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# Urban compaction vs city sprawl : impact of road traffic on air quality in the greater Paris

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Introduction

- ❖ Context
- ❖ The compact city
- ❖ The integrated modelling chain

The modelling chain

- ❖ LUTI (Land use transport interaction)
- ❖ Emissions
- ❖ CTM (Chemistry-transport model)

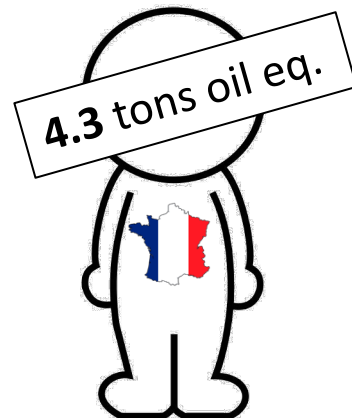
Scenarios

- ❖ COMPACT vs SPRAWL

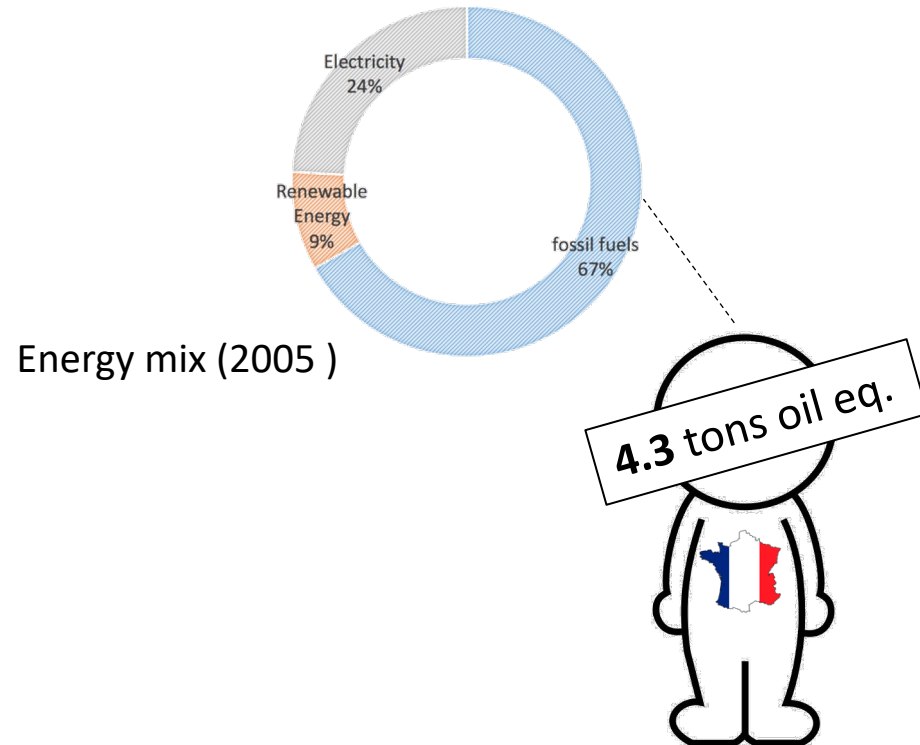
Ongoing

# Context – Energy consumption

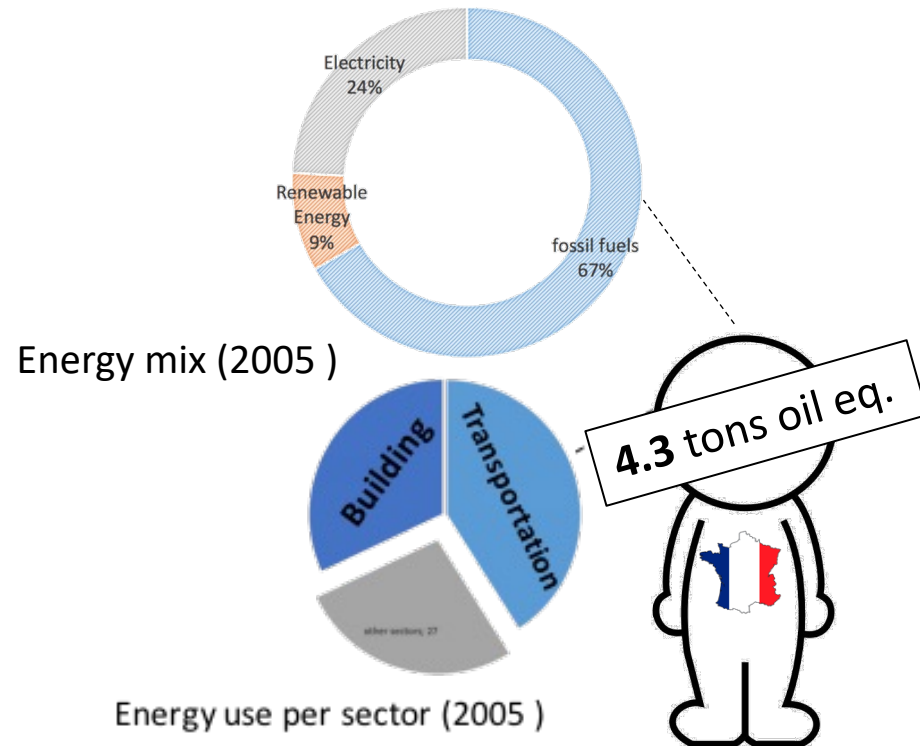
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# Context – Energy consumption



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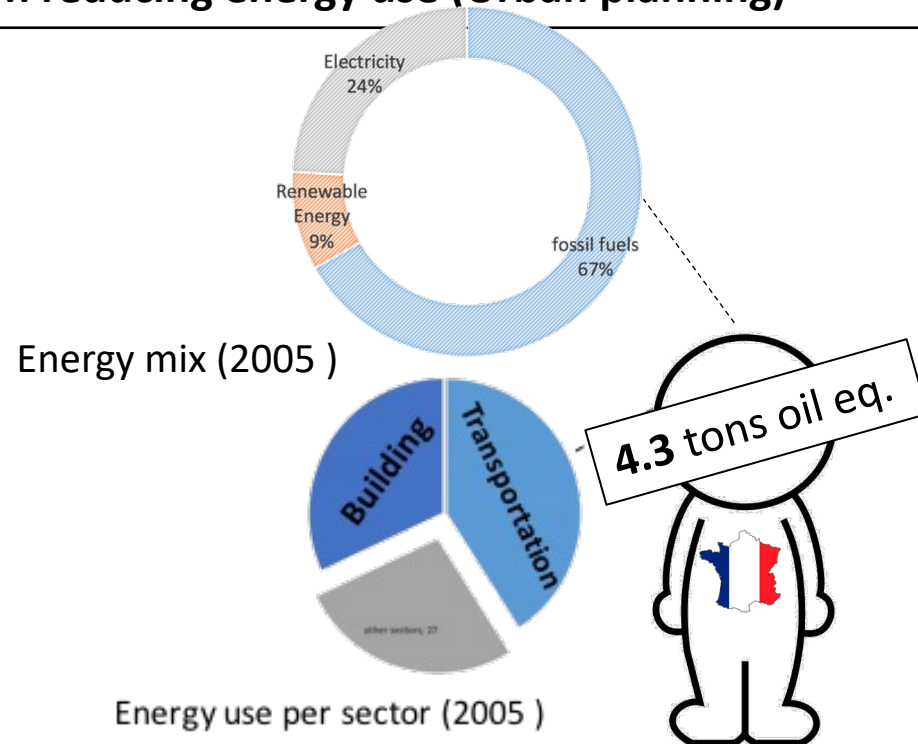
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## Energy transition

- Global priority
- Environmental policies to reduce GHG and air pollutant emissions
- Limitations of abatement technologies (Internal combustion engine)

## Energy use in the future ?

## New reflexions on reducing energy use (Urban planning)



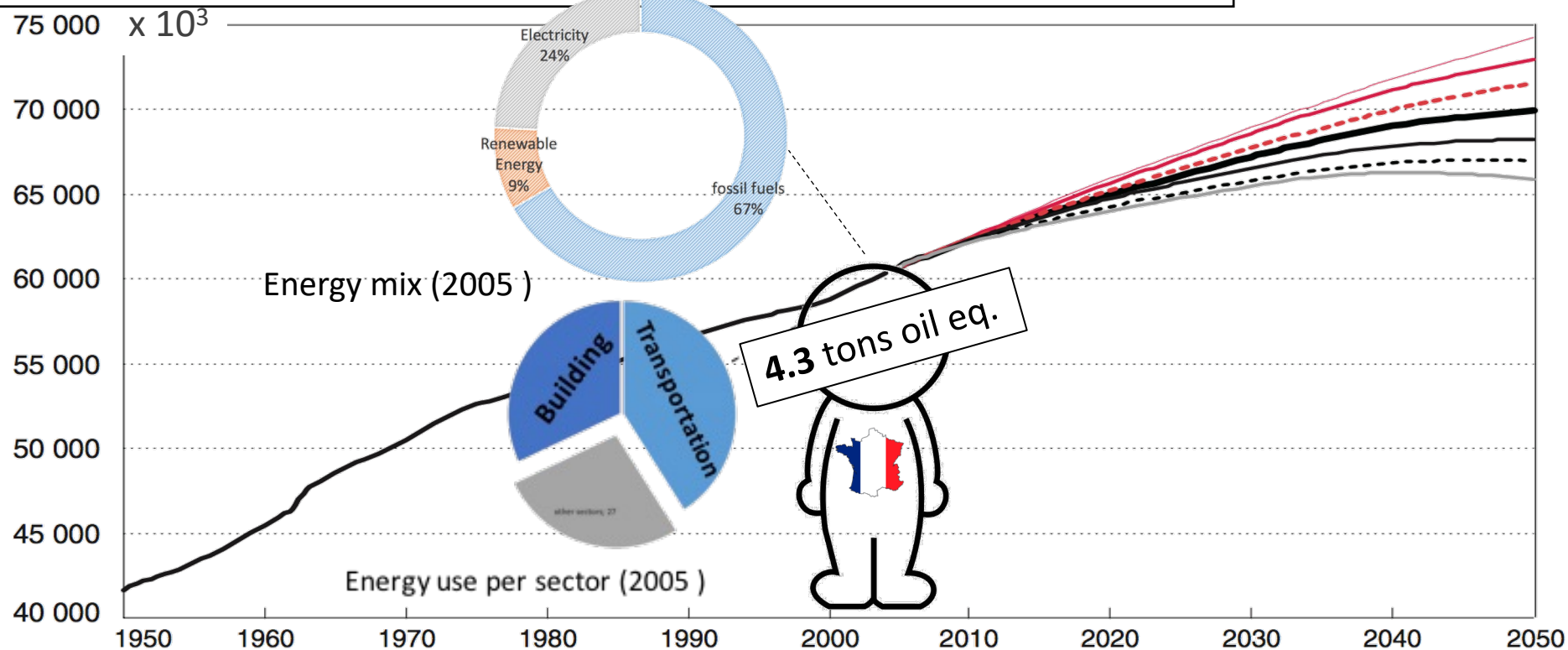
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Source: INSEE, population projections 2005-2050

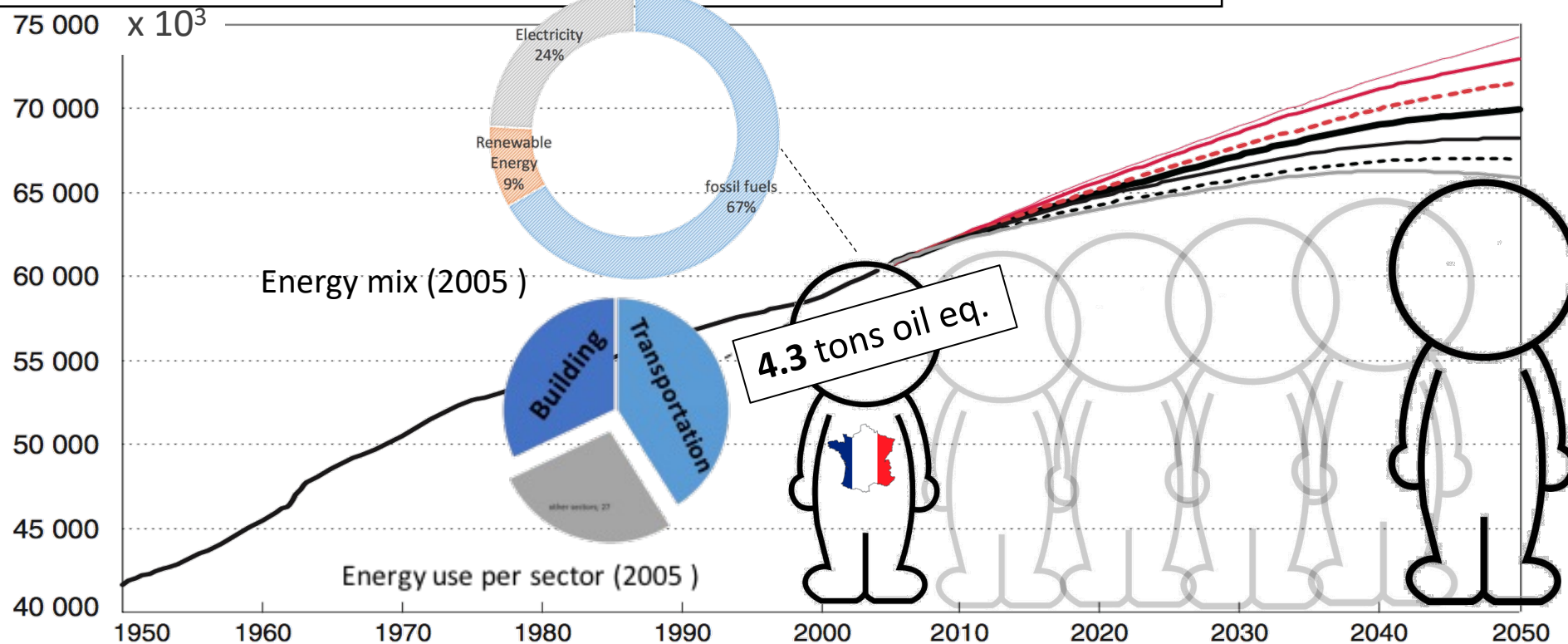
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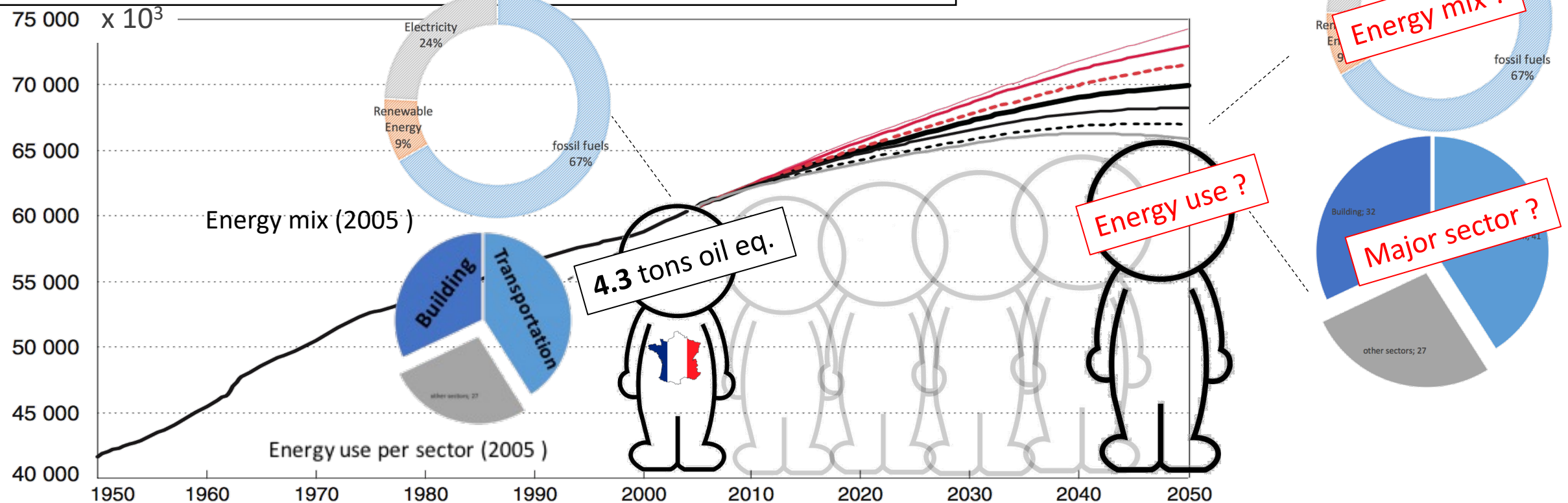
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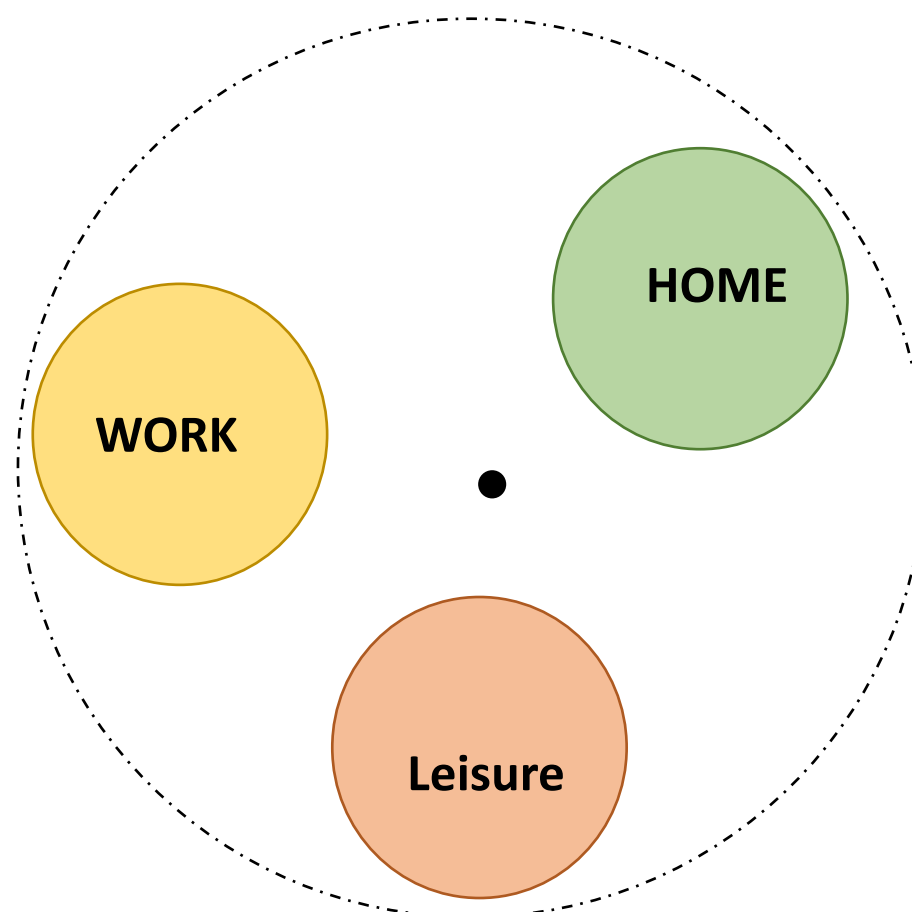
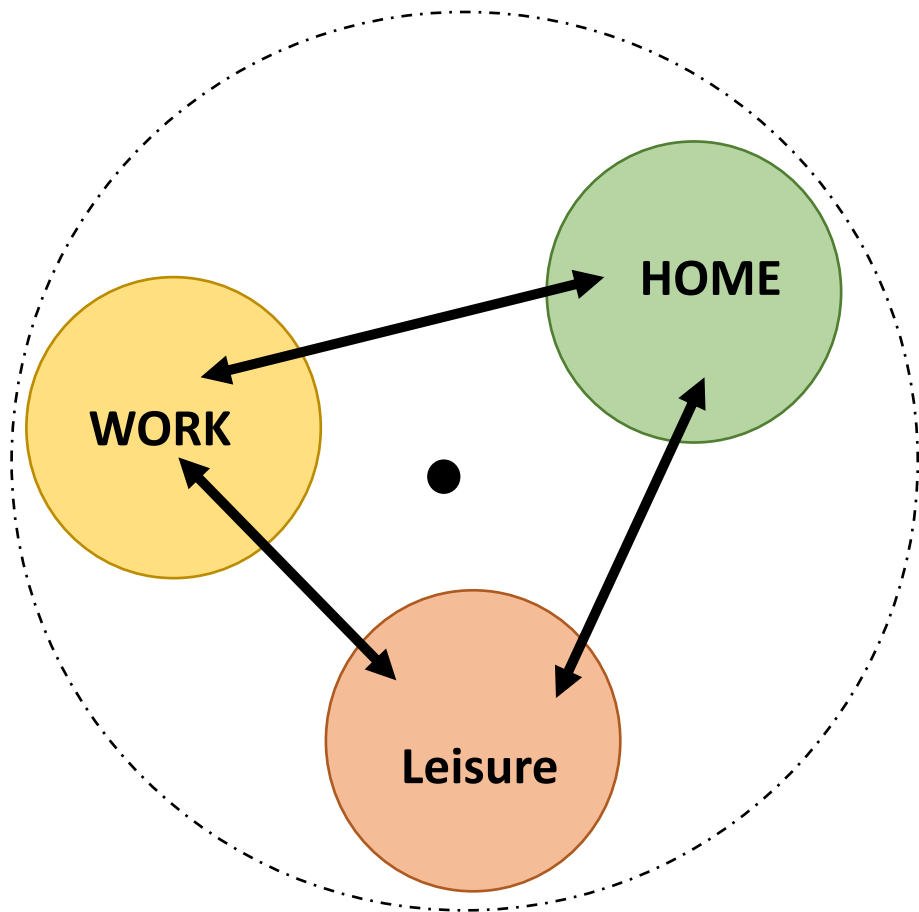
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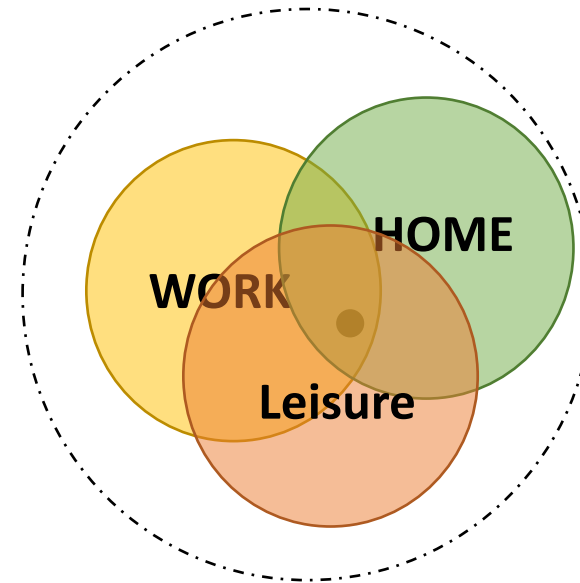
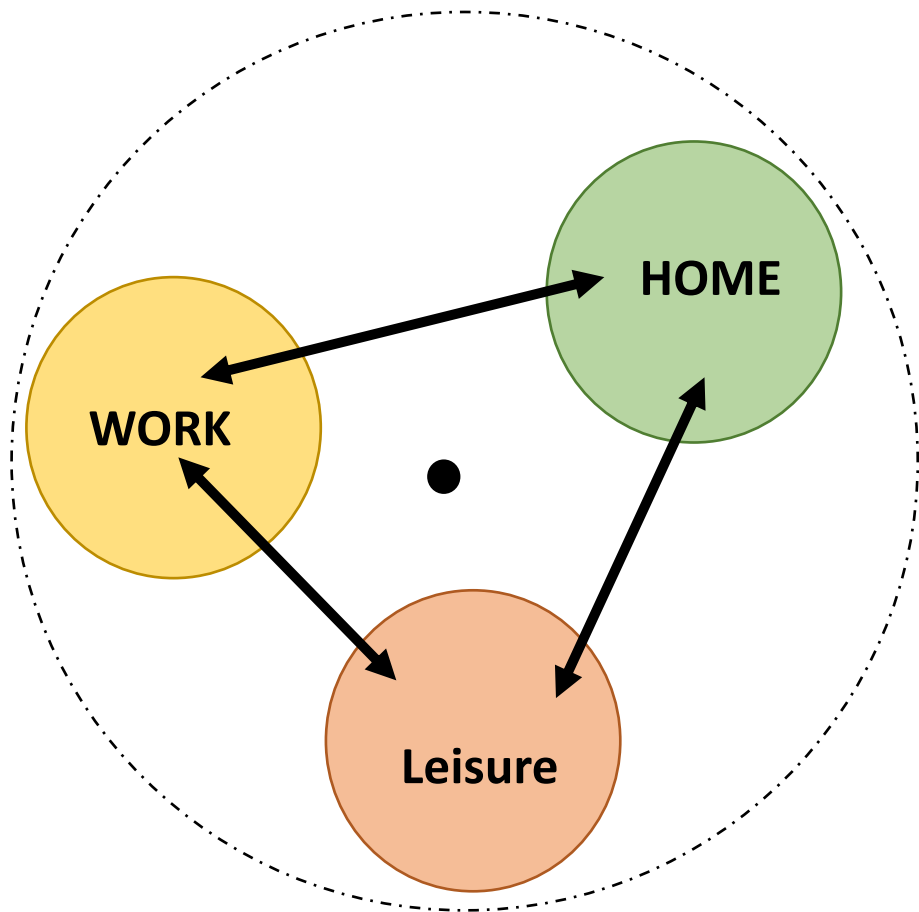
# Compact city

