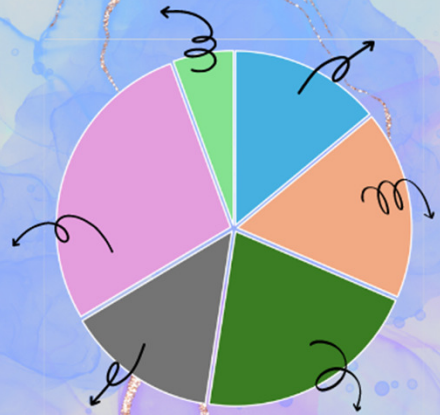
What is Air Pollution Source Apportionment?



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URBAN emissions .info

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UrbanEmissions (UEinfo) was founded in 2007 with the vision to be a repository of information, research, and analysis related to air pollution.

This primer is the 2nd edition on source apportionment.

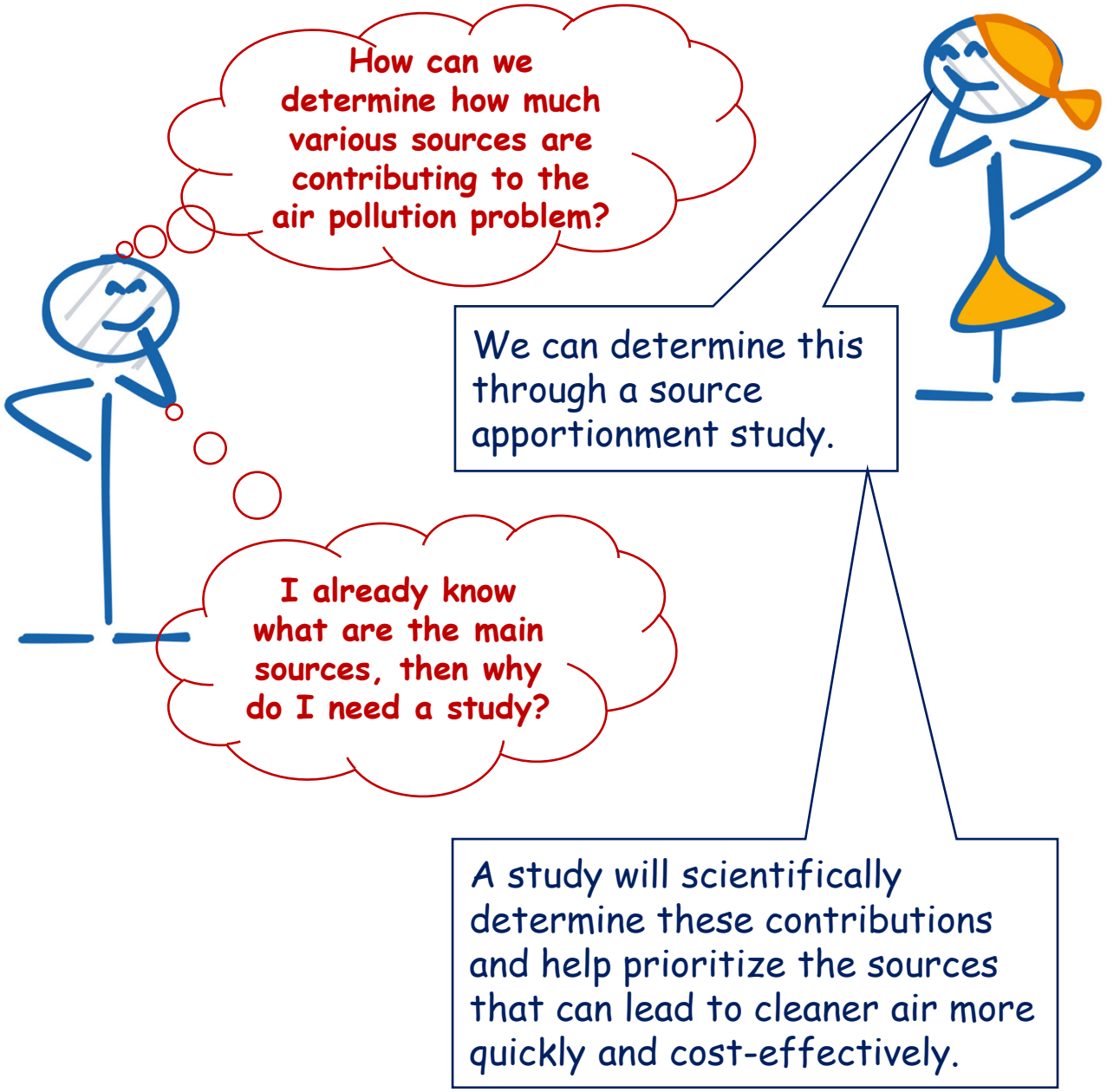
All the primers are available @www.urbanemissions.info/publications
Send your questions and comments to simair@urbanemissions.info

Most of the illustrations are made using the open access “excalidraw” portal.

