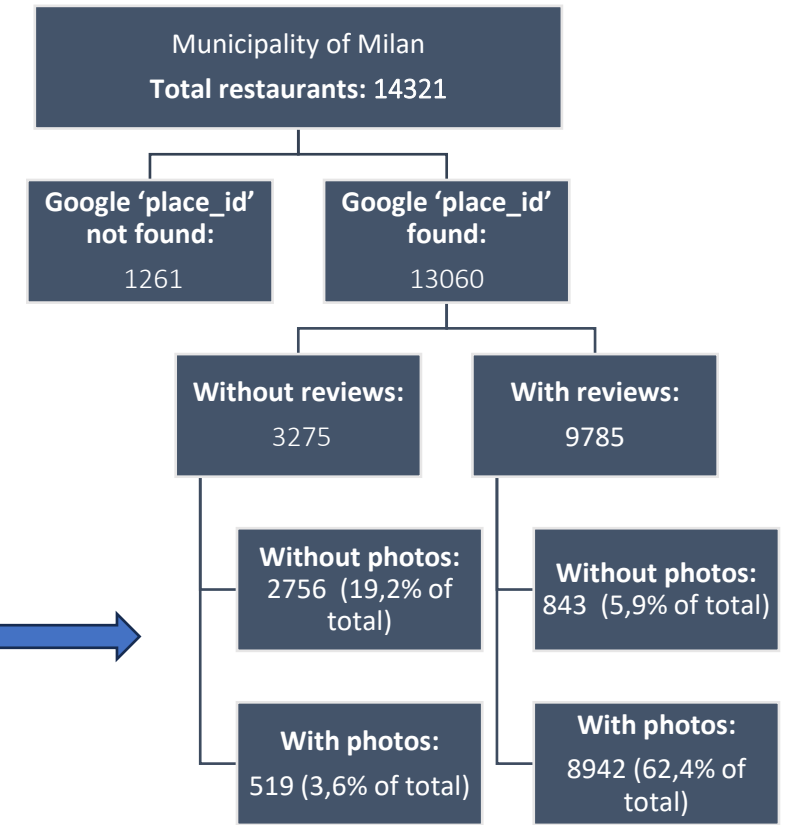
- Calls to the Google Places API were **capped at 2 photos and 5 reviews** to contain costs;
- The integration of the OpenStreetMap tag lookup step was excluded to contain complexity and test the signal based on NLP, CLIP and OCR.

Here are the first results from the demonstrator implementation:



	NO rev NO photo	NO rev YES photo	YES rev NO photo	YES rev YES photo
<b>Wood-fired oven found</b>	0%	23.1%	0%	50.4%
visual (CLIP)	0%	22.3%	0%	48.9%
visual (OCR)	0%	1.7%	0%	1.5%
text (NLP)	0%	0.0%	0%	1.4%

	NO rev NO photo	NO rev YES photo	YES rev NO photo	YES rev YES photo
<b>Wood-fired oven found</b>	0%	12.3%	0%	46.0%
visual (CLIP)	0%	12.3%	0%	45.7%
visual (OCR)	0%	0.0%	0%	0.5%
text (NLP)	0%	0.0%	0%	0.8%



# Next steps

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- Integrate OSM tag-based classification as a deterministic baseline layer
- Revise API retrieval limits to more operationally adequate values (the current 2-photo cap is likely to underperform, as wood-fired ovens are not necessarily captured among the first photos indexed by Google)
- Construct a manually annotated gold set (100–200 samples) to enable signal-level evaluation of precision and recall across the three modalities:
  - Visual for CLIP (images of wood-fired ovens)
  - Visual for OCR (text on shop fronts signaling a wood-fired oven)
  - Text (reviews)
- Stratify results by province and business size to identify systematic blind spots
- Iterative threshold calibration and CLIP fine-tuning on the labelled sample