- High density urban settlement
- Proximity and mixity of services
- Reducing commuting distances



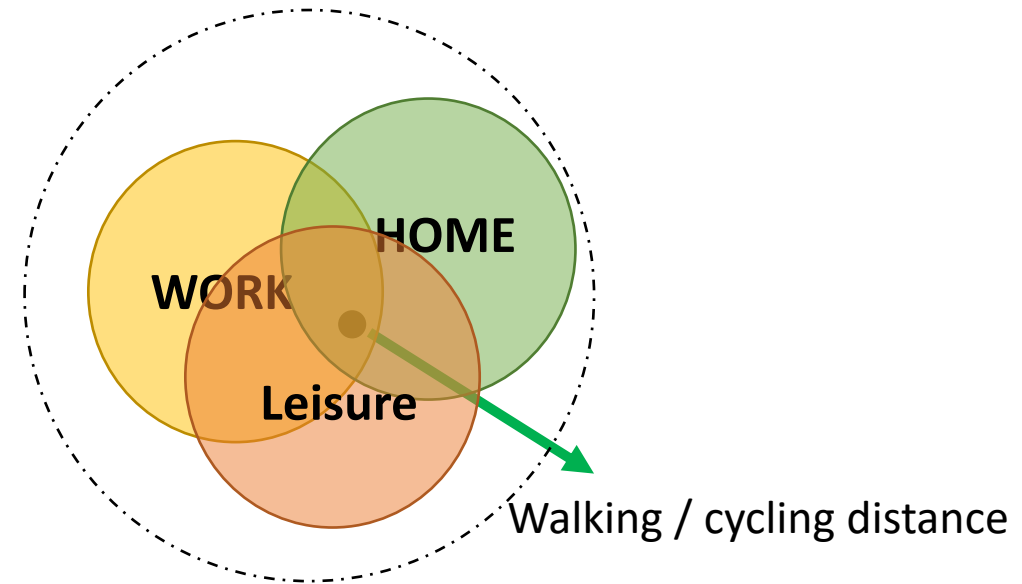
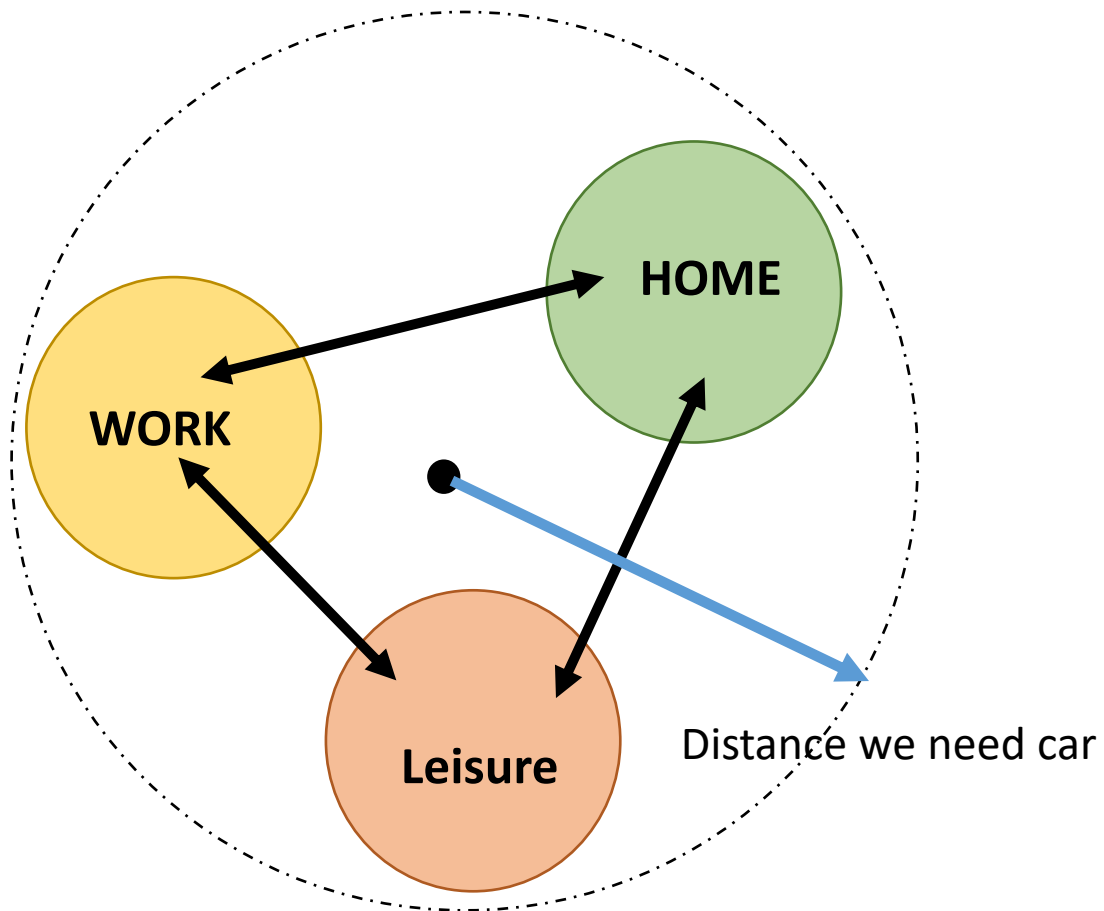
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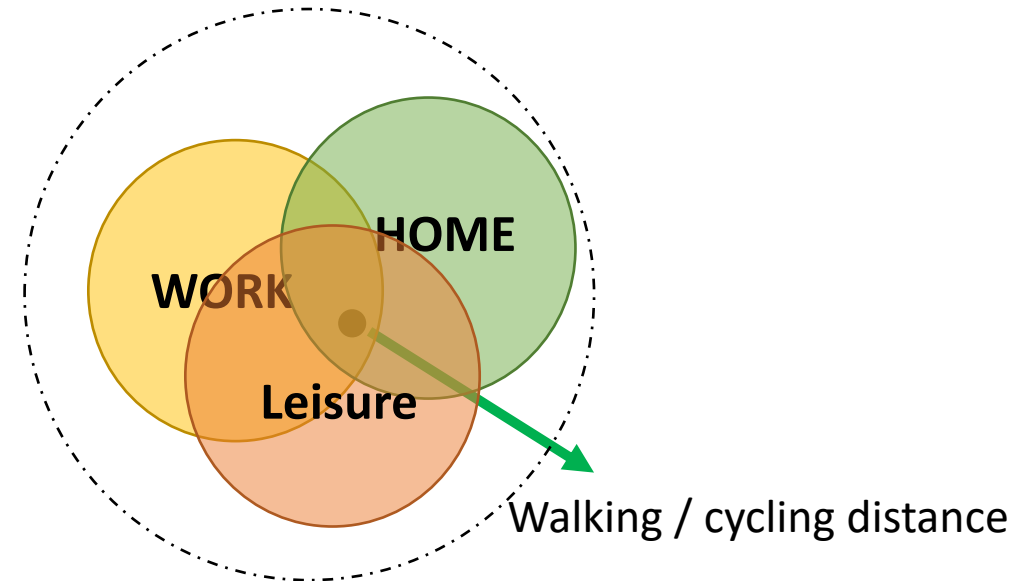
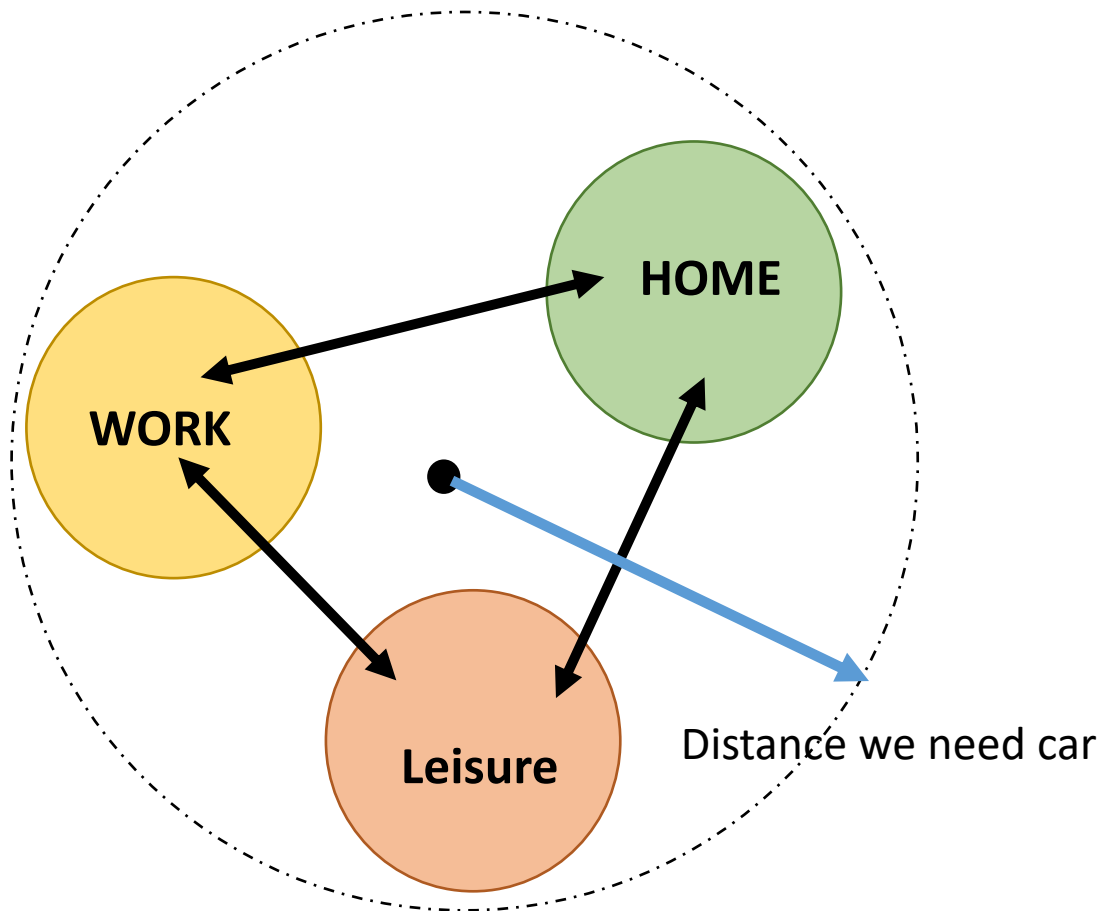
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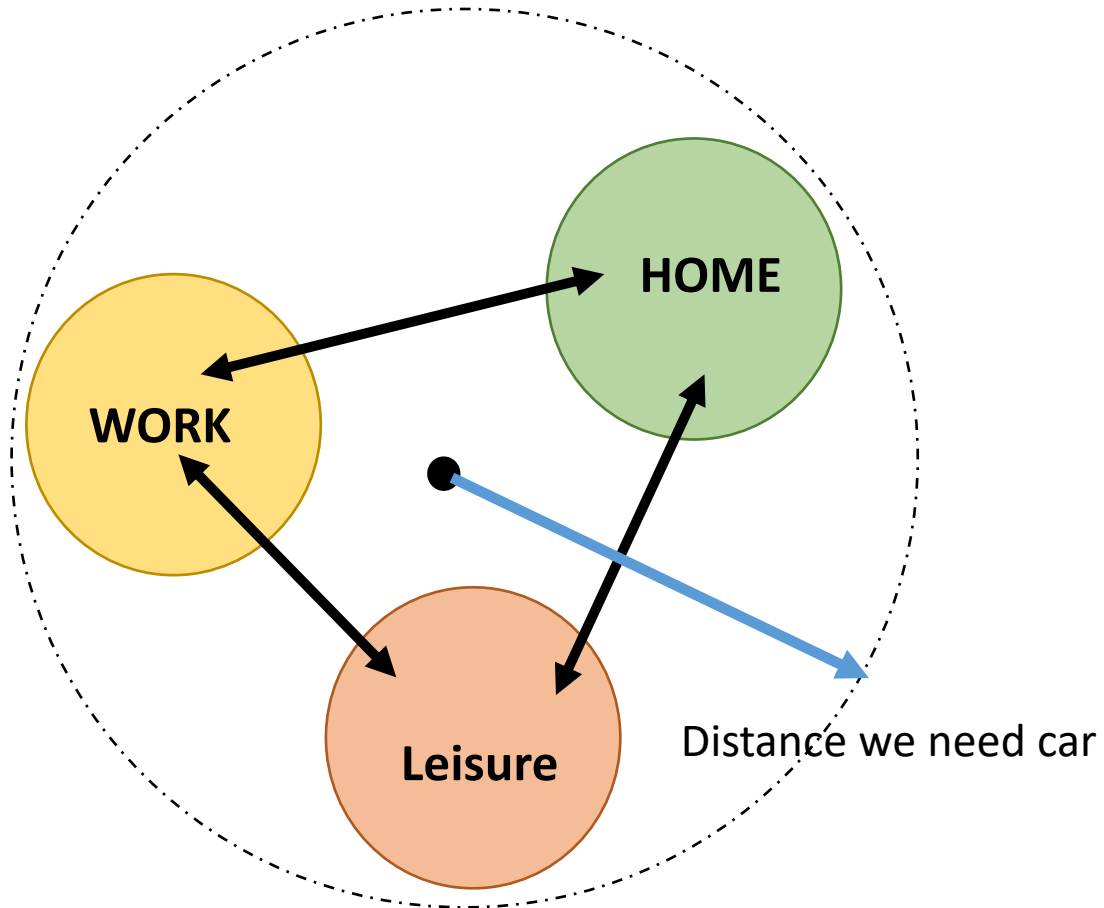
**Reduction of energy use/ GHG /air pollutant**

- Organizing energy networks (heating, services)
- ↘ travel by car ↗ walking / cycling



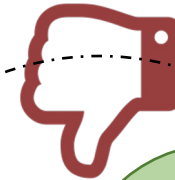
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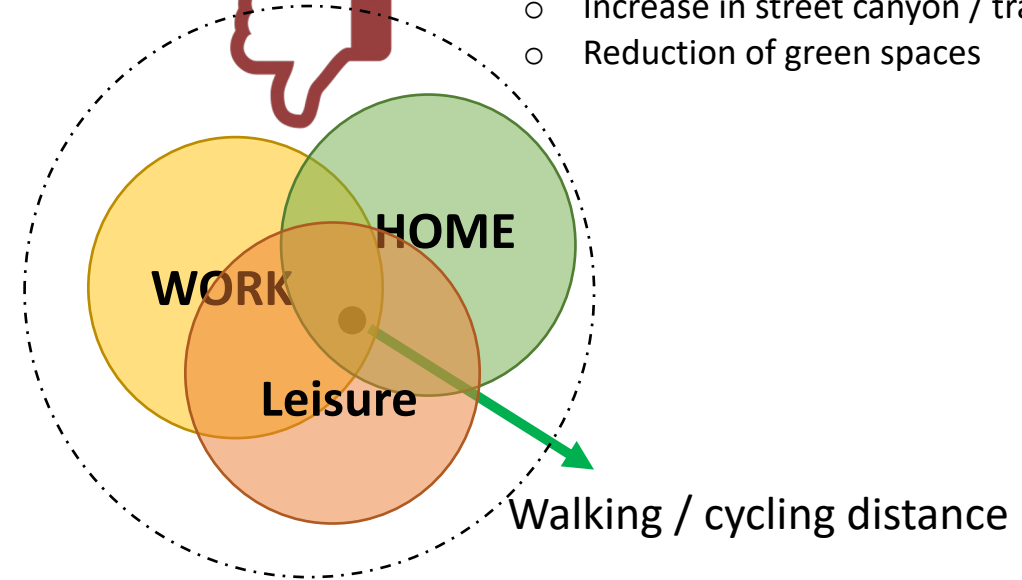
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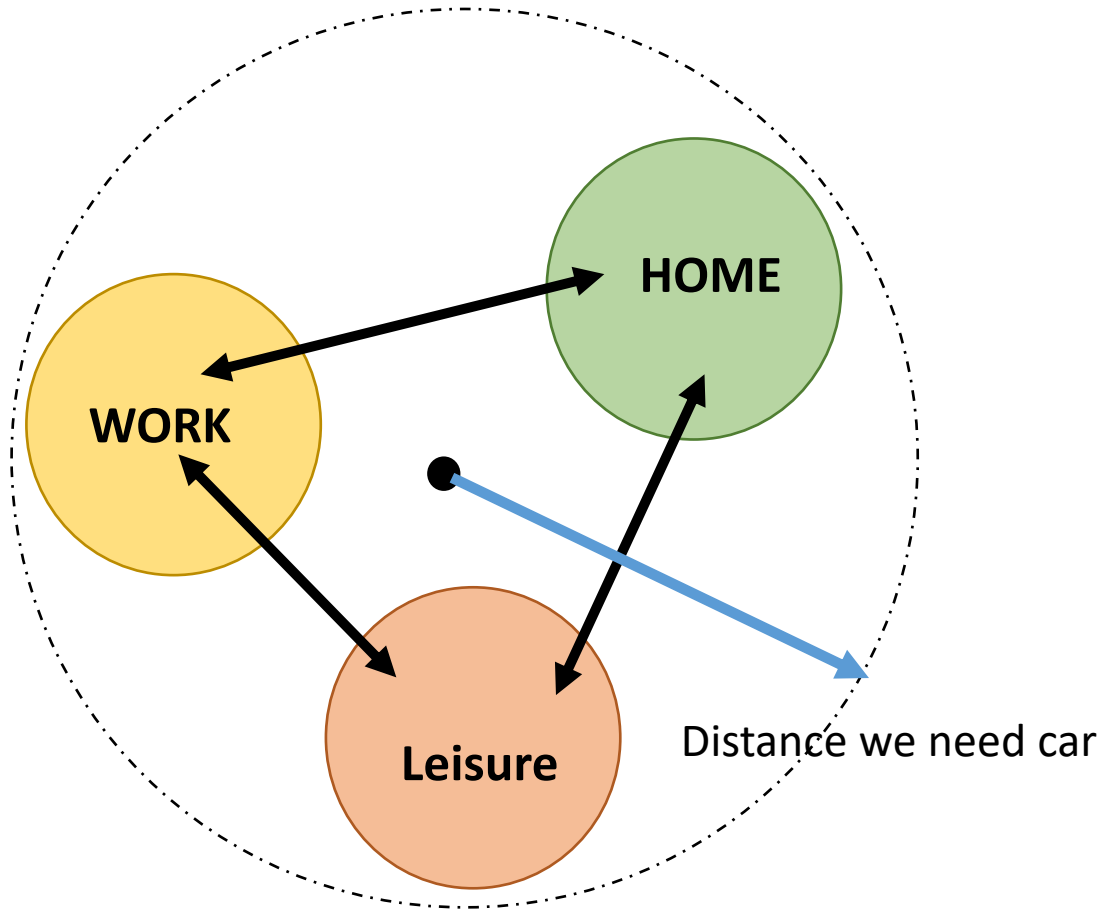
## Reinforcing potential exposure to degraded air quality