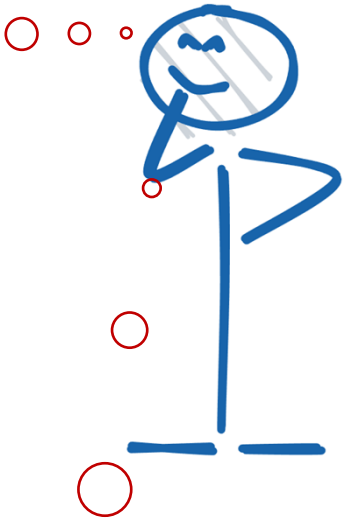
In addition to knowing (1) how much is the pollution (2) where is the pollution and (3) when is the pollution…

.. it is also important to know (4) the contributions of various sources to the air pollution problem.

This includes sources within the city, as well as those outside the city's administrative boundary and the designated airshed.


How can we determine how much various sources are contributing to the air pollution problem?
We can determine this through a source apportionment study.
I already know what are the main sources, then why do I need a study?
A study will scientifically determine these contributions and help prioritize the sources that can lead to cleaner air more quickly and cost-effectively.

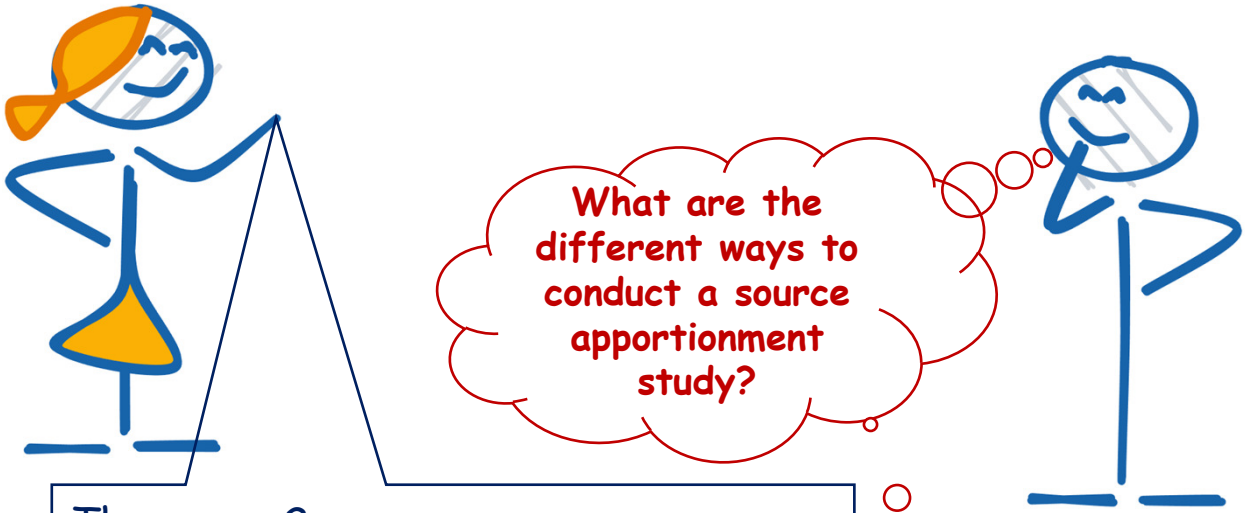
Are these studies easy to conduct?



These studies are scientifically robust but never easy to conduct. They require a lot of skilled personnel for monitoring, data modeling, laboratory facilities, and financial support. There are multiple institutions with resources that can help in conducting these studies.

How often do we have to conduct these studies?

Depending on the availability of resources and technical facilities, these studies can be repeated every year. This will allow us to study the trends in ambient pollution levels and the impacts of various control options implemented in the city airshed.



What are the different ways to conduct a source apportionment study?

There are 2 ways
(a) Top-down (sampling way)
(b) Bottom-up (emissions way)

Are the results from these two methods same?

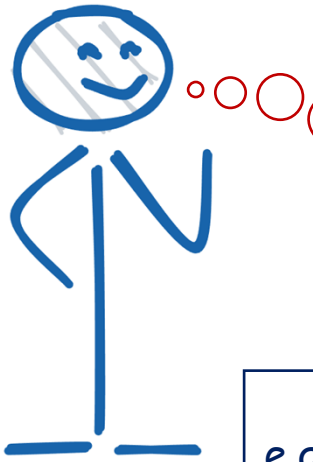
Ideally, yes.

The top-down approach provides results specific to sampling locations, which are then averaged to create a city-level profile.

The bottom-up approach provides results for the city's designated airshed, with spatial granularity based on the available emissions inventory.

Top-down approach (sampling way)

This approach measures pollution using filters, which are analysed in the laboratory for chemical signatures. Then the sample profiles are statistically matched with source profiles to assess source contributions.



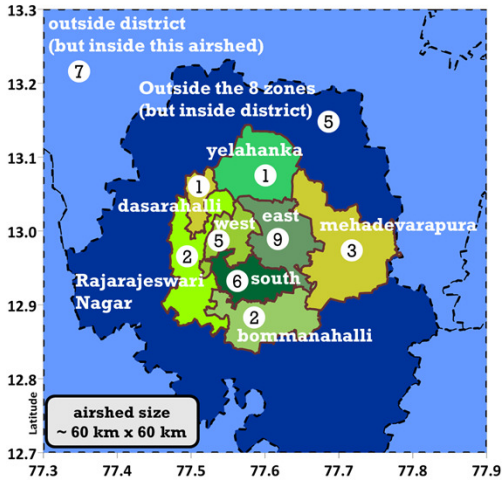
Are there any rules for how many samples must be collected?

Yes, there are some thumb rules.
e.g., India defined the following based on total population (TP)

For TP under 100,000 -- 4 units
For TP under 1 million - 4 + 0.6 per 100,000
For TP under 5 million – 7.5 + 0.25 per 100,000
For TP above 5 million - 12 + 0.16 per 100,000

Table source: CPCB, India

For example:
City of Bengaluru requires 41 locations

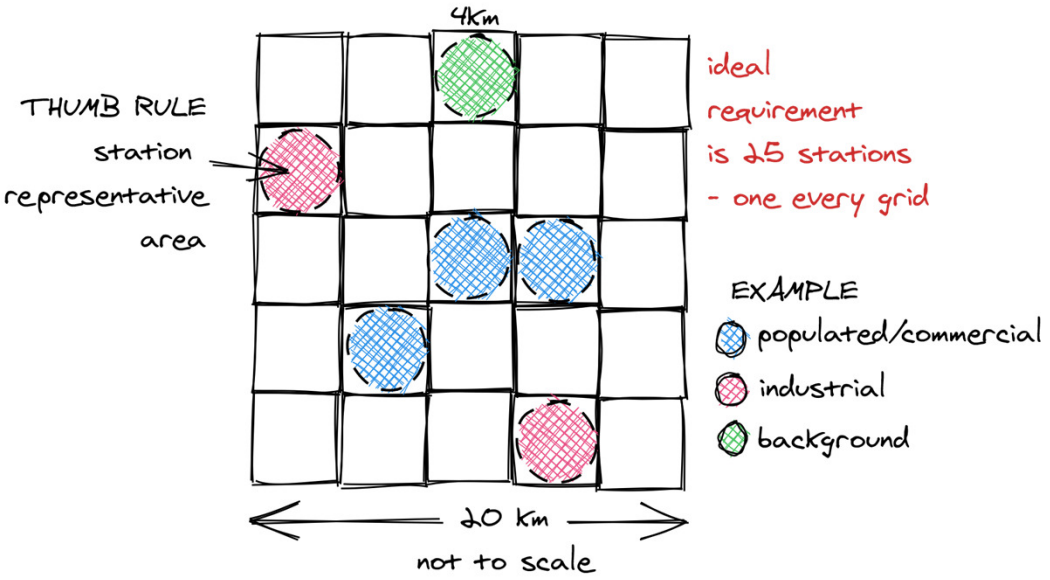


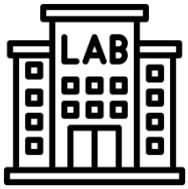
Finally, the city's financial, personnel, and operational capacity decides how many locations are selected.

How do you select the sampling locations?

If locations are not selected representatively, the sample results will be biased.

To minimize these biases, the protocol suggests selecting multiple locations representing all areas and activities in the study airshed.