- Increase in street canyon / traffic congestion
- Reduction of green spaces



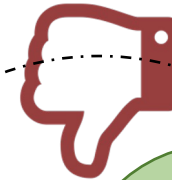
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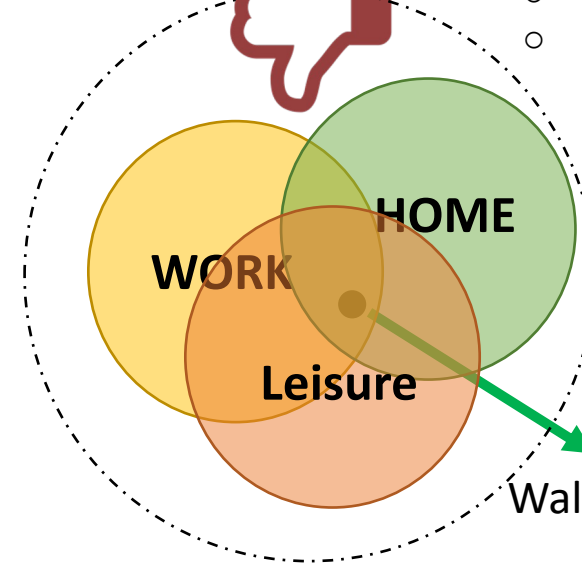
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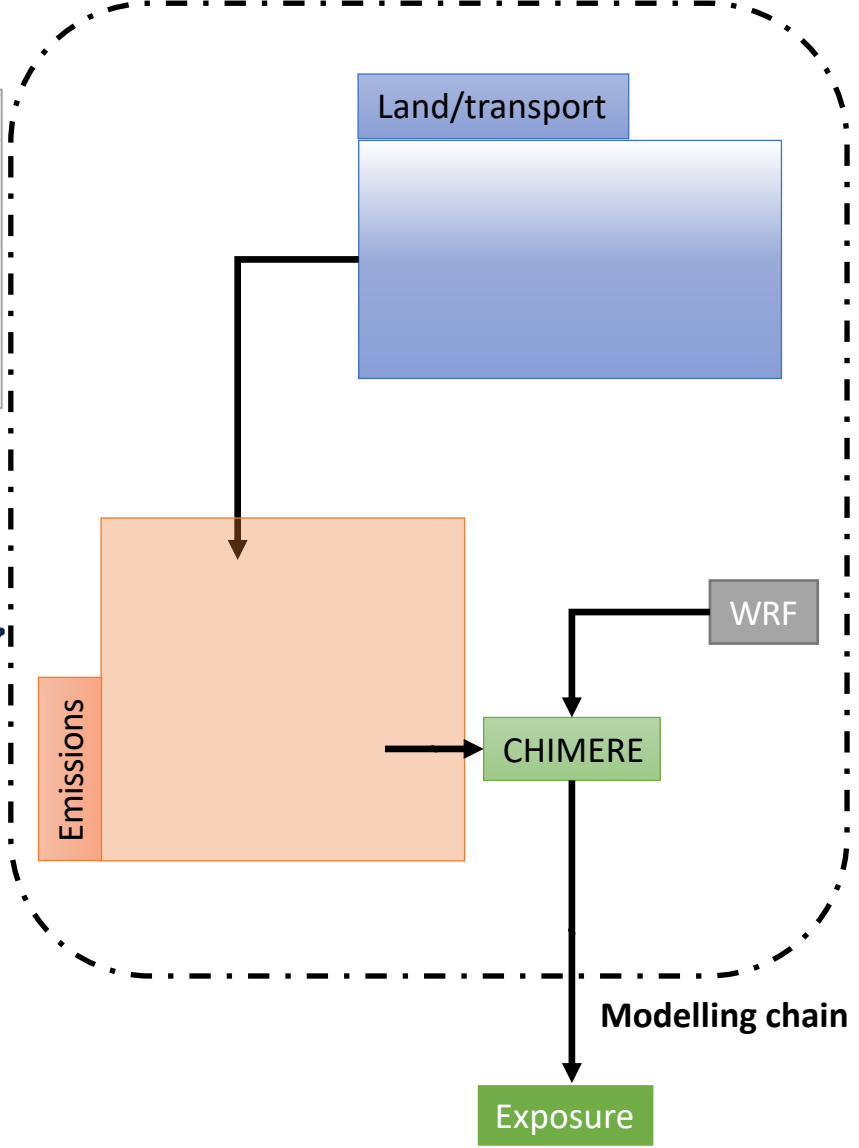
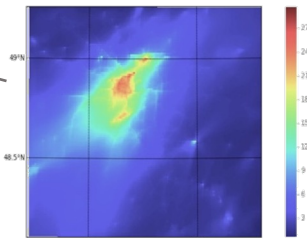
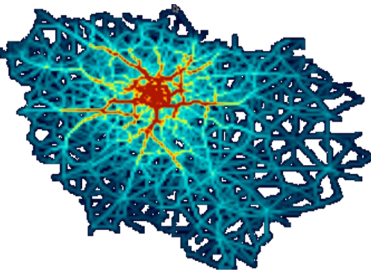
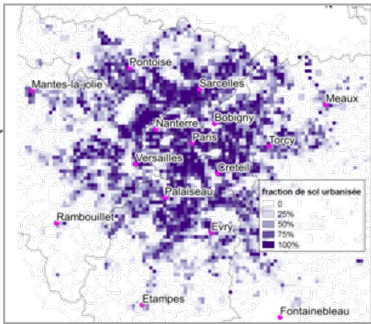
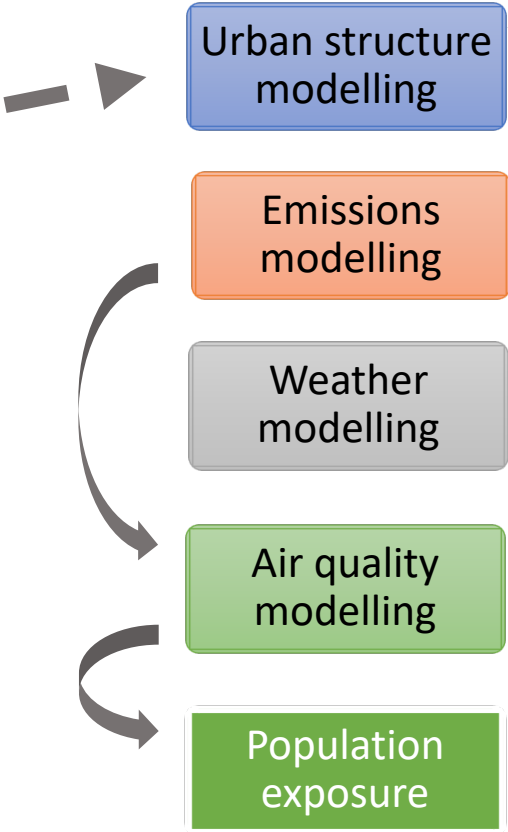
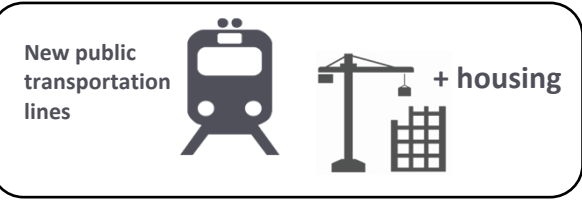
impacts of urban policies on air quality ?

How to model those impacts ?

# Integrated modeling of the analysis of impacts of urban policies on air quality

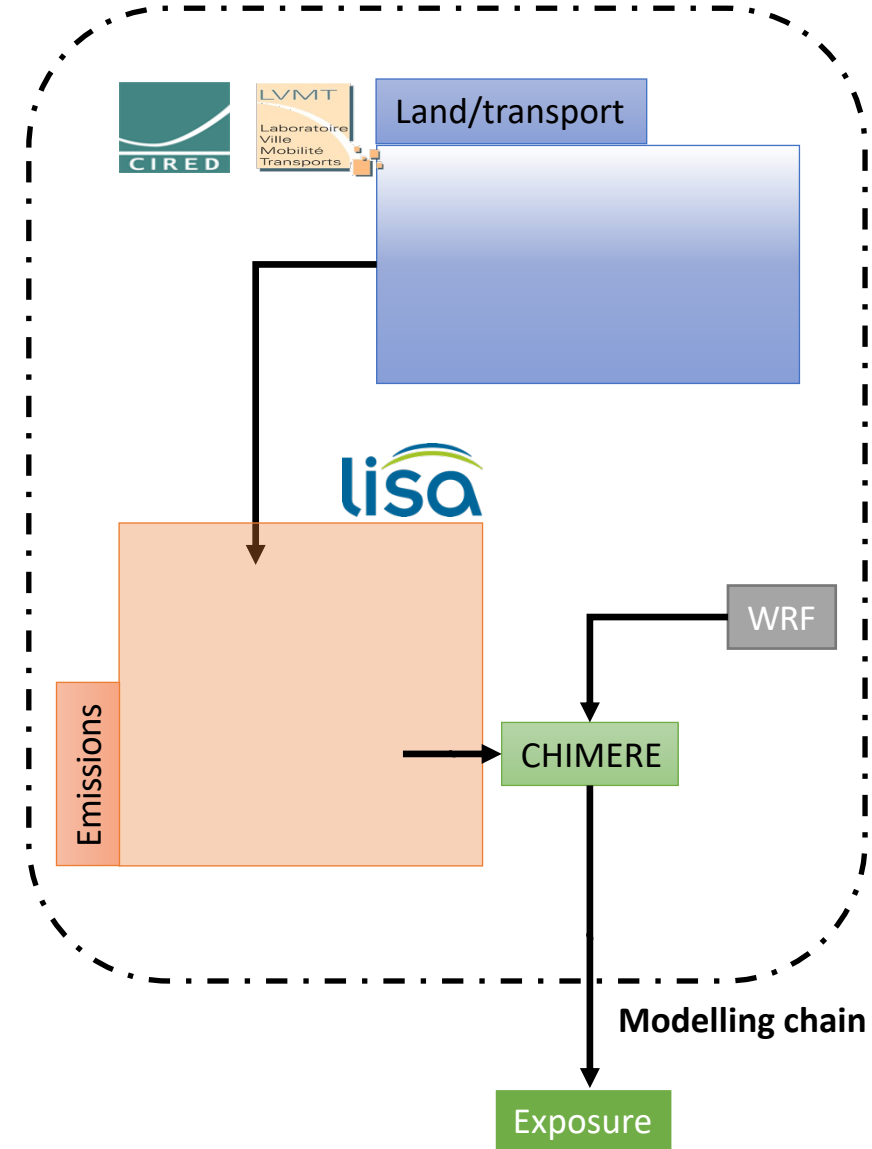
- Diagnosis of future scenarios**
- Academics (Compact, sprawl cities)
  - Territorial planning schemes
- Taking into account the major determinants of the city**
- Economic / Energy / Housing / Transport / Health

## Urban policies

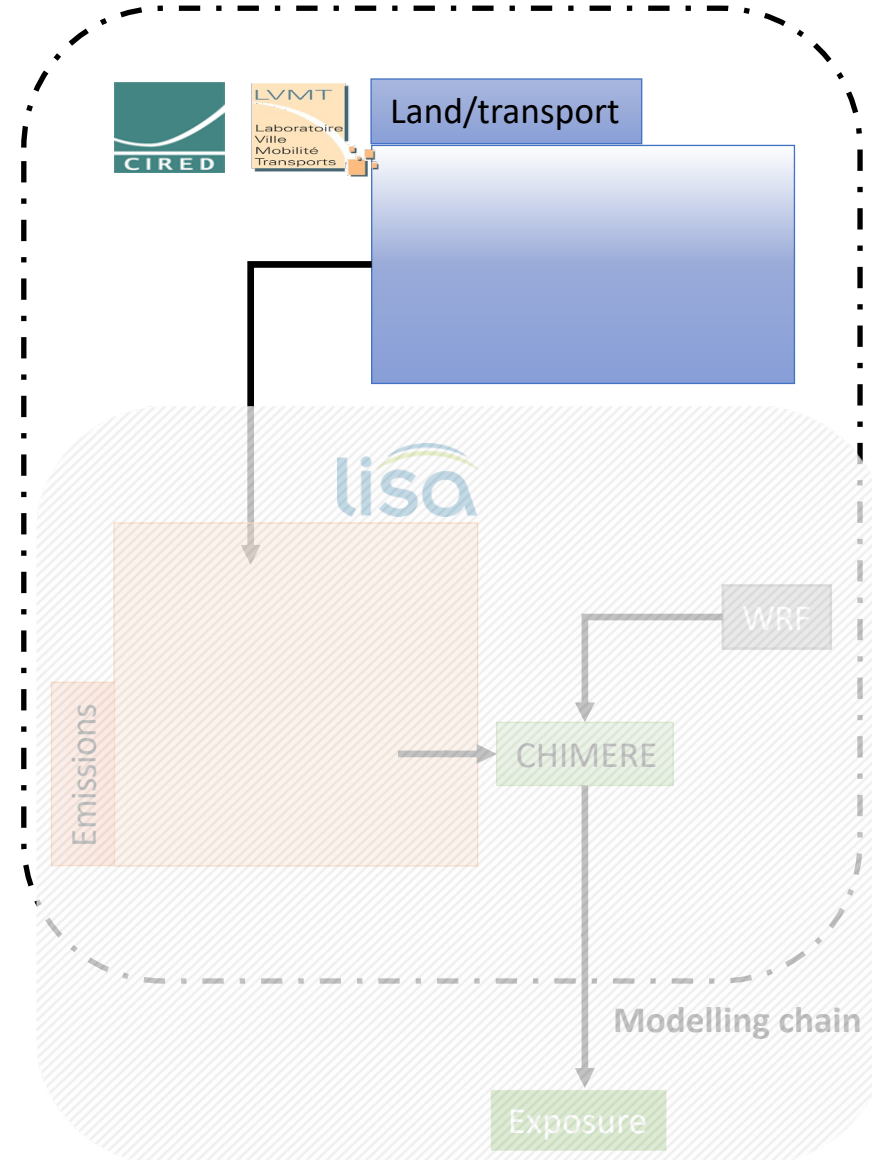
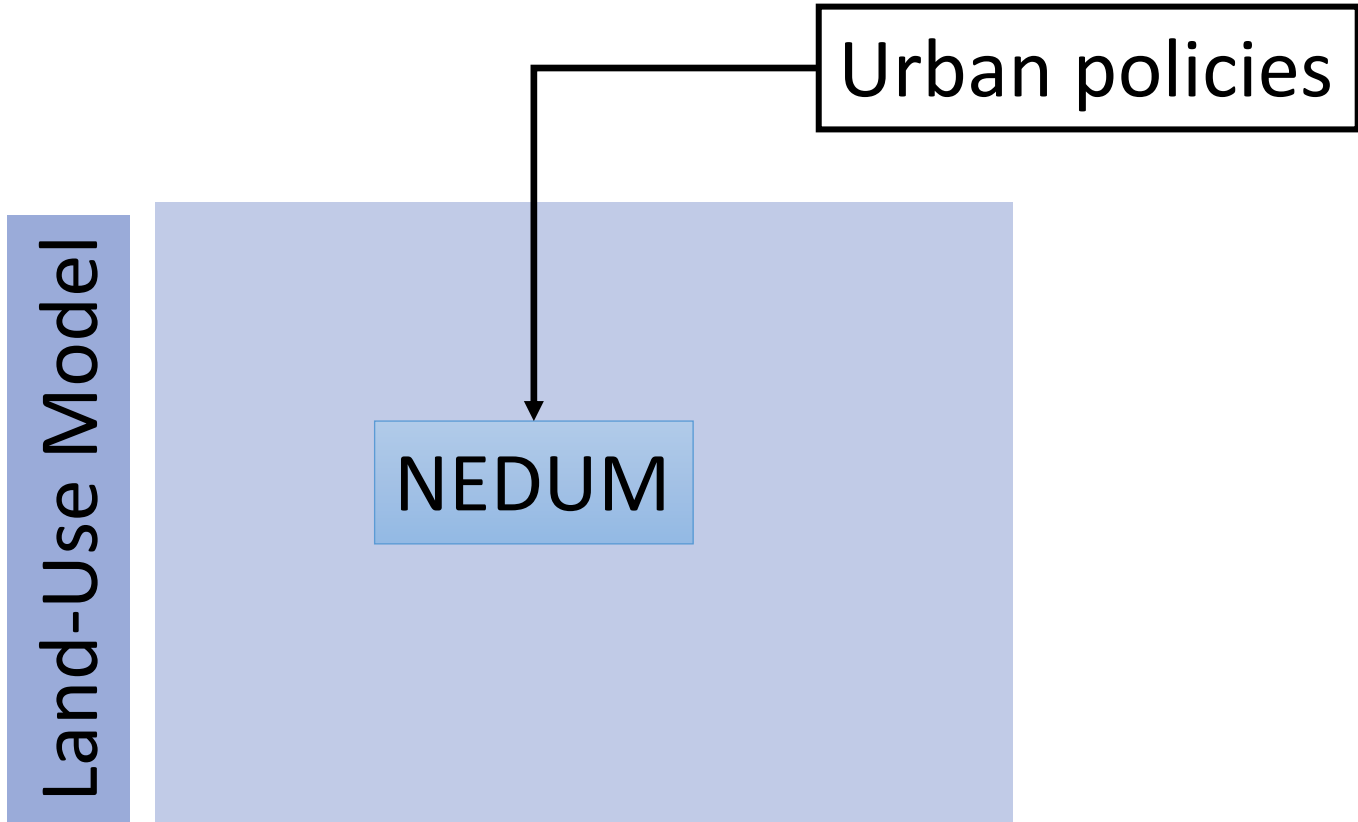




# The modeling chain



# The modeling chain : NEDUM

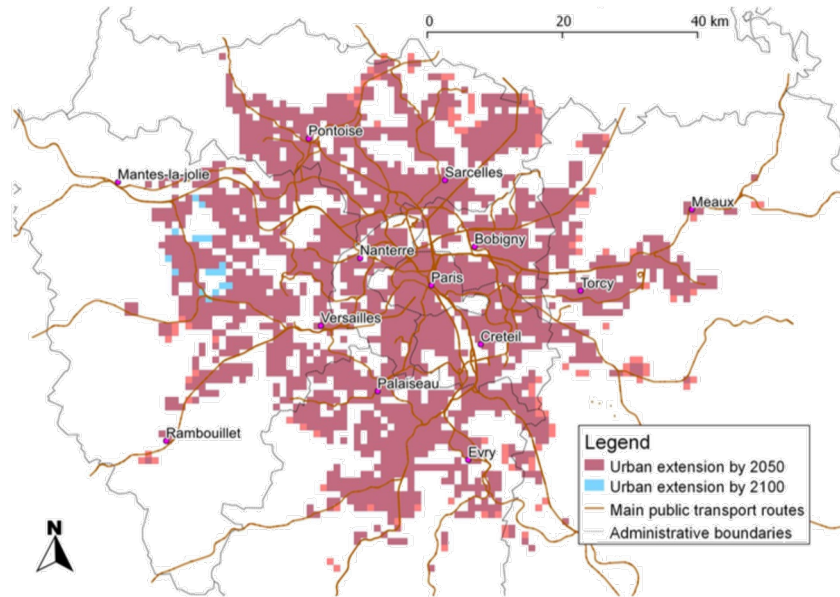


# The modeling chain : NEDUM

## NEDUM

Simulates the evolution over time of the spatial distribution of land use, population density, height of buildings ...