MASS -- gravimetric analysis
ELEMENTS -- Na, Mg, Al, Si, P, S, Cl, K, Ca, Ti, V, Cr, Mn, Fe, Co, Ni, Cu, Zn, Ga, As, Se, Br, Rb, Sr, Y, Zr, Mo, Pd, Ag, Cd, In, Sn, Sb, Ba, La, Au, Hg, Ti, Pb and U
IONS -- SO_4^{2-}, NO_3^-, NH_4^+, Cl^-, Na^+, K^+
CARBON -- elemental, organic, and total

The sampled filters are stored in a controlled environment and sent to the lab for chemical analysis.

We require information on the total sample weight, fractions of elements, ions, and carbon. Each of these elements is analyzed using different machines.

How expensive is this step?

The lab equipment is not cheap. If the city does not operate its own lab, samples can be sent to a certified lab.

With the city's own lab, the study can be replicated at many locations and over more years.

The most common receptor models used are CMB and PMF.

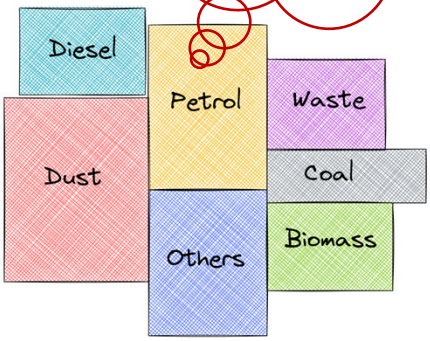
Local source profiles are preferred. If not available, take representative profiles from the library.

Results:
Modeled source contributions

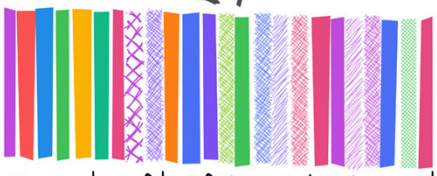
Here the term source is often referred to the fuel.

Receptor Model

Ambient Sample



Collect chemical profiles of all known sources



Chemical profile of the ambient sample as ions, metals, and carbon species

PRIMARY AEROSOLS – METALS & ELEMENTS

K	Na	Ca	Al	Se	Co	As	Fe	Zn	Cu	Pb	etc
POTASSIUM (biomass)	SODIUM (sea salt)	Calcium (cement)	ALUMINIUM, SELENIUM, COBALT, ARSENIC (coal burning)				IRON, ZINC, COPPER, LEAD, and OTHERS (ferrous and othr non-ferrous industries)				

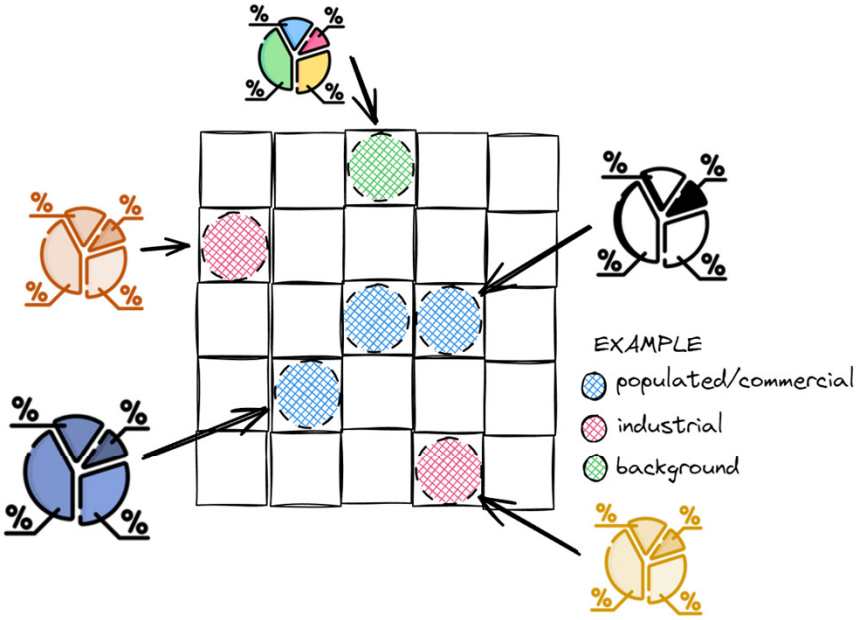
Al	Si	Ca	V	Ni	Mn	Fe	EC	OC	K	Zn	Pb
ALUMINIUM, SILICON, CALCIUM (soil and road dust)			VANADIUM, NICKEL, MANGANESE, IRON (oil burning)				ELE. & ORG. CARBON (biomass, diesel, petrol)		POTASSIUM, ZINC, LEAD (refuse incineration)		