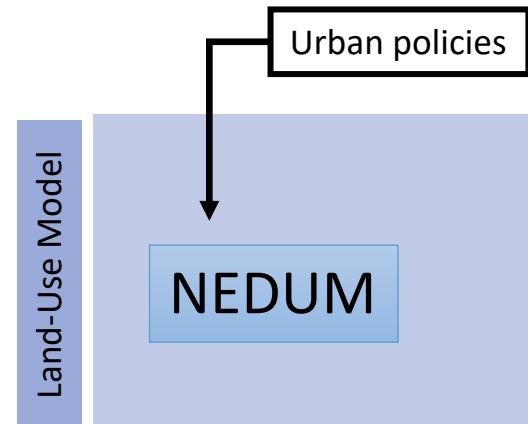
[Viquié, V. et Al 2014.](#)



**NEDUM simulated urban area extension.**

## NEDUM : Land-Use model

- how the inhabitants choose to locate in a city ?
- how policies can influence their choice ?
- what are the socio-economic effects associated to these policies ?



# NEDUM - Methodology



## NEDUM

Locate households of a zone in terms

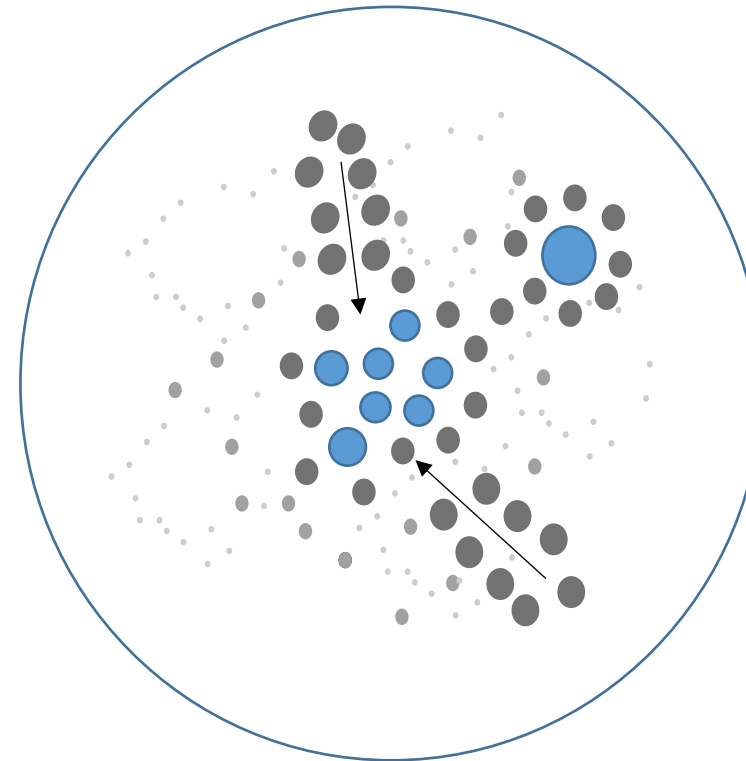
- ❑ based on budgetary constraint of households (cost of transport, housing, and size of dwellings)
- ❑ Real estate development depend on the demand
- ❑ development of transport infrastructure favor the spreading out of the city



Minimize transport and rent cost



Maximize its profit



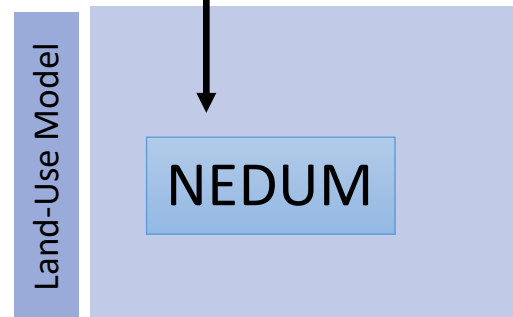
Job center

Household

Transport infrastructure



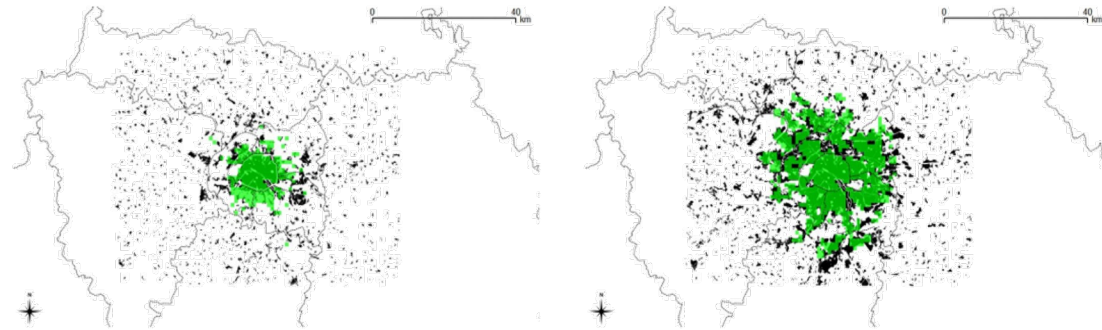
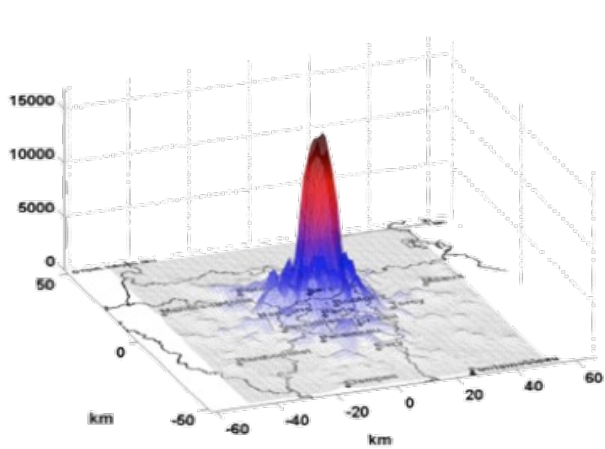
Urban policies



# NEDUM - Validation

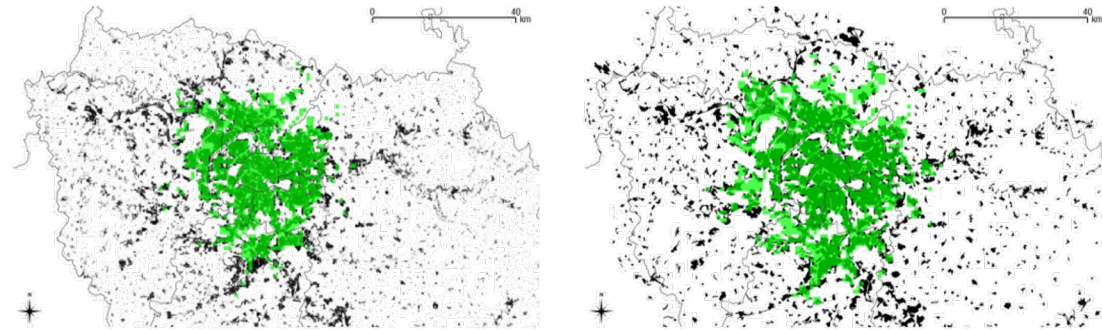
## NEDUM

- ☐ Calibrated on the greater Paris



(a) 1900

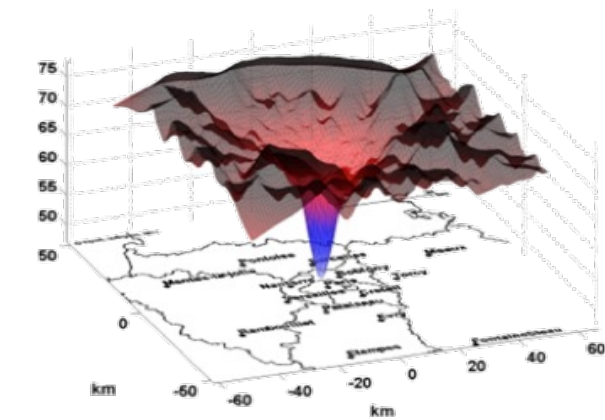
(b) 1960



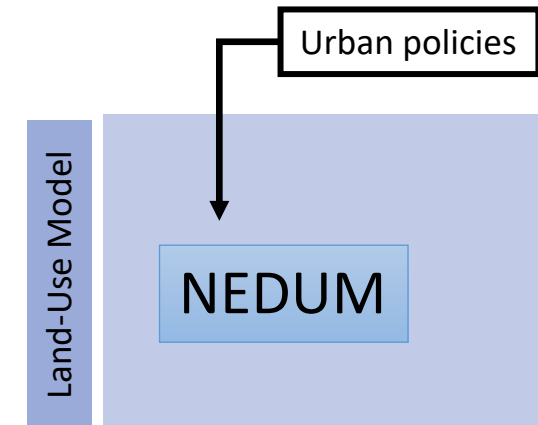
(c) 1982

(d) 2008

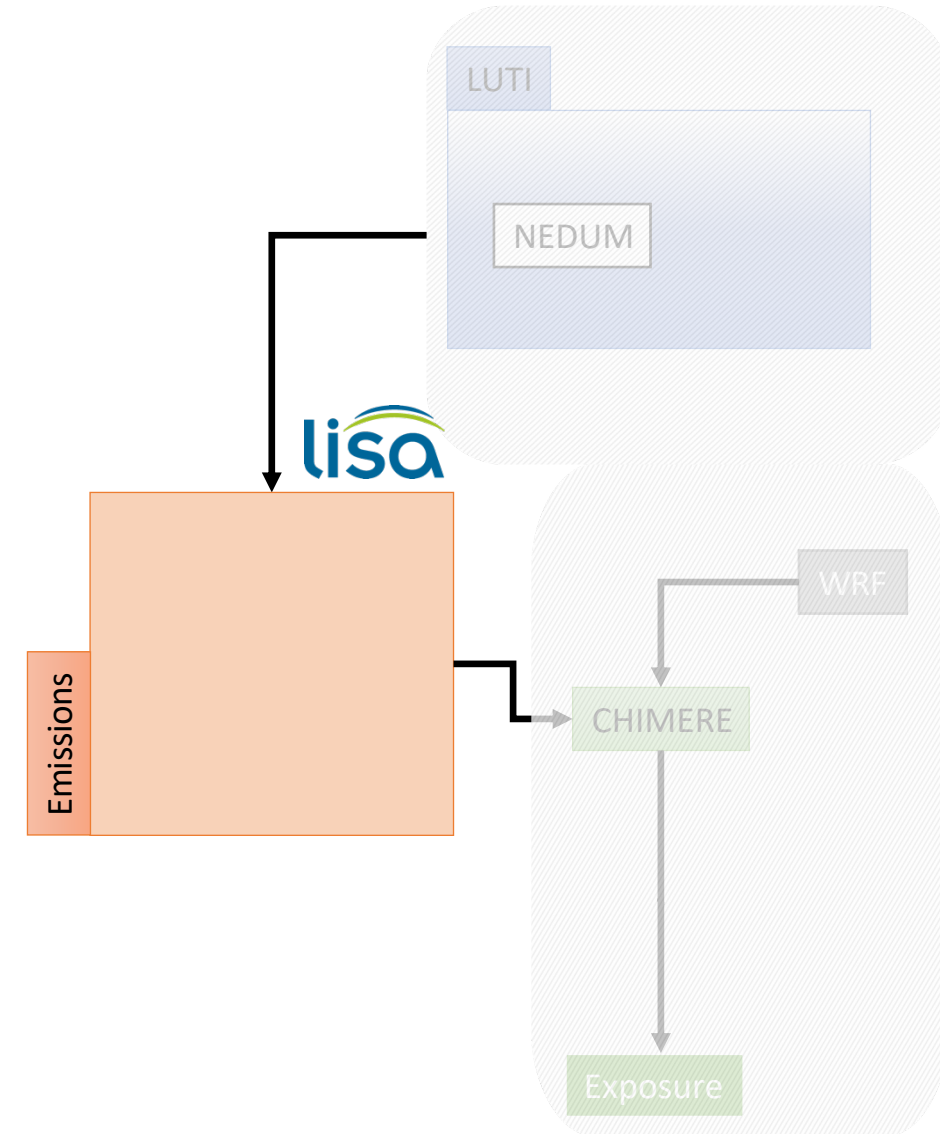
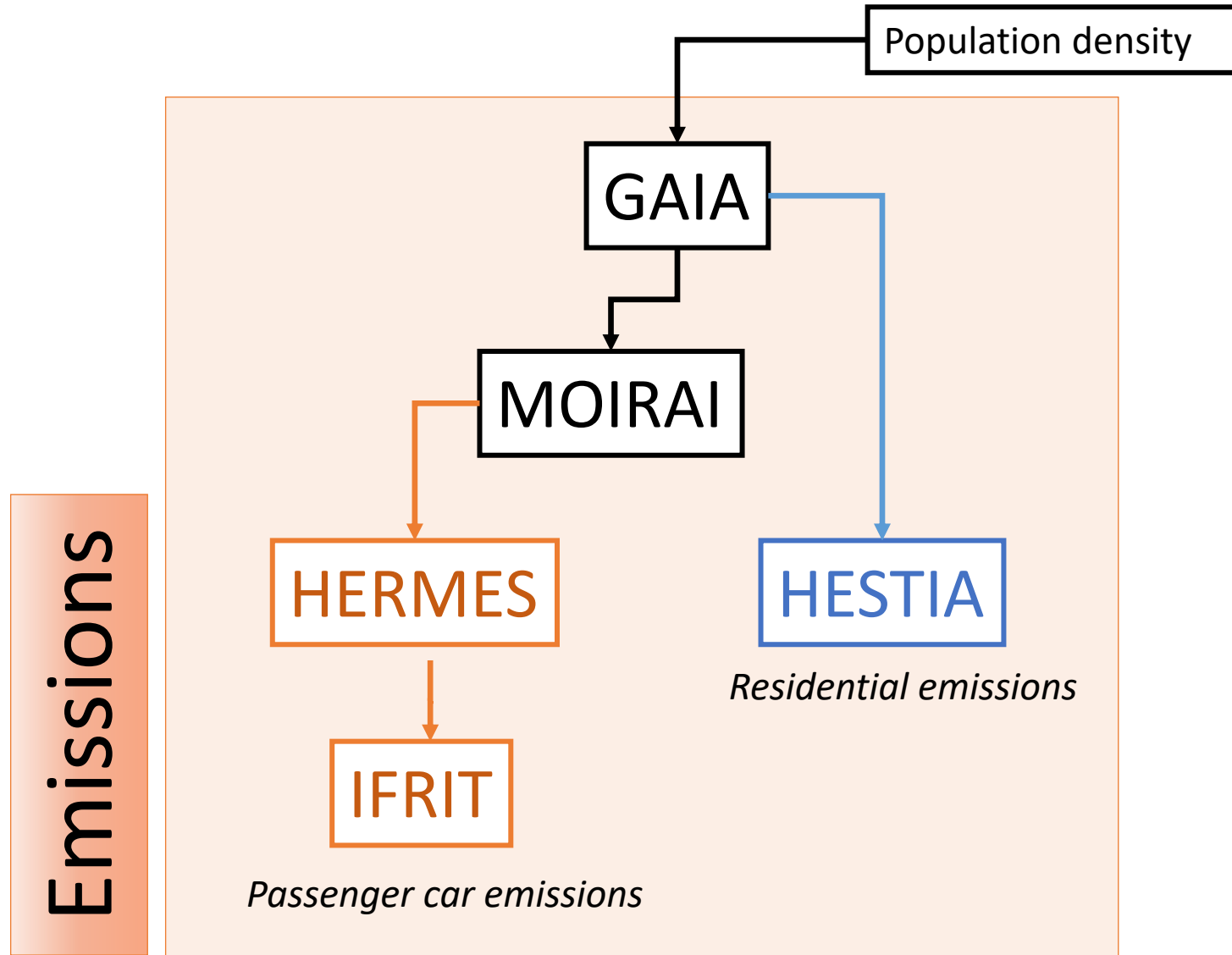
**Figure : Simulated urbanized area compared to actual urbanized area.**  
Actual urban area appears in black (Source : Corinne Land Cover and IAU), whereas model simulation appears in transparent green.



Number and size of houses



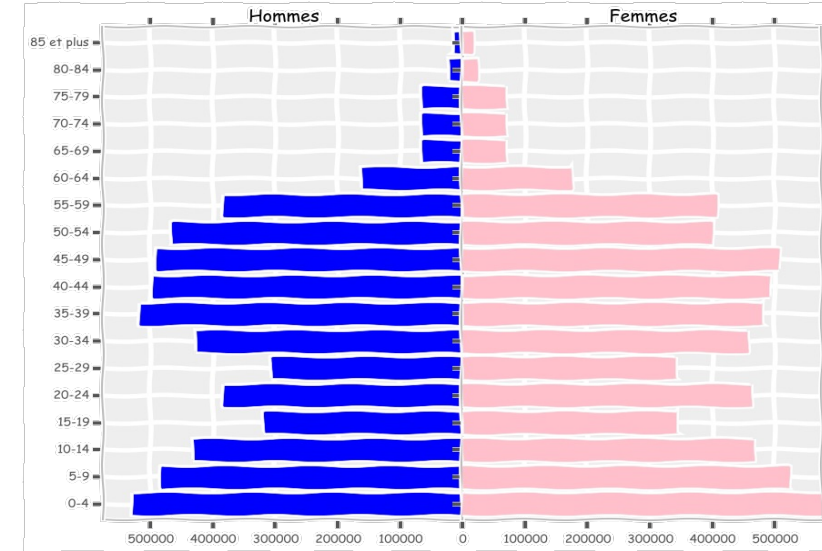
# The modeling chain : emission modeling chain



# The modeling chain : GAIA

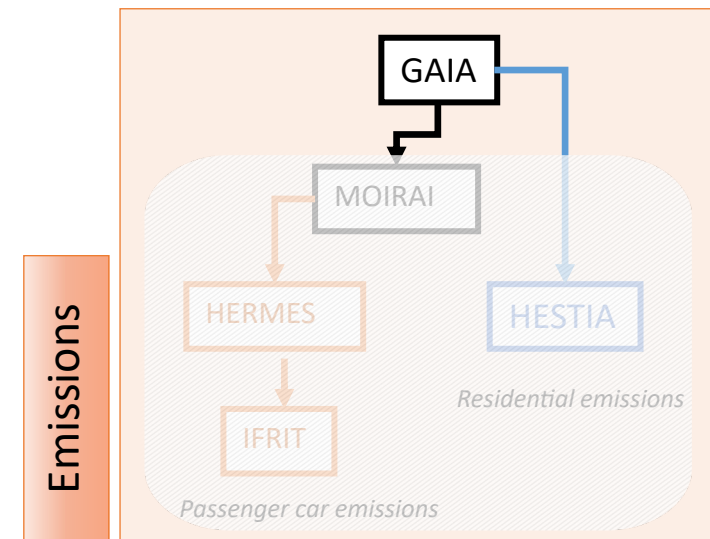
## GAIA (GenerAtion of synthetic populAtion)

- Generate a synthetic population based on population density (at district level)
- Provides several data (age, sex, job, driving licence, car...)