SECONDARY AEROSOLS – GAS to AEROSOL CHEMICAL CONVERSIONS

SO_4	NO_3	NH_4	SOA
SULFATES origin - SO_2 emissions (diesel and coal combustion)	NITRATES origin - NO_x emissions (high temperature combustion (eg. vehicles, heavy industry)	AMMONIUM origin – NH_3 emissions (fertilizer usage and animal husbandry)	ORGANIC AEROSOL origin – VOC emissions (biomass, diesel, petrol, & gas combustion)

These are the common chemical markers of various sources for $PM_{2.5}$. The source profiles are developed by collecting filter samples immediately closer to the sources.

There are overlapping signatures between sources using the same fuels. Extra scrutiny is required in dissecting these results. For example: road dust versus construction dust; coal in a cooking stove versus an industrial boiler; and diesel in a bus versus a truck versus a generator set.



Chemical analysis and receptor modelling results represent the activities around a fixed area of influence and for the day of sampling. An ideal setup will include as many sampling locations and sampling days as possible to represent the entire airshed and seasons.

A pollution map with concentrations and source contributions at various locations can be averaged to represent the city airshed.

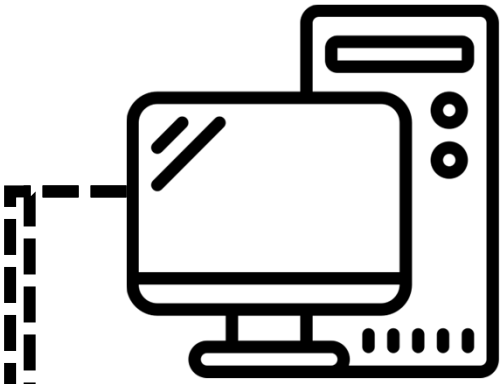
Bottom-up approach (emissions way)

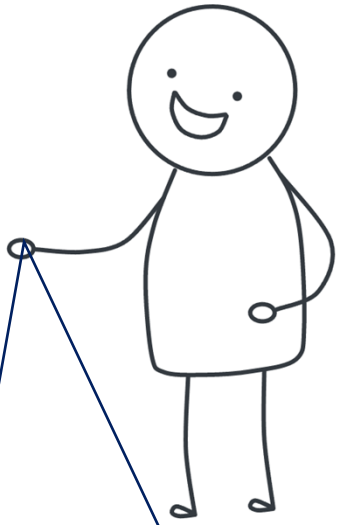
Gridded-Emission Inventories

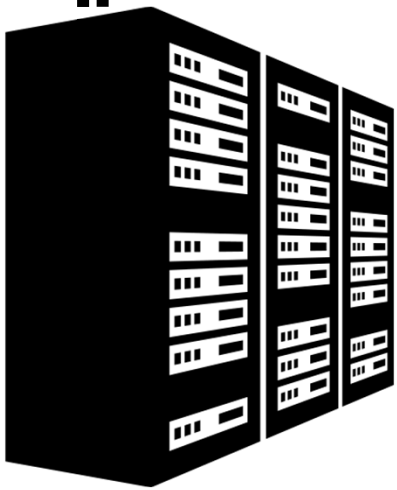
Meteorology

Chemical-Transport Modelling

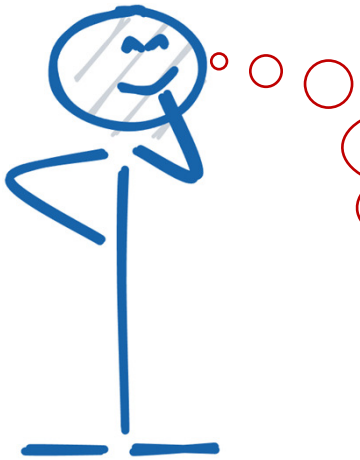
This approach utilizes grid-level emission inventories of all known sources, along with meteorology and airshed boundary conditions, as input to chemical-transport models to assess source contributions.







Depending on the size of the airshed and the chosen model, this approach can be computationally demanding.
It requires personnel with training to simulate meteorological and atmospheric models, as well as skills in GIS databases, mapping, and data analytics.

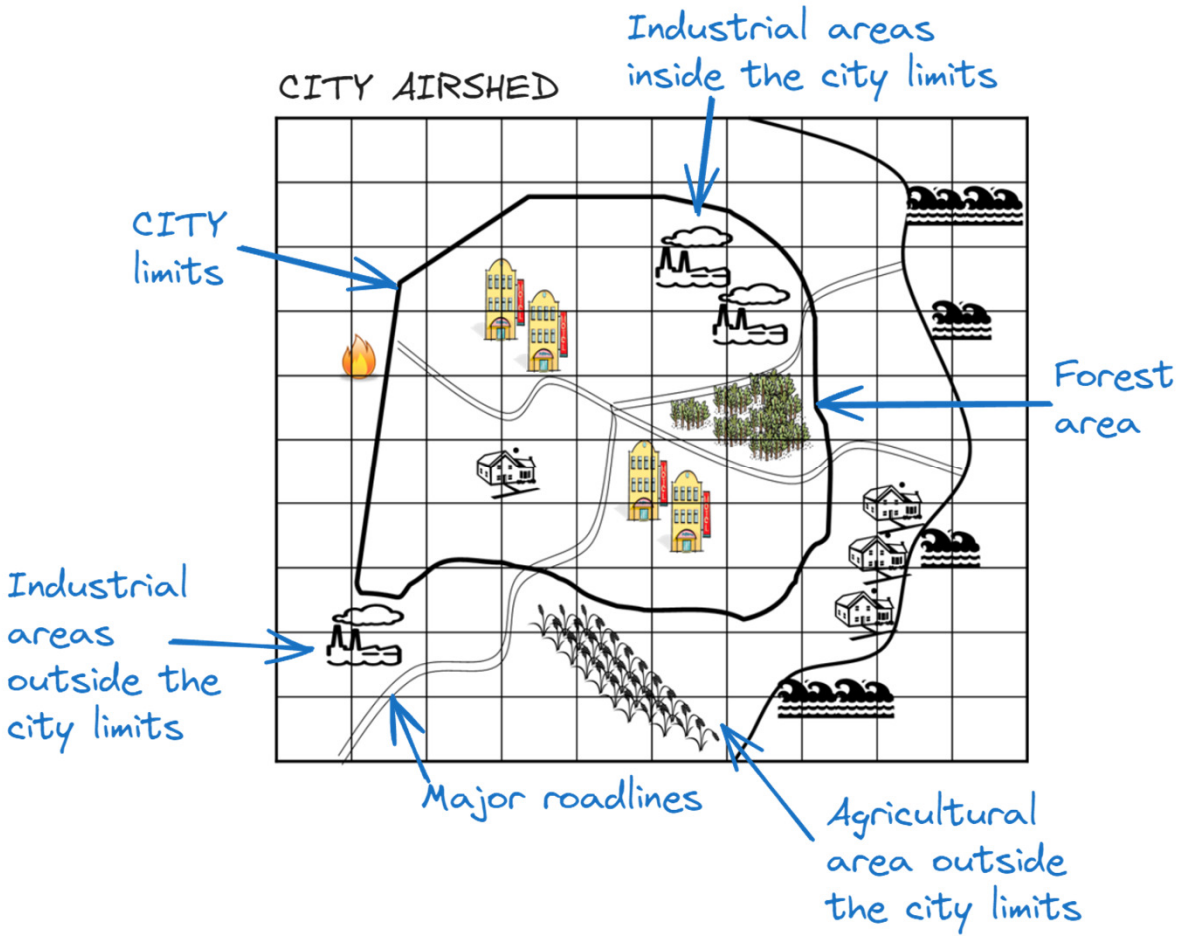


What are the basic layers of information we must gather for this approach?

Define your area of interest. Outside your city, include as much as possible all the areas with sources that could influence local air quality in the short term. This area is often referred to as the city's airshed.

Collect information from archives on geography, land use-land cover, population, urbanization maps, industrial maps, residential maps, commercial activities, energy consumption rates, vehicle registration and usage numbers, meteorological statistics, and ambient monitoring data.

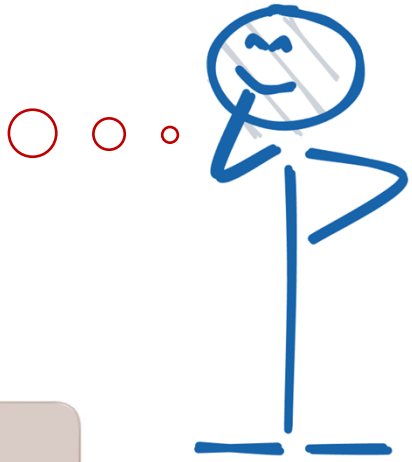
While this may seem like a lot, most cities already have this information, which needs to be archived for final use.