Greater Paris population pyramid (GAIA)

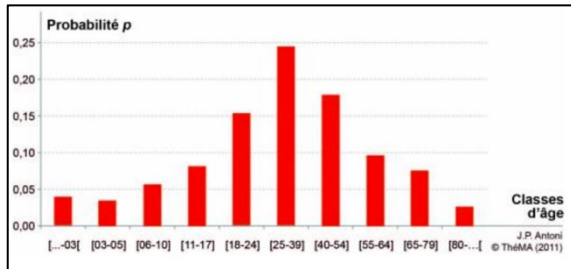
	Agent_1	Agent_22	Agent_32	Agent_45	Agent_98
Age	40	25	30	67	2
Sex	M	M	F	M	F
Activity	unemployed	School	employed	Retired	None
Driving licence	NO	YES	YES	YES	NO
Car	0	0	1	1	0



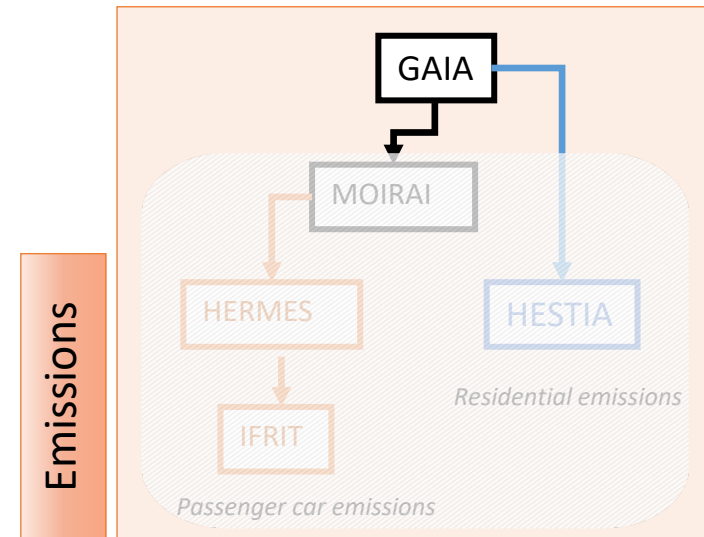
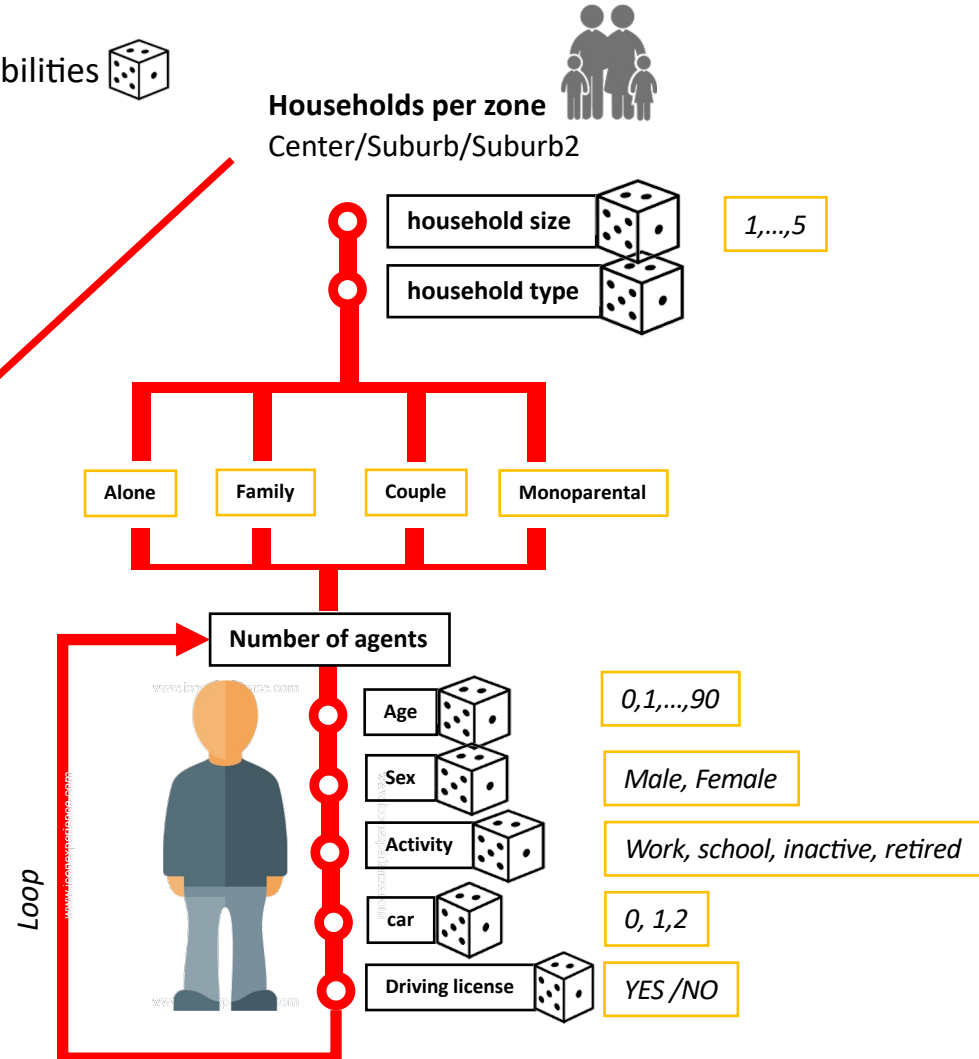
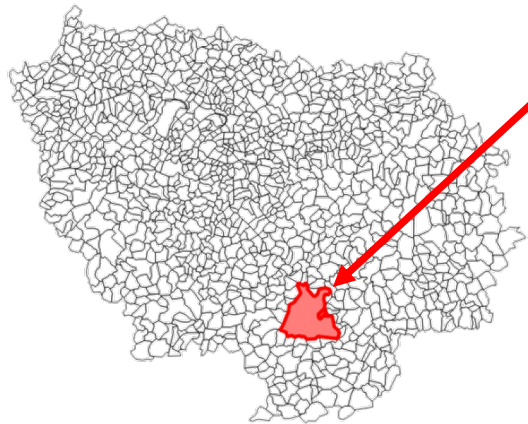
# GAIA - Methodology

## GAIA (GenerAtion of synthetic populAtion)

- ☐ Identification of discrete conditional probabilities (data Census)
- ☐ Random distribution law based on these probabilities
- ☐ Agent generation



Distribution of population by age group

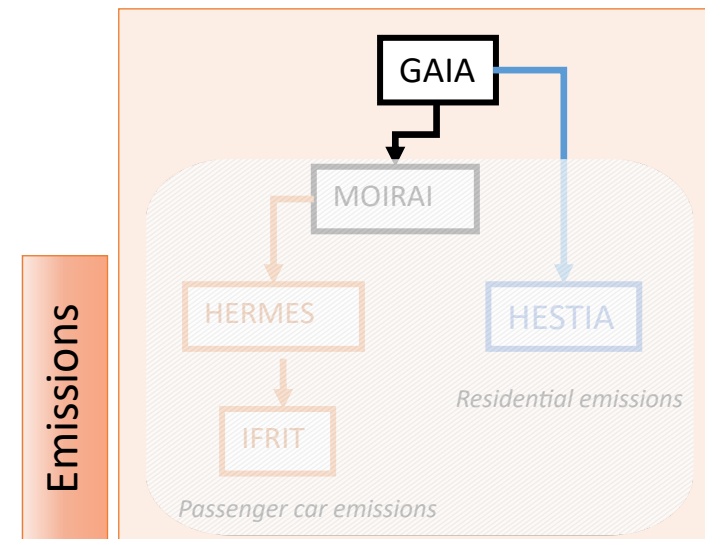
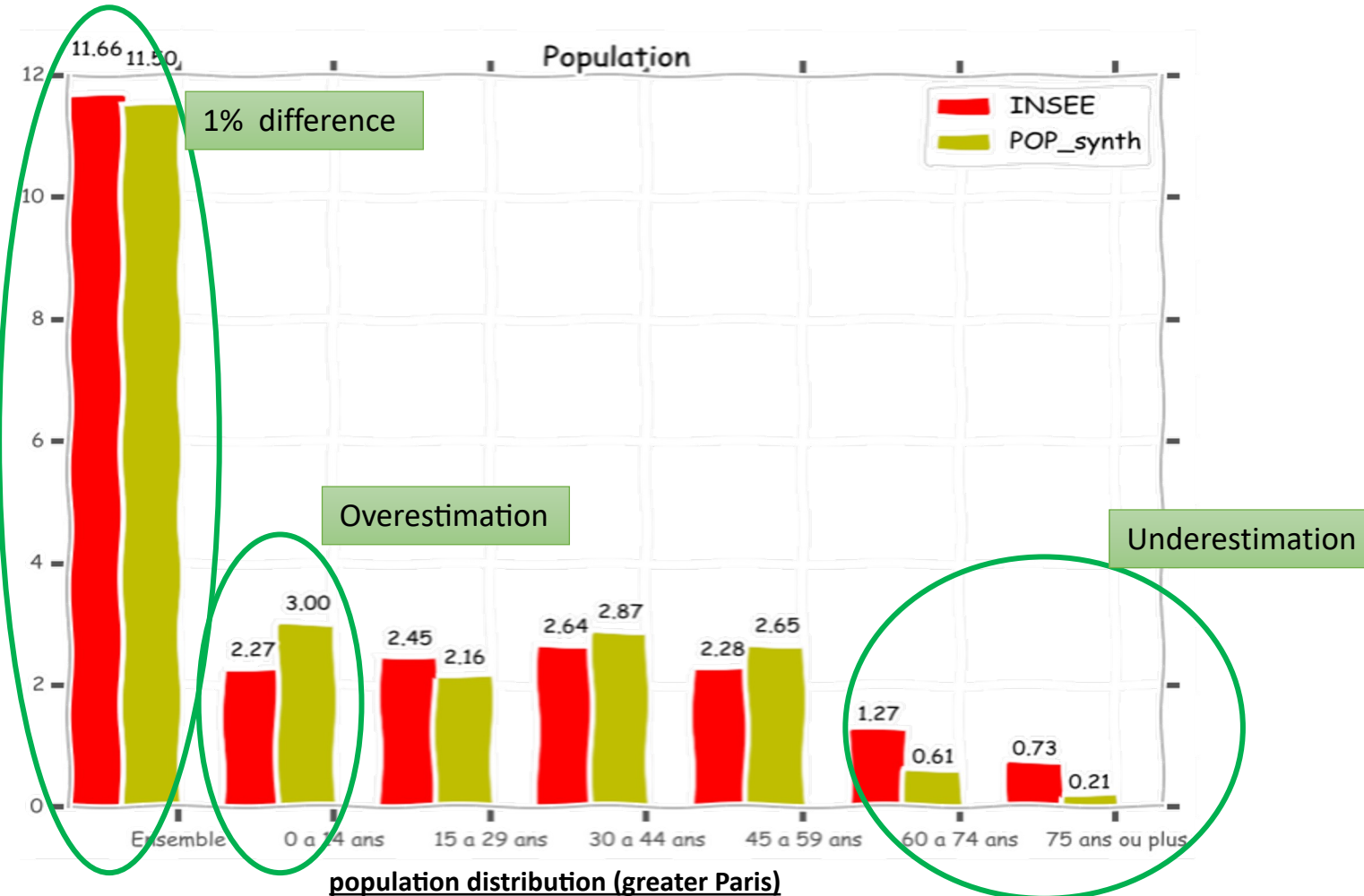




# GAIA - Validation

## GAIA

- Calibrated on the greater Paris
- Good estimation

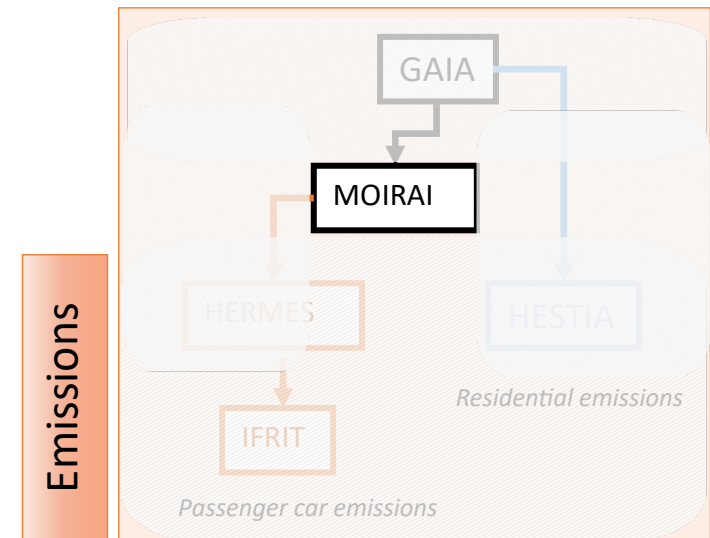
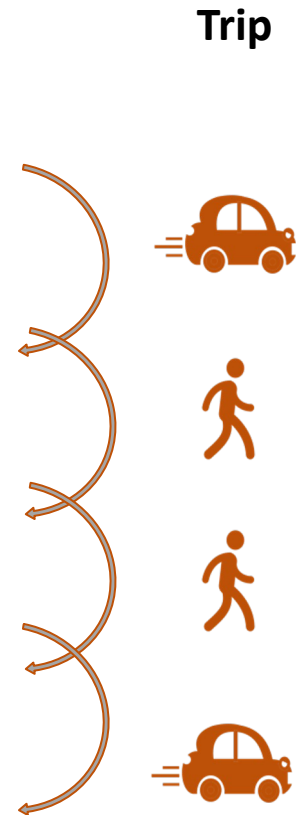


# The modelling chain : Moirai

MOIRAI (MOdelling with high Resolution individual populAtion timetable)



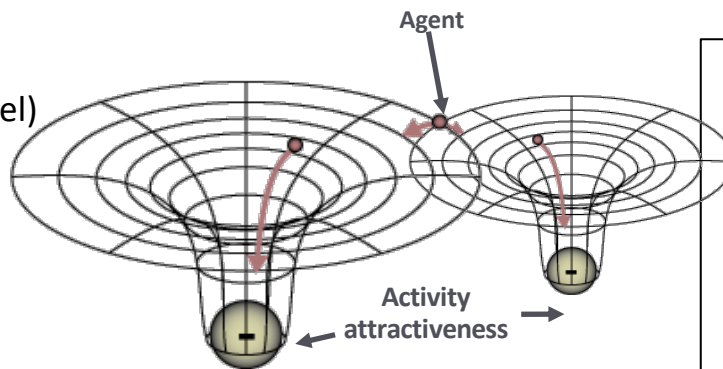
- Generation of agent timetable
- Modal split
- Activity duration



# MOIRAI - Methodology

## MOIRAI

- Generation of districts attractiveness (Gravity model)
- For each agent
  - Timetable (Number of daily trips, priorities)
  - Location of activities(attractiveness)
  - Modal split (Car, driving license)



### Calculation of the attractiveness of jobs center per zone

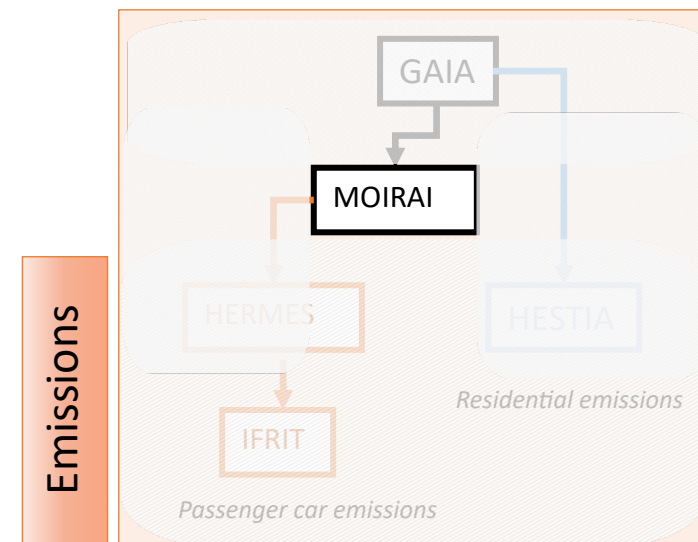
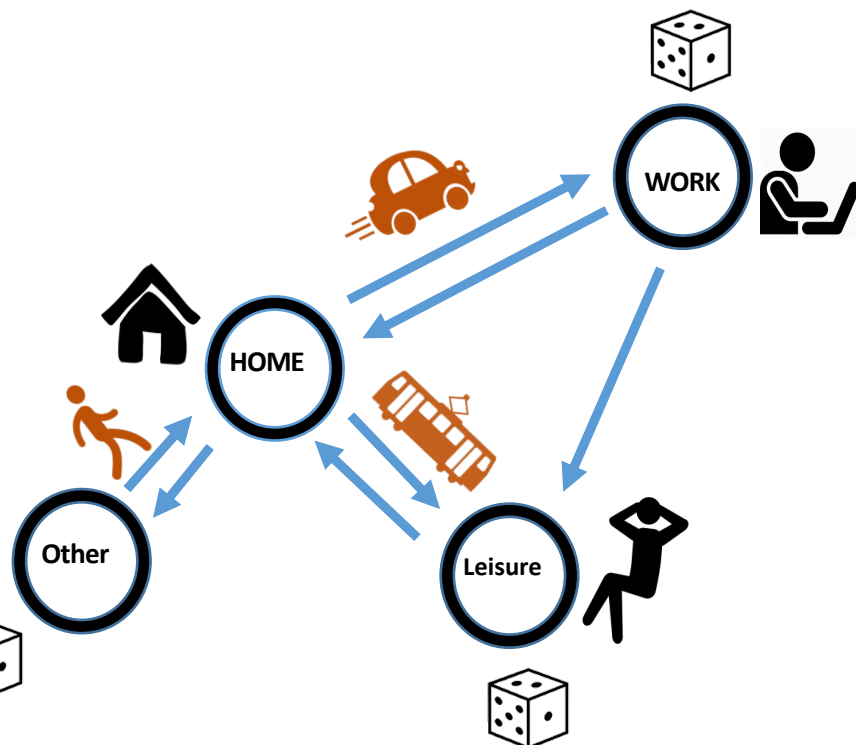
$$Probability_{Attractivity}(i, j, distance) = K \times Attractivity$$

$$Attractivity(i, j, distance) = Employ_i \times Employ_j \times \frac{1}{\sigma\sqrt{2\pi}} e^{-\frac{1}{2} \left( \frac{x - distance_{moyenne}}{\sigma} \right)^2}$$

$$\sigma = \frac{distance_{moyenne}}{2}$$

$$K = \frac{Attractivity(ij)}{\sum_{j=zone_0}^{j=zone_n} Attractivity(i, j)}$$

The attractivities of the activities vary according to the average distance calibrated using the EGT (French Census)

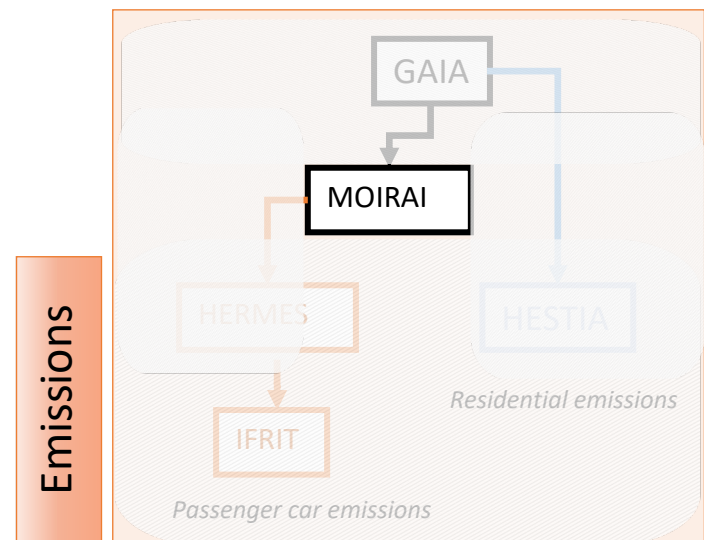
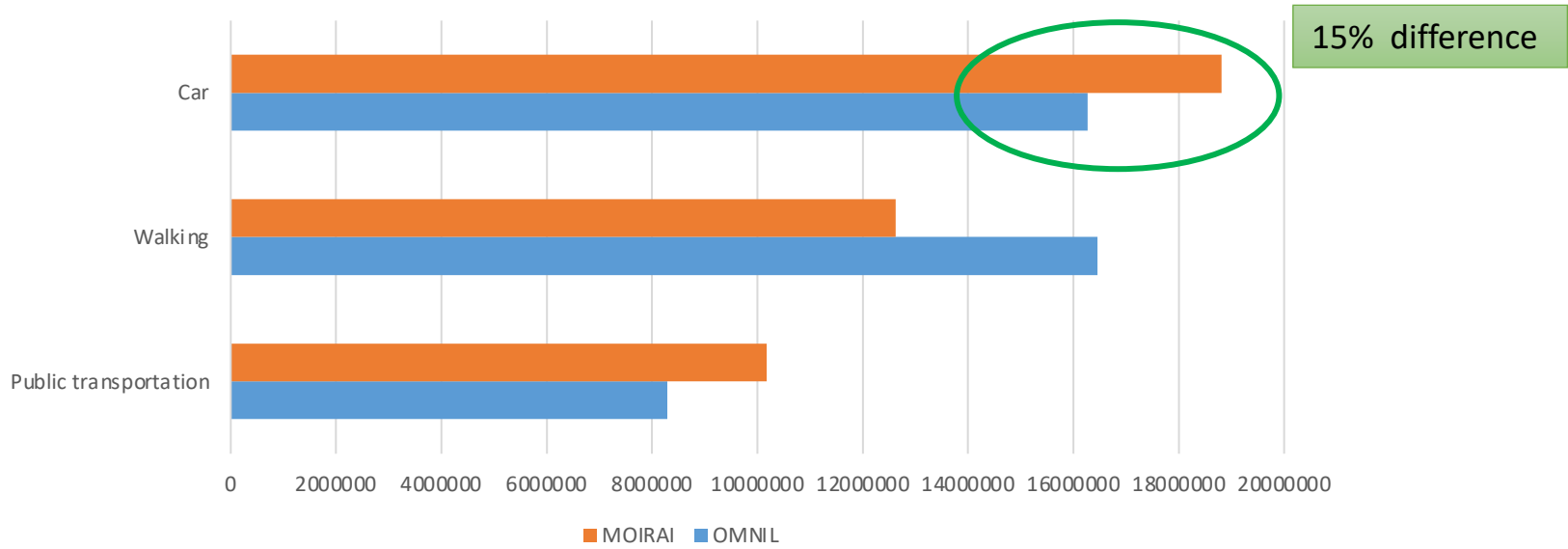