For urban-scale studies, typical grid-size is 1-km and typical airshed size is 30x30 for small cities to 80x80 grids for big cities, in north-south and east-west directions.

For larger airsheds with more grids, the grid-size increases as a compromise to support computational needs.

What is the fundamental equation to start building an emissions inventory?



Fundamental equation

Emissions = Activity * Emission Factor

Emissions = fuel consumption (PJ) * emission factor (kg/PJ)

Emissions = fuel consumption (tons) * emissions factor (kg/tons)

Emissions = #vehicles * vehicle usage (km) * emission factor (gm/km)

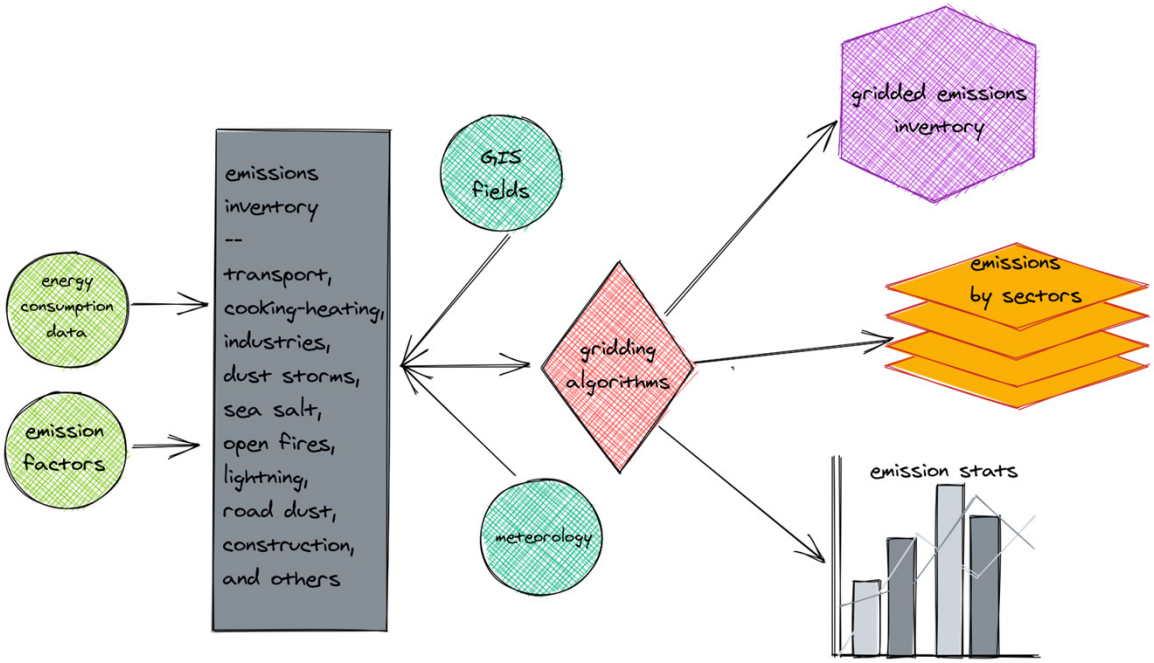
Emissions = waste burnt (kg) * emission factor (gm/kg)

Emissions = diesel burnt (lit) * emission factor (gm/lit)

Depending on the level of detail in the activity data for each sector, the equation can become more complicated. If detailed information is not available, begin with total city activity data.

If local emission factors are unavailable, use averages from a library.

However, it is crucial to start!



The first step is to utilize available emission inventories—either from a local resource or extract from a global inventory.

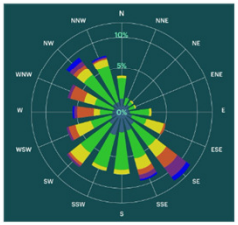
Then, expand the data collection exercises to collate activity data through primary surveys.

Spatial allocation of the emissions to airshed grids requires multiple layers of information in GIS formats.

Meteorology influences emission intensity & pollution dispersion

Emissions

. wet conditions = lesser dust resuspension
. cold temperatures = more heating demand
. windy conditions = more dust resuspension and dust storms



Formation

. Temperature, pressure, and humidity dependent chemical reactions
. cloudy conditions = lesser photochemistry

Dispersion

. rain = wet deposition of pollutants
. windy conditions = more dispersion

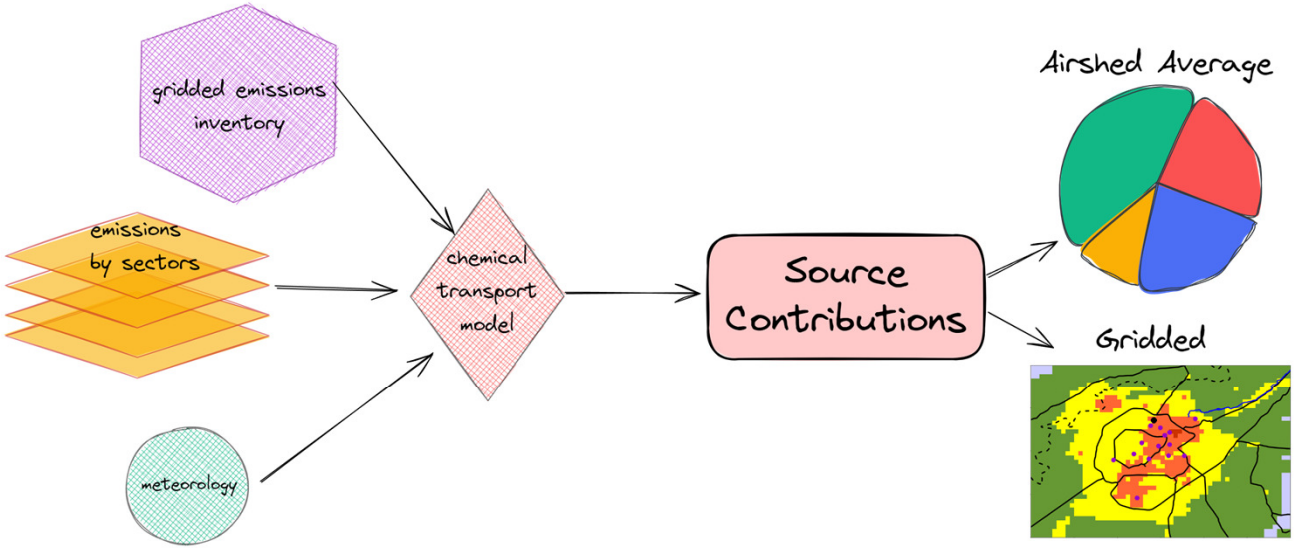
Pollution

. lower mixing height = more pollution
. windy conditions = lesser pollution
. wet conditions = lesser pollution
. foggy conditions = more pollution

3-dimensional meteorological information is must for modelling studies. This includes information on pressure, temperature, wind speed, wind direction, precipitation, relative humidity, inversion heights, and others.

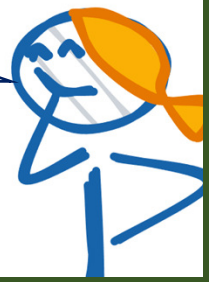
Weather Research Forecasts (WRF) model is state-of-the-art for urban, regional, and global applications.

There exist various types of chemical transport models



-- Box-models treat the whole city as a box and are good enough for broad calculations.
-- Gaussian-models treat emissions as plumes. This approach is fast but limited in chemical mechanisms.
-- Eulerian-models treat every grid independently and has state-of-the art physics & chemistry modules.

Select an appropriate model depending on your computational capacity and analysis needs. Consult experts.

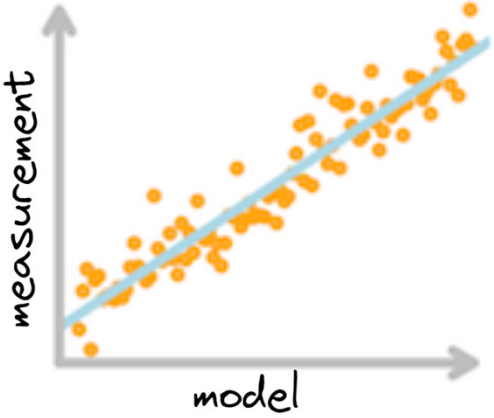


How can we validate the modelling results?

A large pool of ground monitoring data means a better understanding of the spatial and temporal trends of air pollution in the airshed.

This information can be used to validate the models and increase their confidence levels.

New modeling systems can also utilize satellite observations to validate the modeling results.



Excellent.

These are two distinct approaches to reach the same conclusions.

Depending on our financial and technical resources, we can use either of the approaches (or both). Neither of them is easy, but we must start the study.

Exactly.

Both methods are robust and well-tested in cities across the world. Ideally, both approaches should be applied to consolidate the results.

The most important step is making the decision to conduct the source apportionment study. Then, based on the resources and information available, we can decide which approach is more suitable.