# MOIRAI - Validation



## MOIRAI

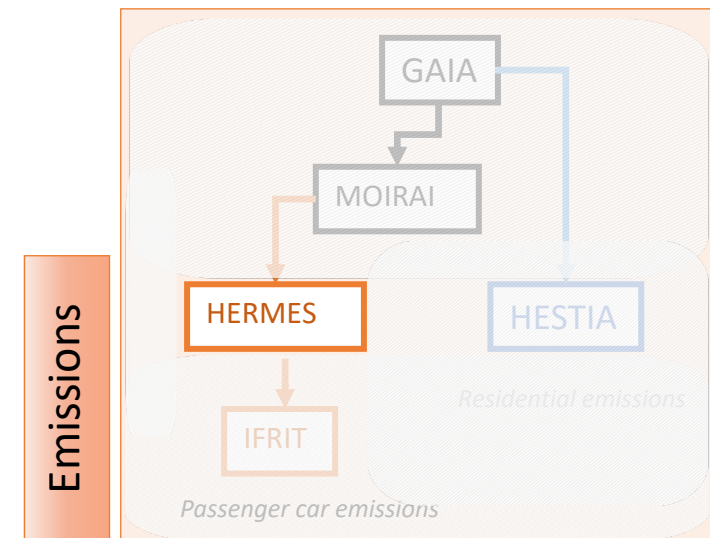
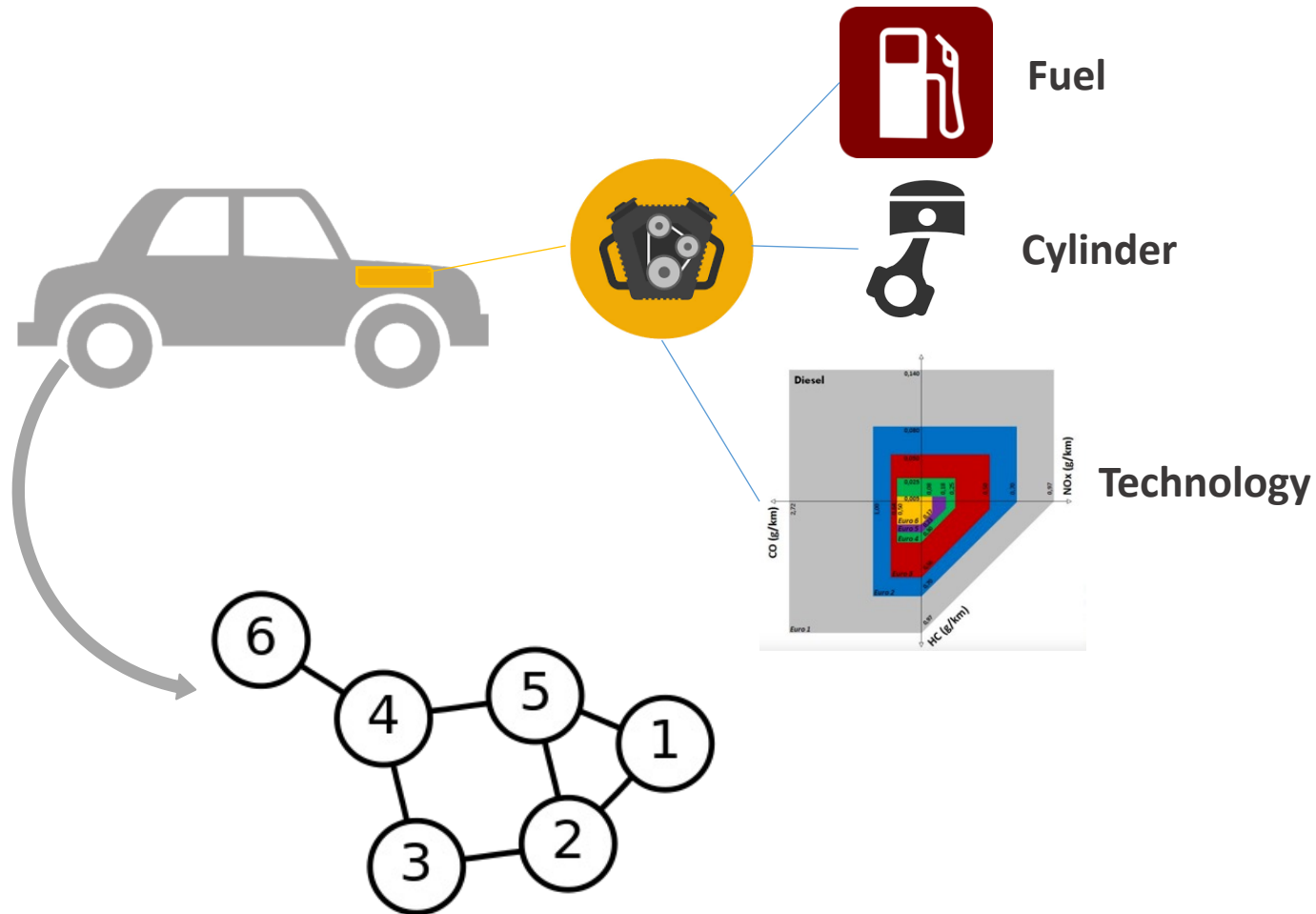
- Calibrated on the greater Paris
- Modal split (work in progress...)



# The modeling chain : HERMES

## HERMES : Spatial modeling of individualized travel path

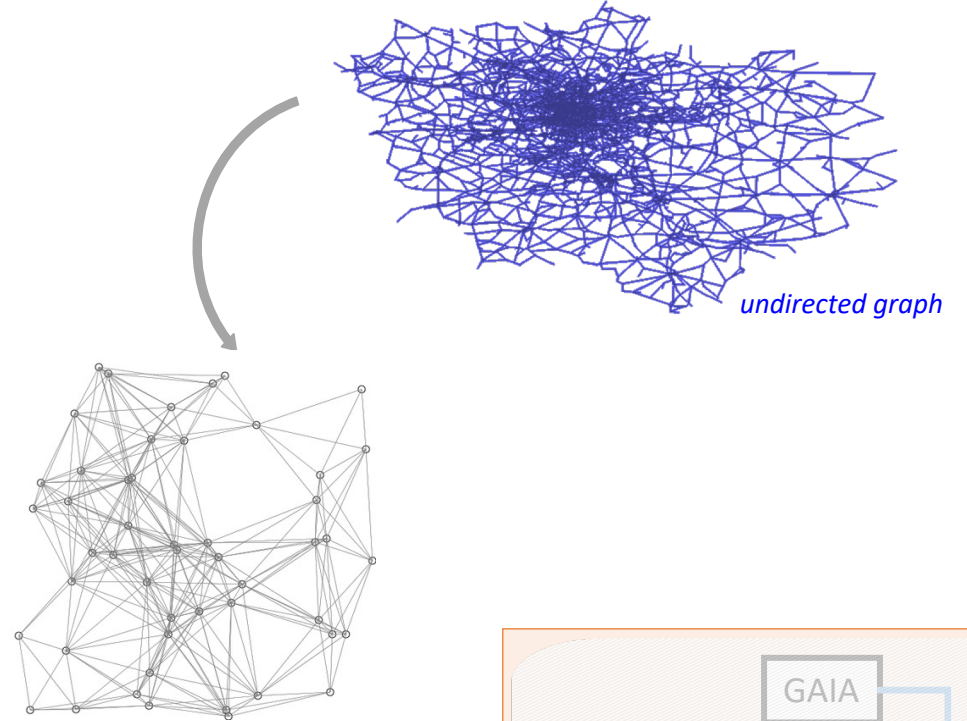
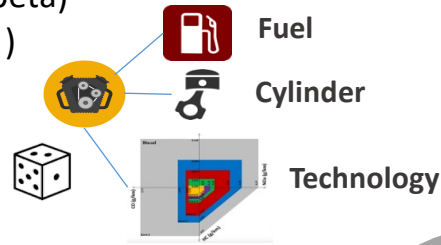
- ❑ Generation of car fleet
- ❑ Generation of the path (Dijkstra algorithm of shortest path – Graph theory)



# HERMES - Methodology

## HERMES

- ❑ Generate the road graph (free speed)
- ❑ For each agent
  - Locate agent origin and destination trips closest nodes
  - Get the path (Dijkstra)
  - Calculate the **cold start engine section** (beta)
  - Generate car profile (M. Carteret (2014) )



$$\beta = 0.6474 - 0.02545 \times l_{trip} - (0.00974 - 0.000385 \times l_{trip}) \times t_a$$

Dijkstra shortest path algorithm  
Based on the euclidean distances and weighted of the time spent on the section

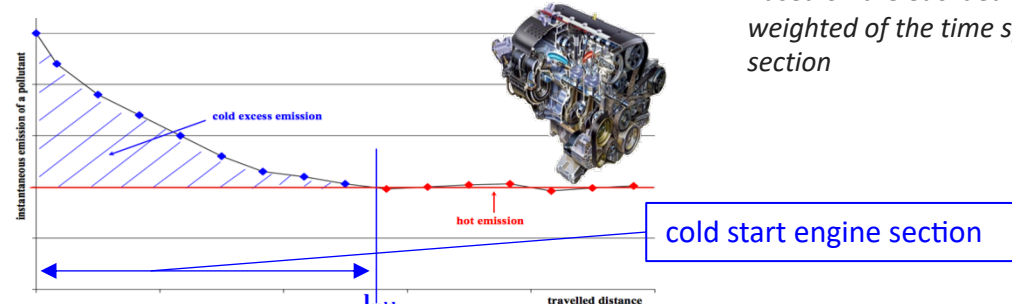
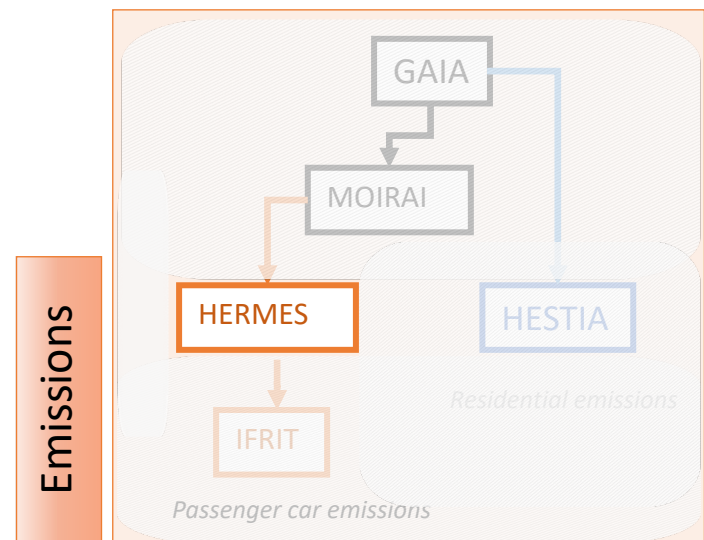


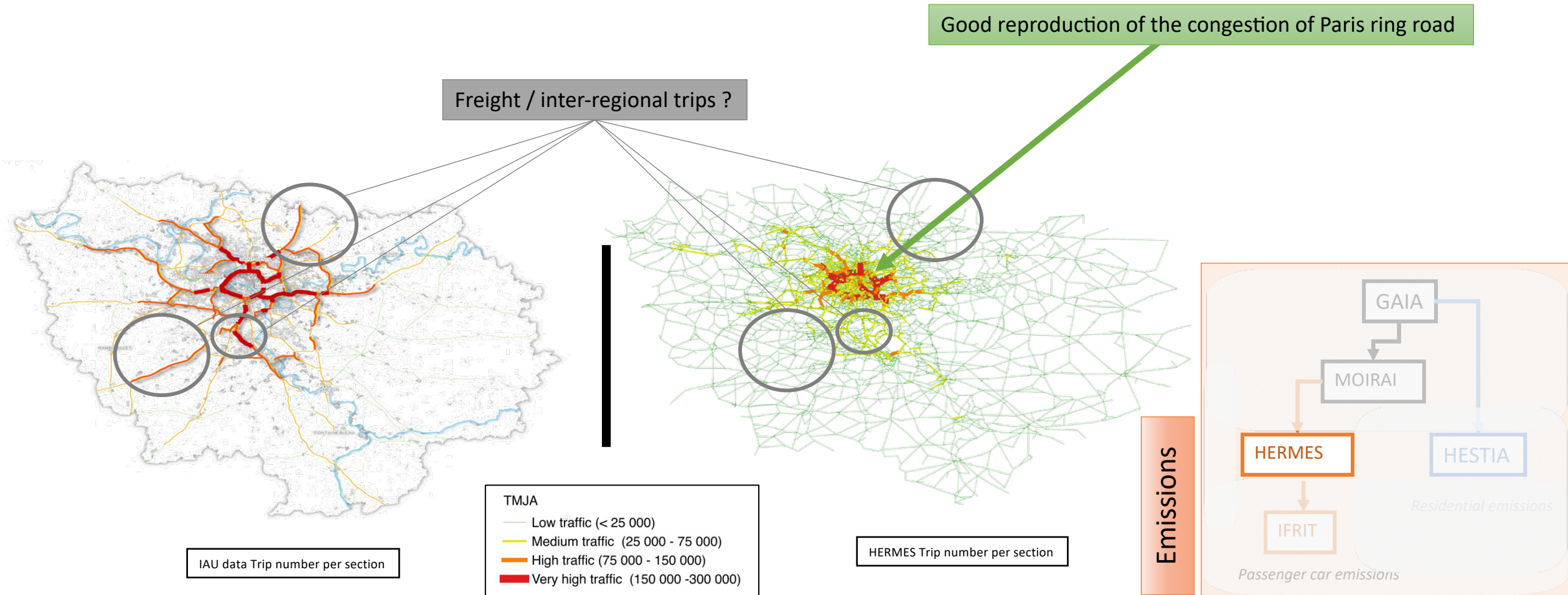
Figure 2: Evolution of the instantaneous emission of a vehicle according to travelled distance in given running conditions.



# HERMES - Validation

## HERMES

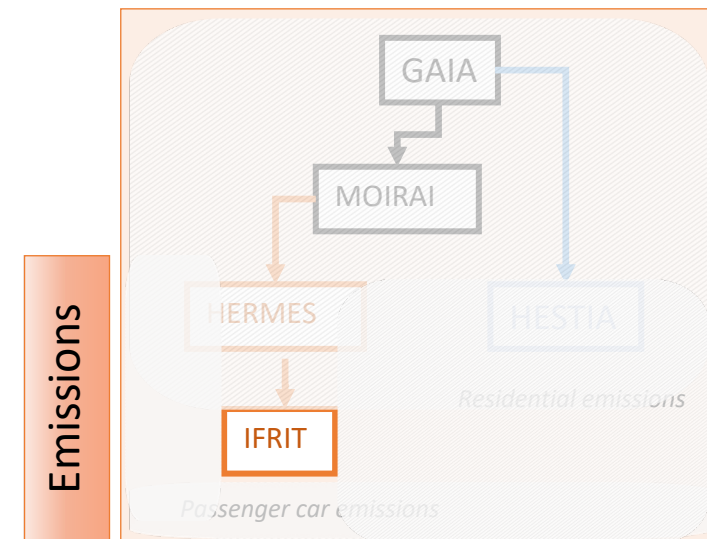
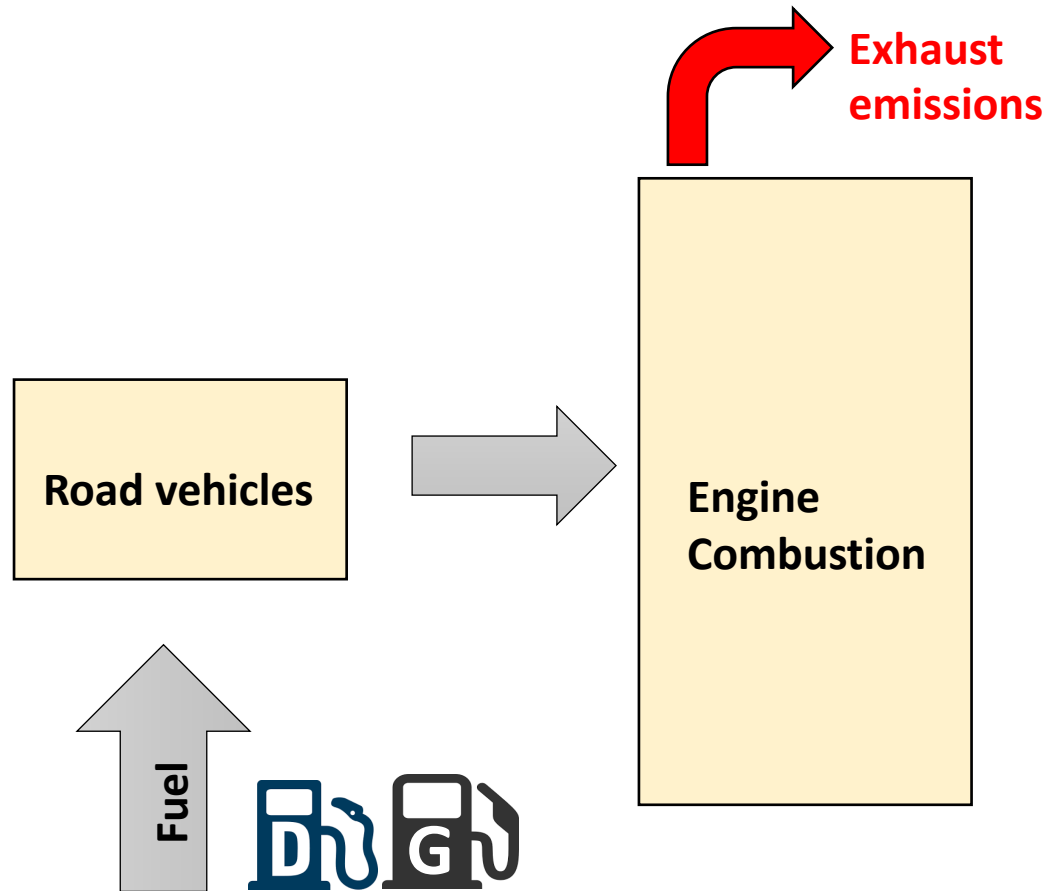
- Calibrated on the greater Paris
- Validation in progress



# The modeling chain : IFRIT

IFRIT : Spatial modeling of individualized travel emissions

- ❑ Modelling the **the exhaust emissions** for passenger car





# IFRIT - Methodology



## IFRIT : Spatial modeling of individualized travel emissions

- Calculate hot and cold start emissions NO<sub>x</sub>, NMVOC, CO, PM for every trip (COPERT methodology)



**Fuel variable**  
Consumption

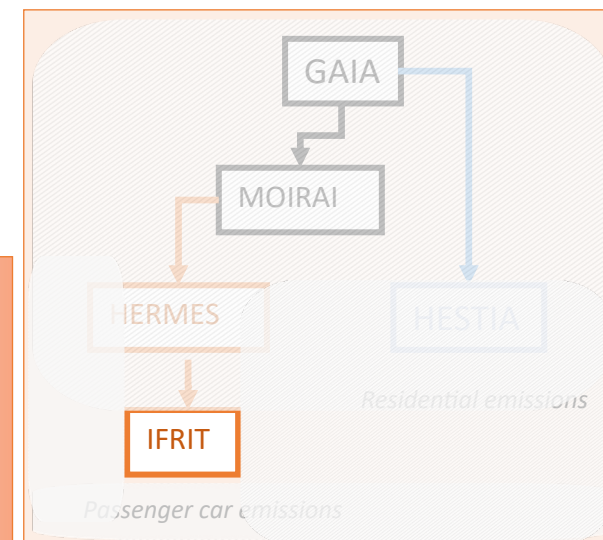
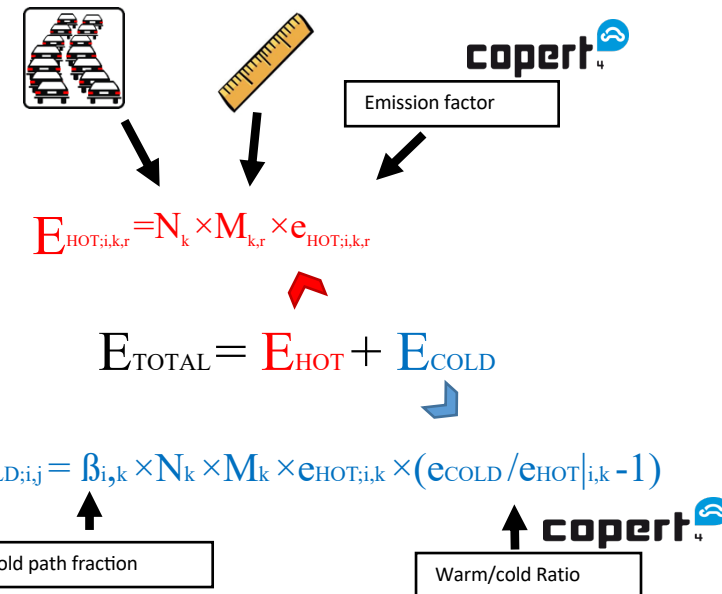
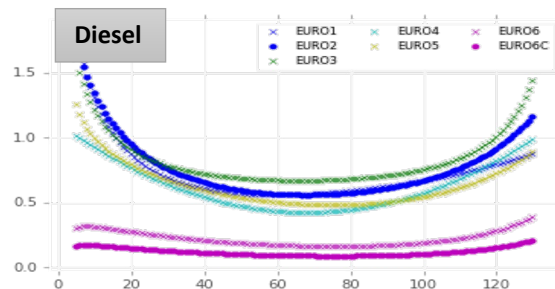
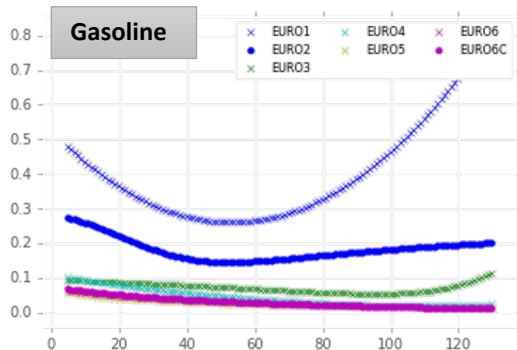
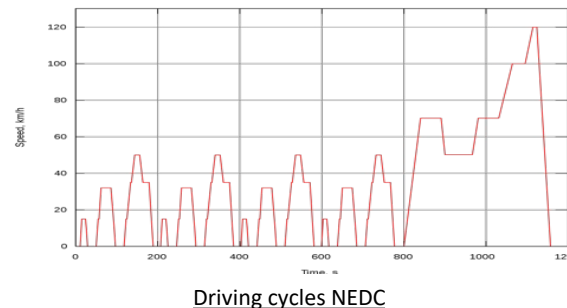
**Activity data**  
Mileage per vehicle class

**Driving conditions**  
Average speed per vehicle type and per road

**Other variable**  
Climatic condition  
Mean trip distance

**Emissions factors**  
Per type of emission (hot, cold)

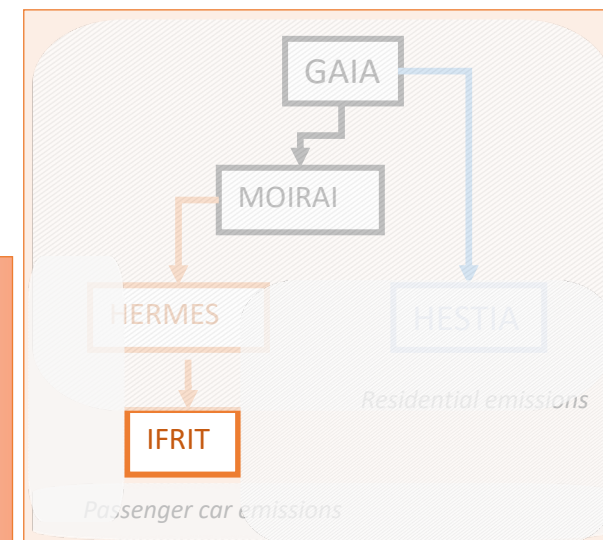
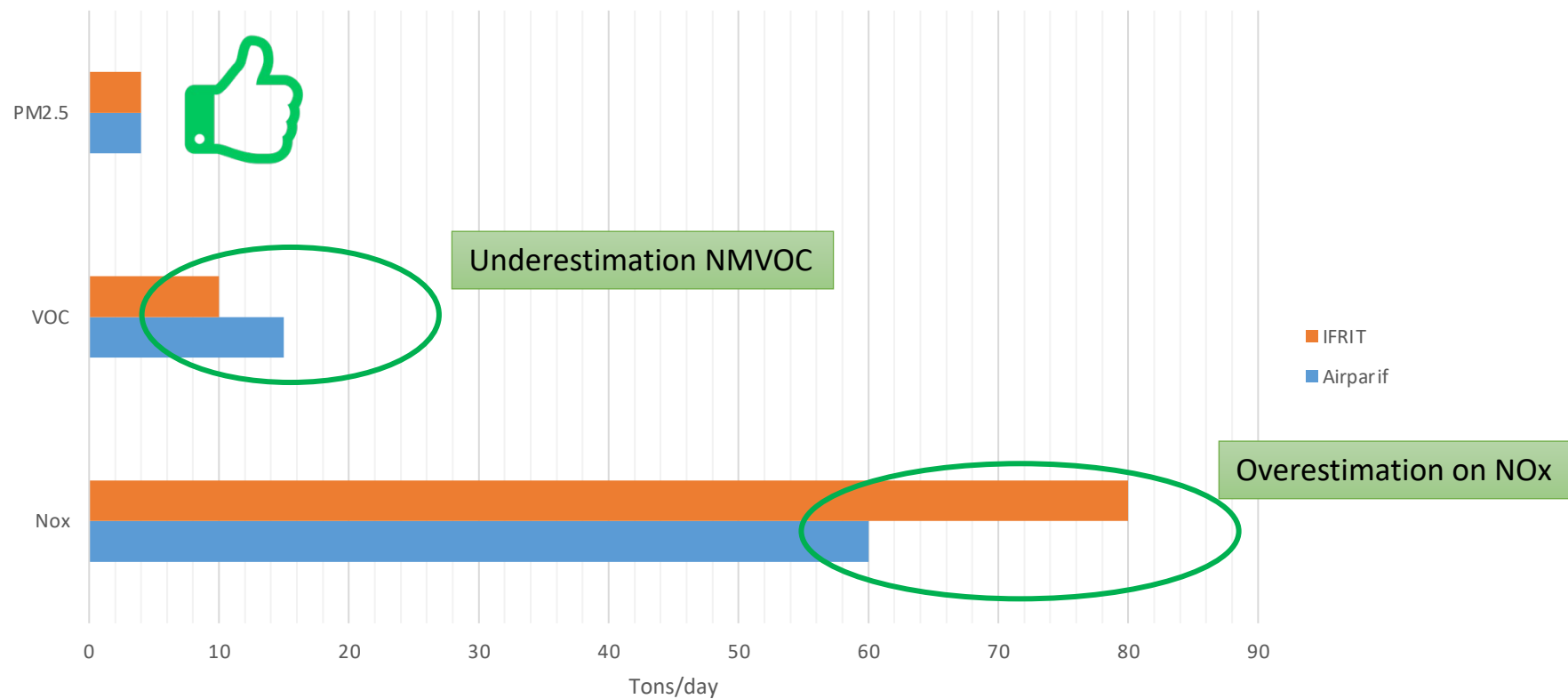
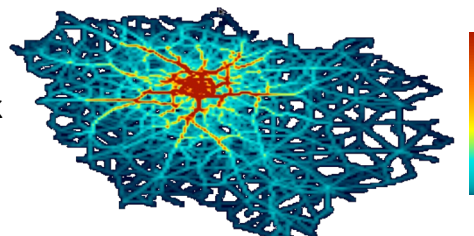
Emissions for all pollutant for all Corinair road traffic source categories



# IFRIT - Validation

## IFRIT

- Comparison with french Air quality monitoring network
- in progress...



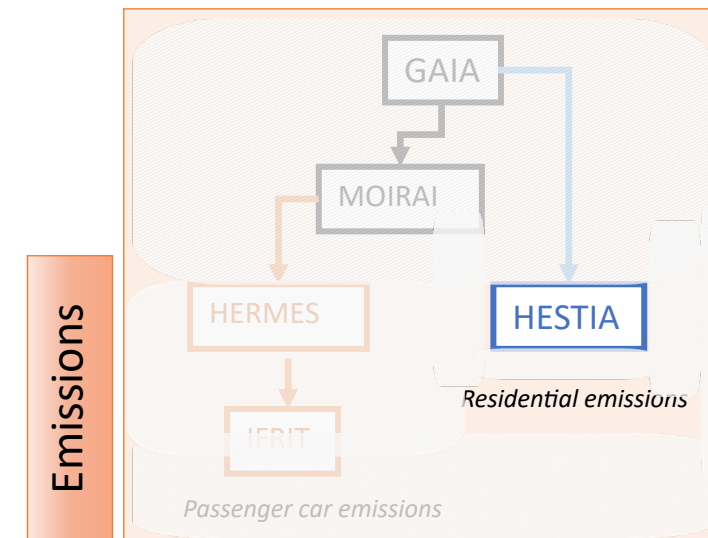
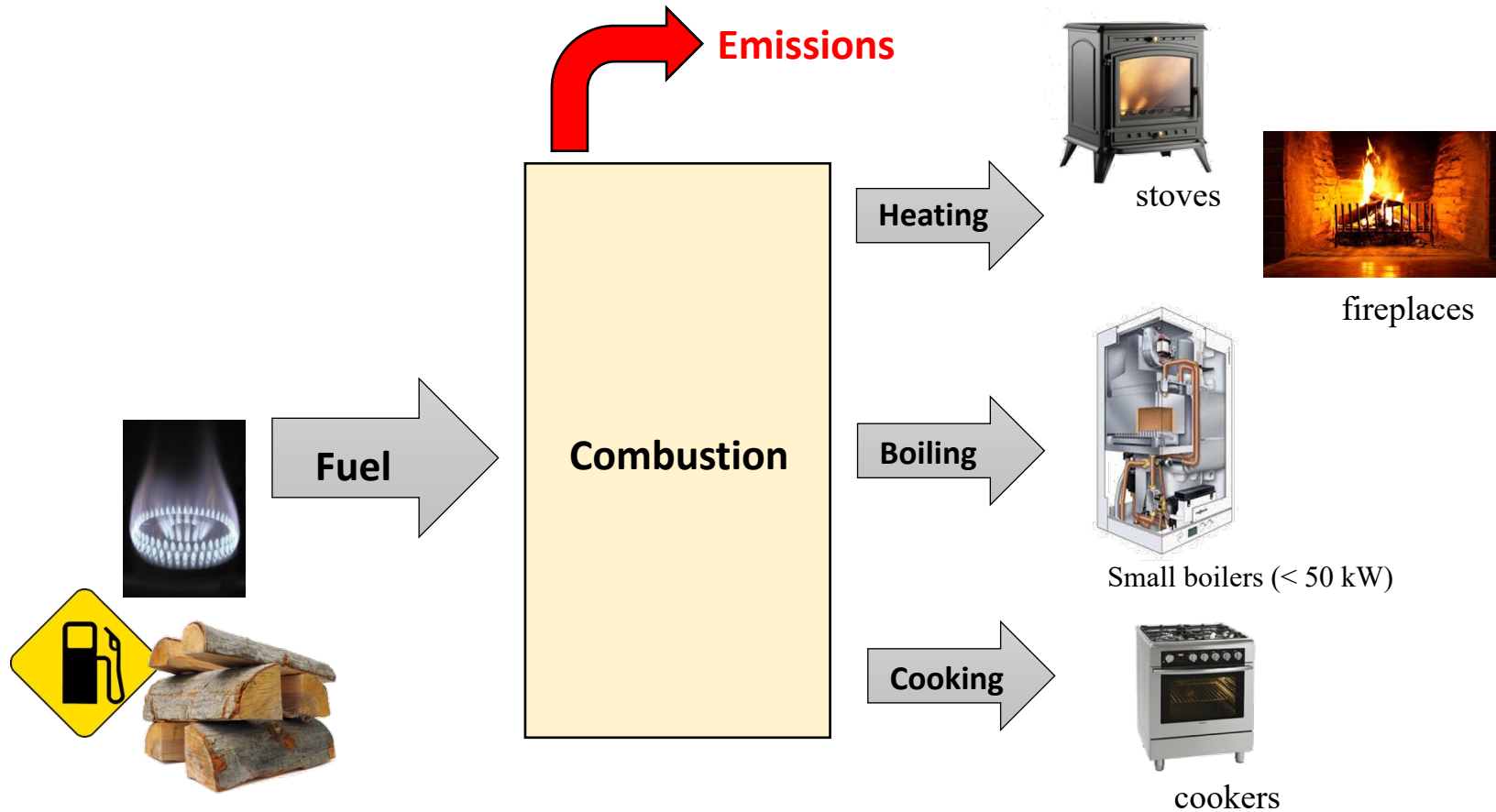
Emissions

# The modeling chain : HESTIA

HESTIA : Spatial modeling of small combustion emissions



- Modelling the **small combustion** installations for every household in residential sector
  - heating
  - provision of hot water

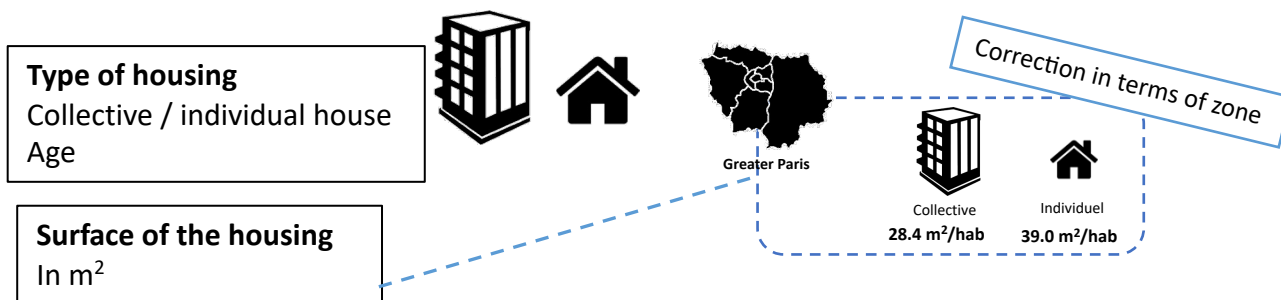


# HESTIA - Methodology

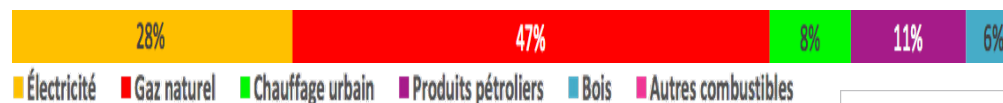
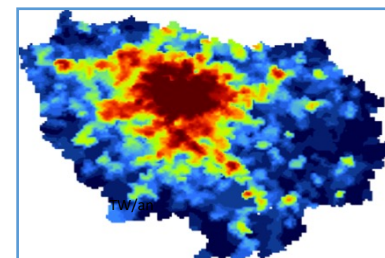
## HESTIA

Modelling the **small combustion** installations for every household in residential sector

- Generation of the energy demand
- Climatic correction
- Small combustion emission factor



Based on consommations unitaires des résidences principales par usage à climat normal en kWh/m2  
**186 kWh/m2 (2011)**



**Energy use of housing**  
Annual energy consumption in kWh

**Energy type**  
Electricity, Gas, oil, wood, other

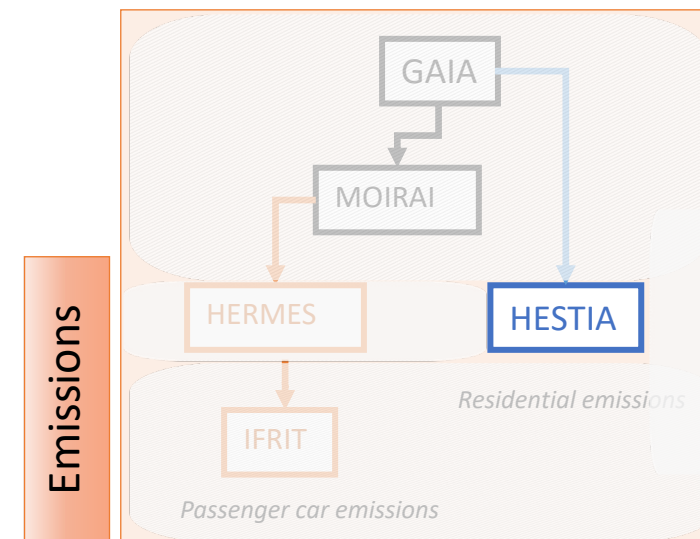
**Climatic correction**  
Based on Degree day

Emissions for all pollutant for all Corinair small combustion source categories

$$E_i = \sum EF_{i,j,k} \cdot A_{j,k}$$

$E_i$  = annual emission of pollutant  $i$ ,  
 $EF_{i,j,k}$  = default emission factor of pollutant  $i$  for source type  $j$  and fuel  $k$   
 $A_{j,k}$  = annual consumption of fuel  $k$  in source type  $j$ .

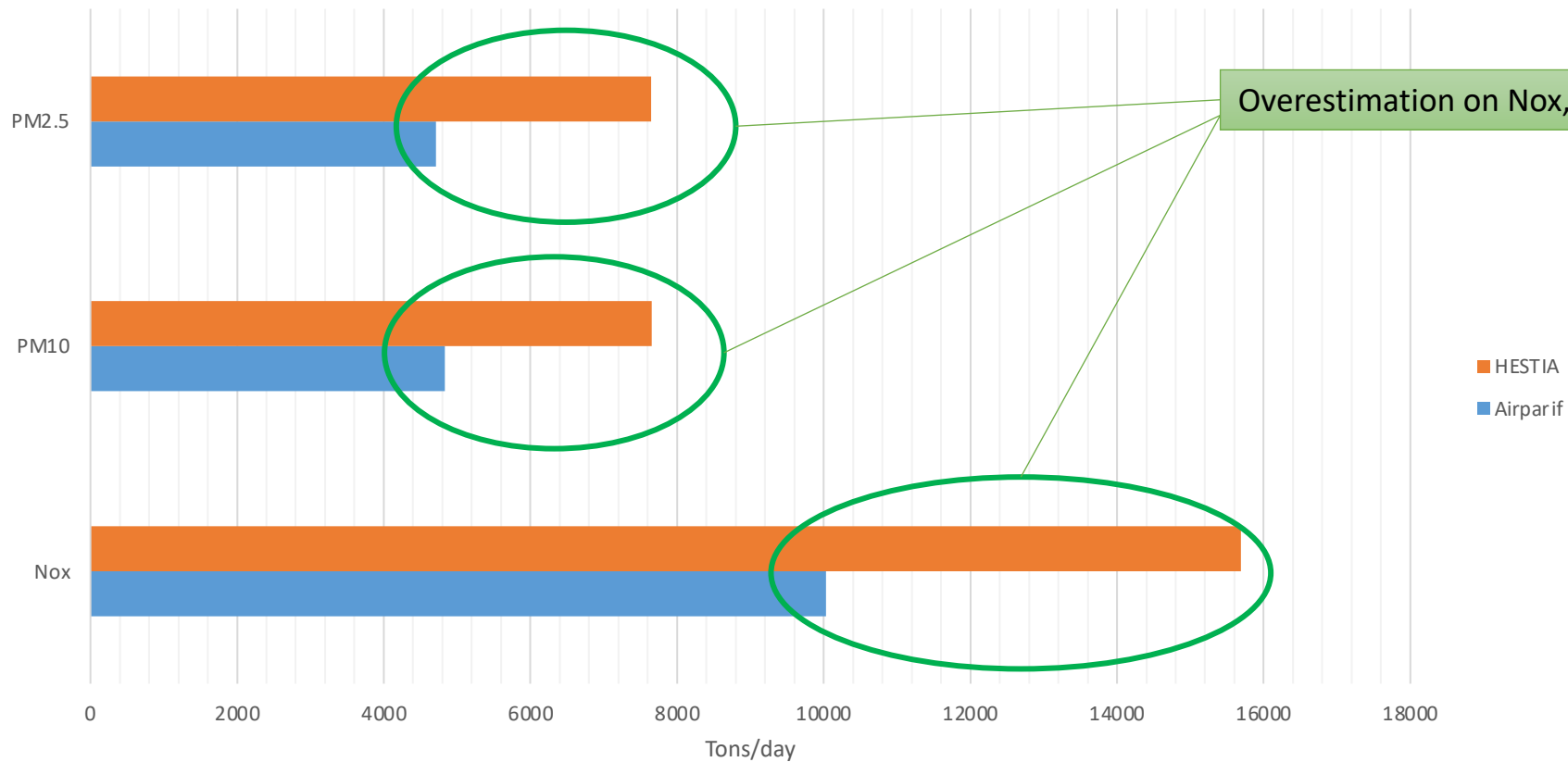
Pfeiffer et al., (2000), Kubica, et al., (2004), CITEPA Small combustion



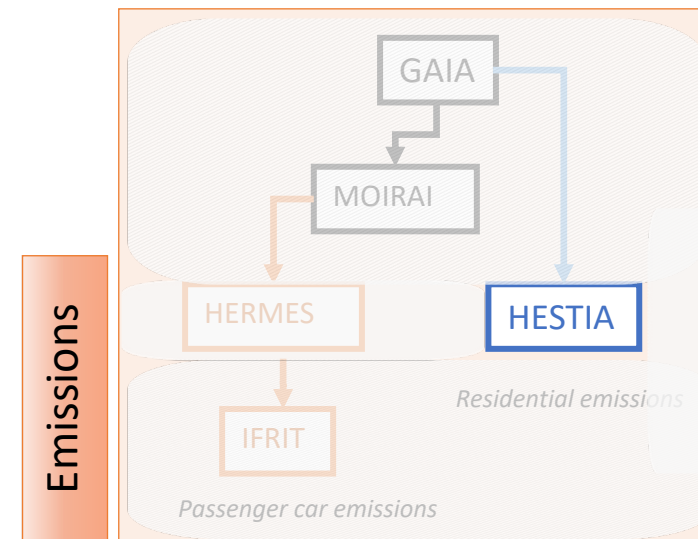
# HESTIA - Validation

## HESTIA

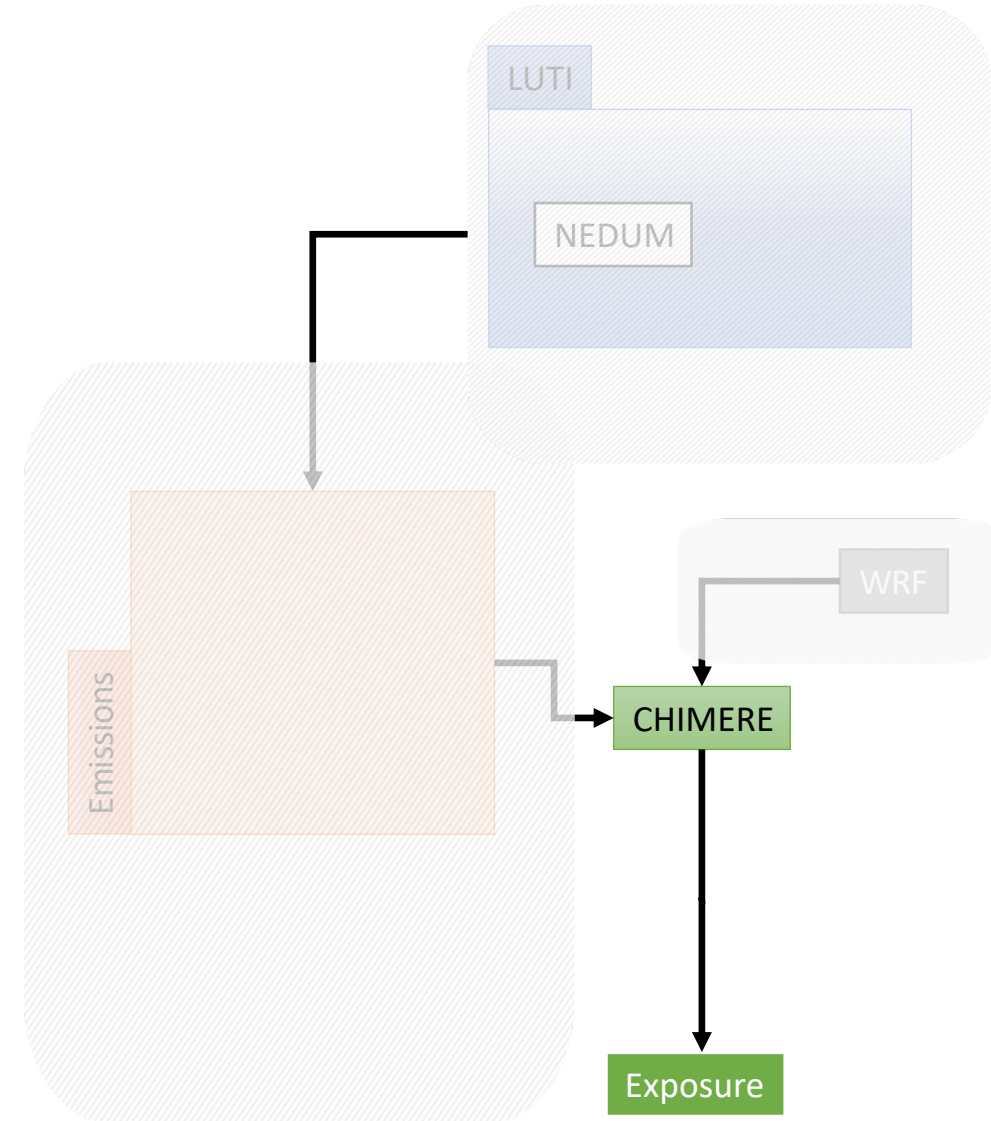
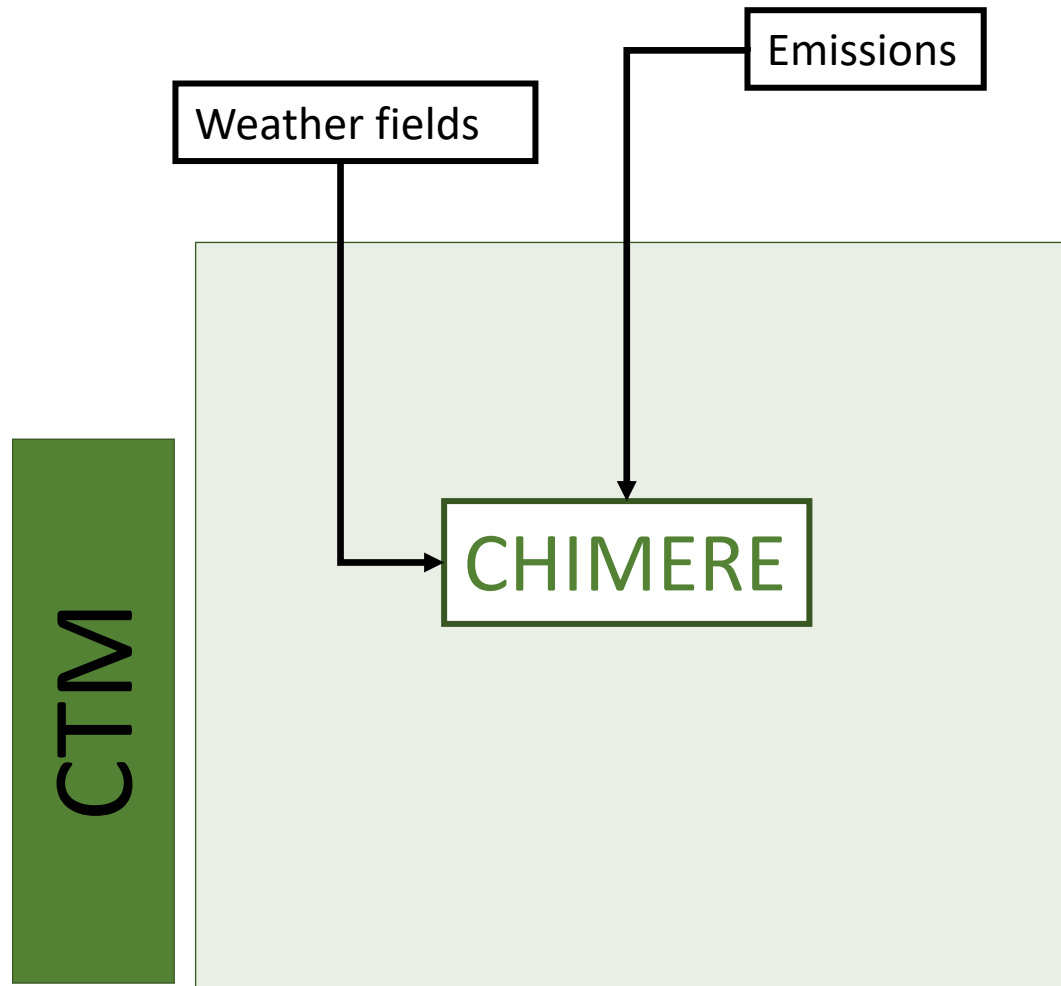
- Validation in progress
- Comparison with french Air quality monitoring network



Heating/ boiling Fleet ?  
Emissions Factor ?



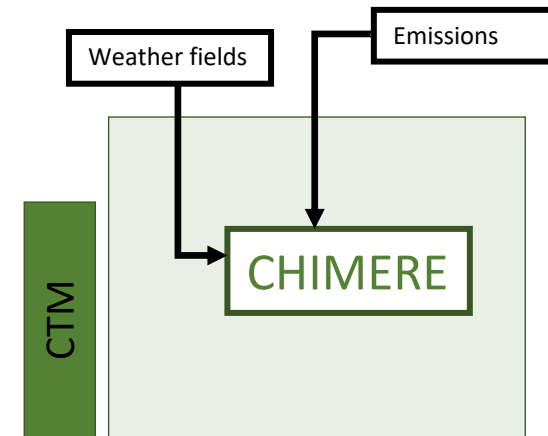
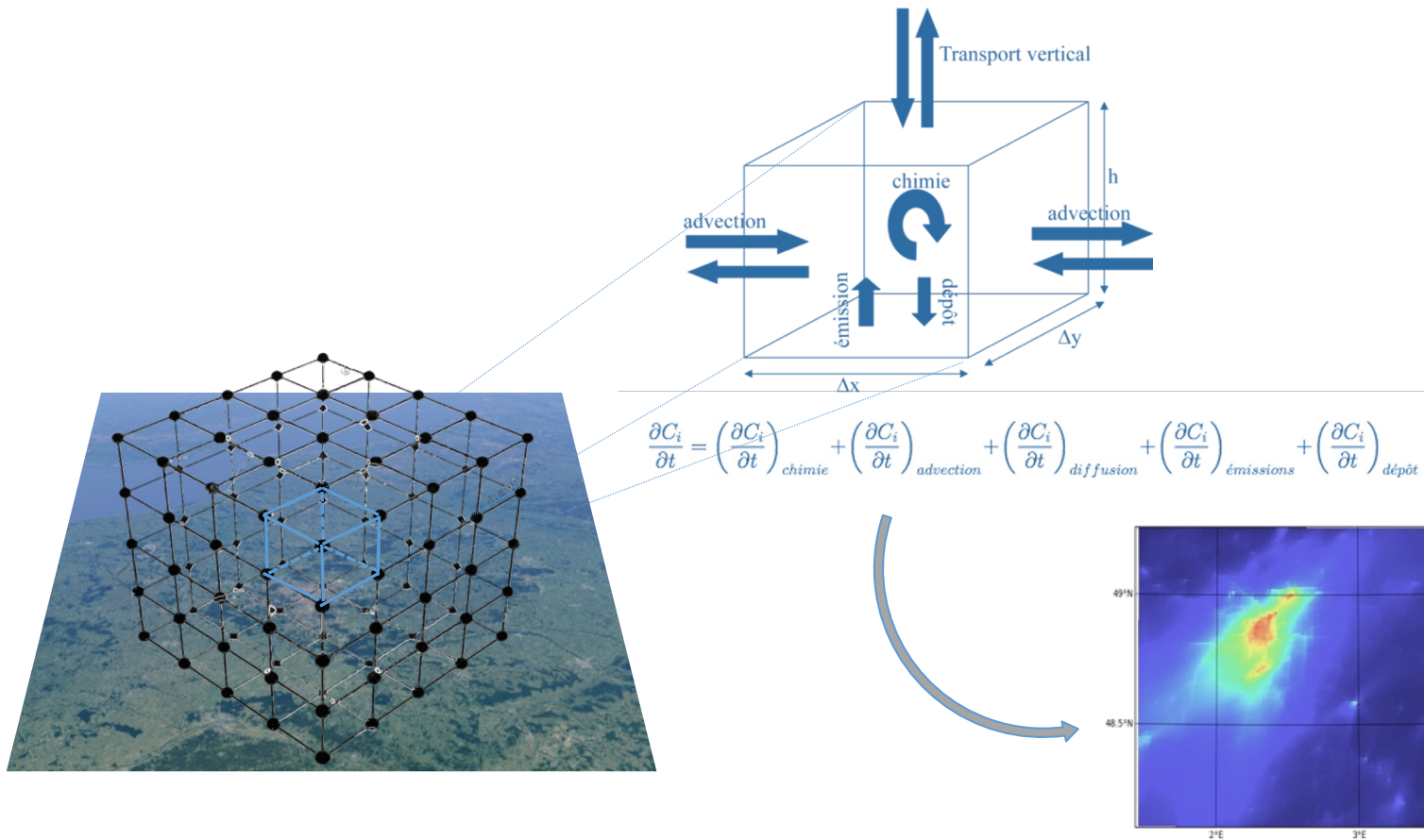
# The modeling chain : Chemistry-transport model



# The modeling chain : CHIMERE

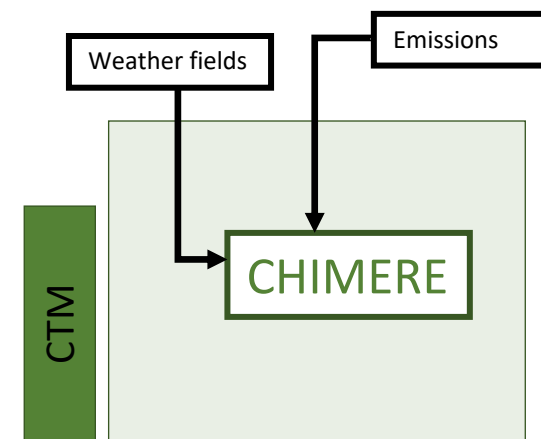
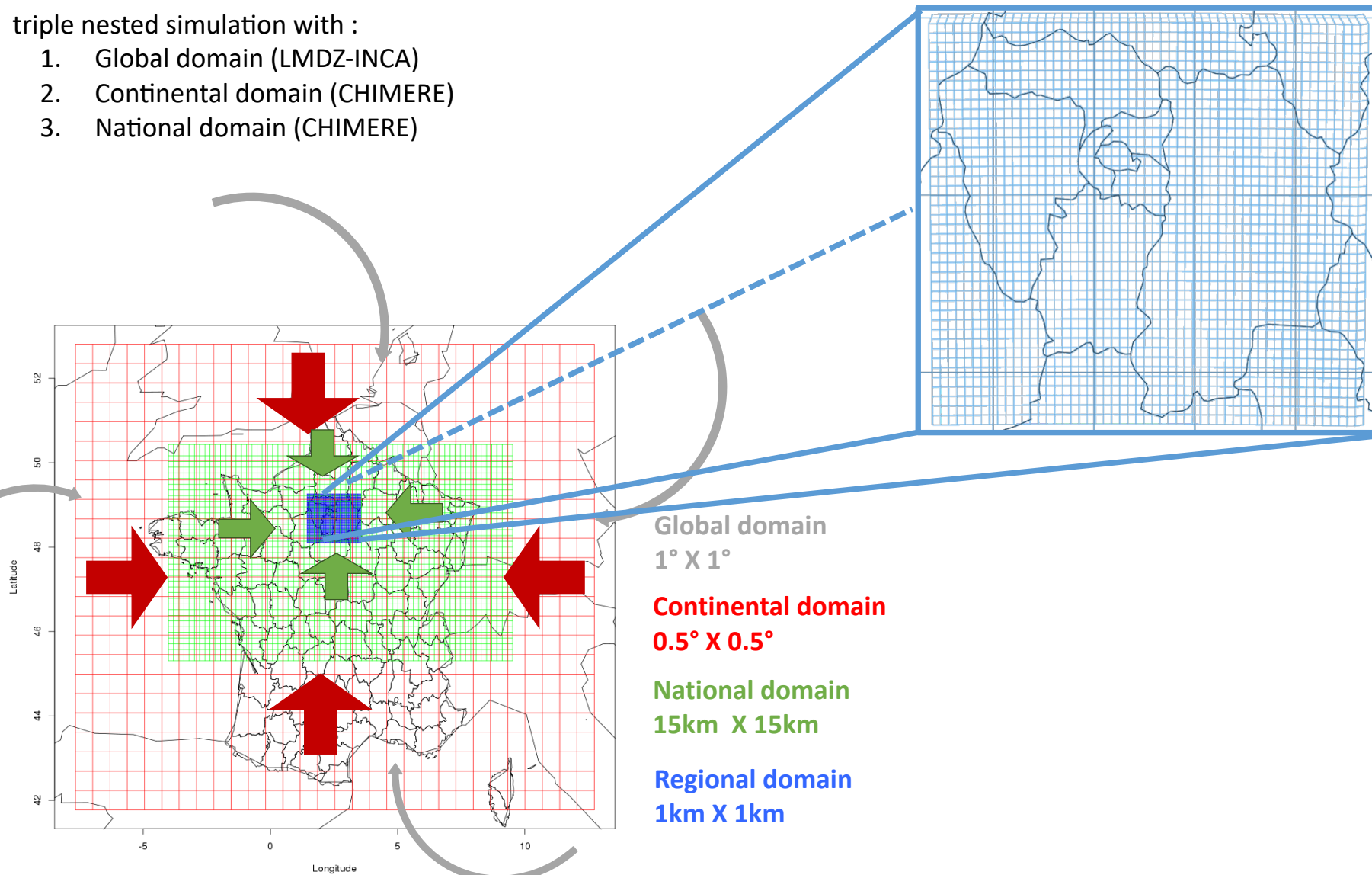
Eulerian off-line chemistry-transport model (CTM) chimere

- ❑ Calculate at each timestep  $\Delta C$  in each box
- ❑ Forecasting and analysis of air quality
- ❑ Driven by weather outputs WRF



# CHIMERE – simulations

- ☐ triple nested simulation with :
  1. Global domain (LMDZ-INCA)
  2. Continental domain (CHIMERE)
  3. National domain (CHIMERE)

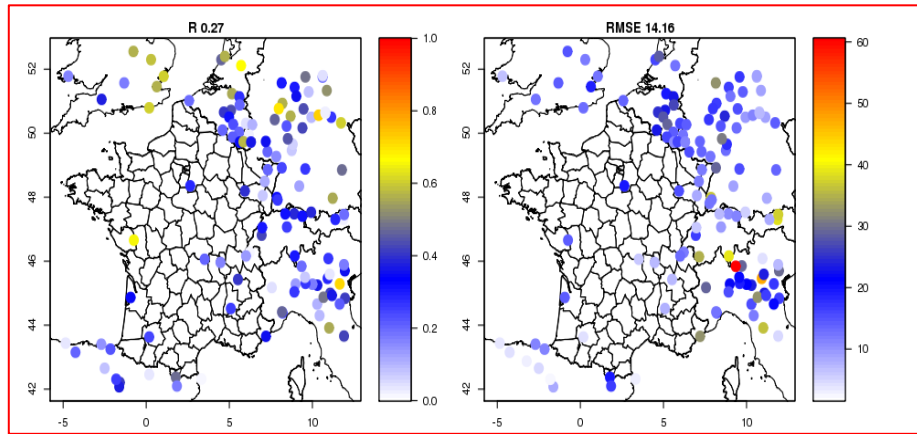




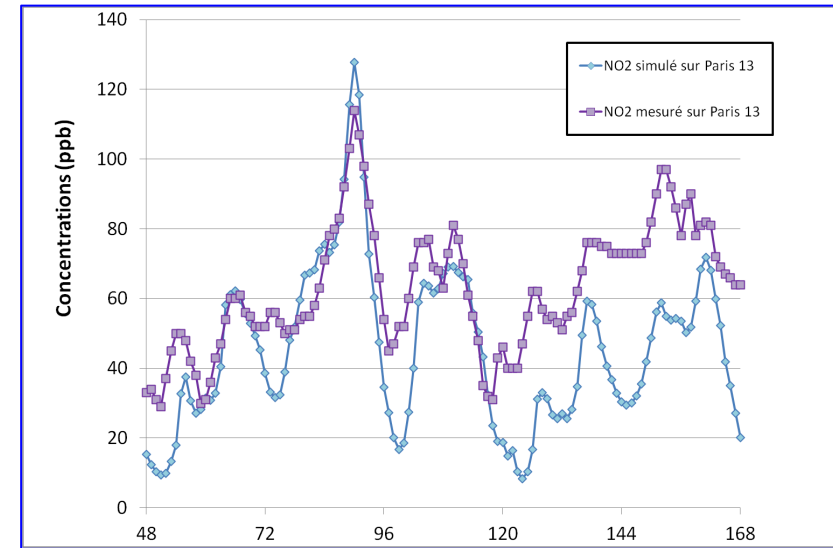
# CHIMERE – validation

## CHIMERE

- ☐ Validation in progress
- ☐ Comparison with french Air quality monitoring network

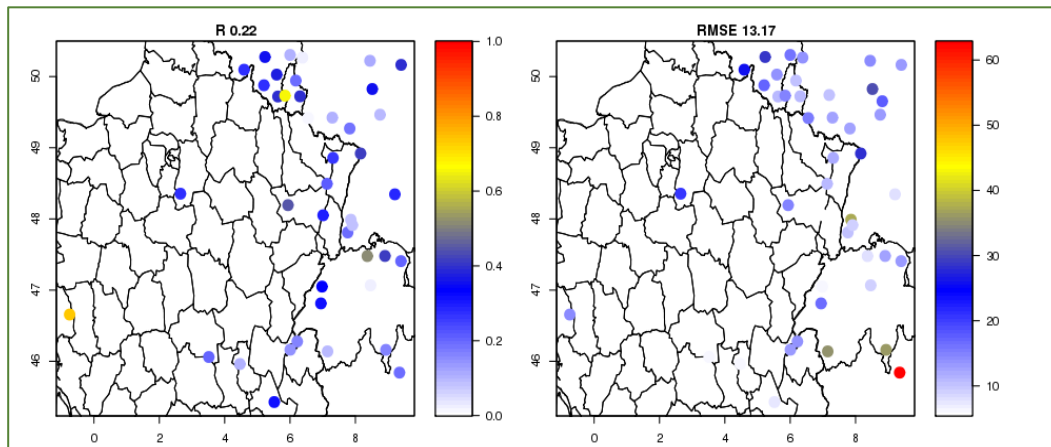


Continental domain  
0.5° X 0.5°

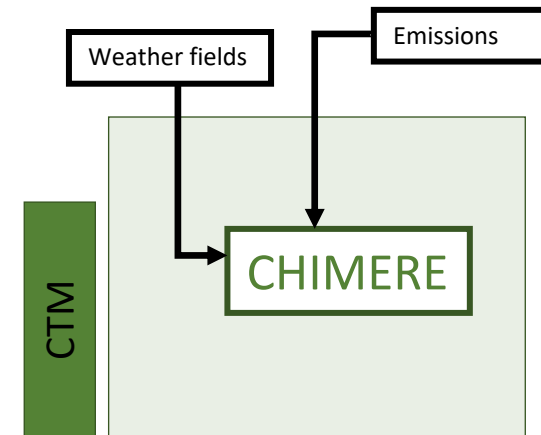


Regional domain  
1km X 1km

Concentrations of NO<sub>2</sub> in ppb (City station Paris 13<sup>ème</sup>)

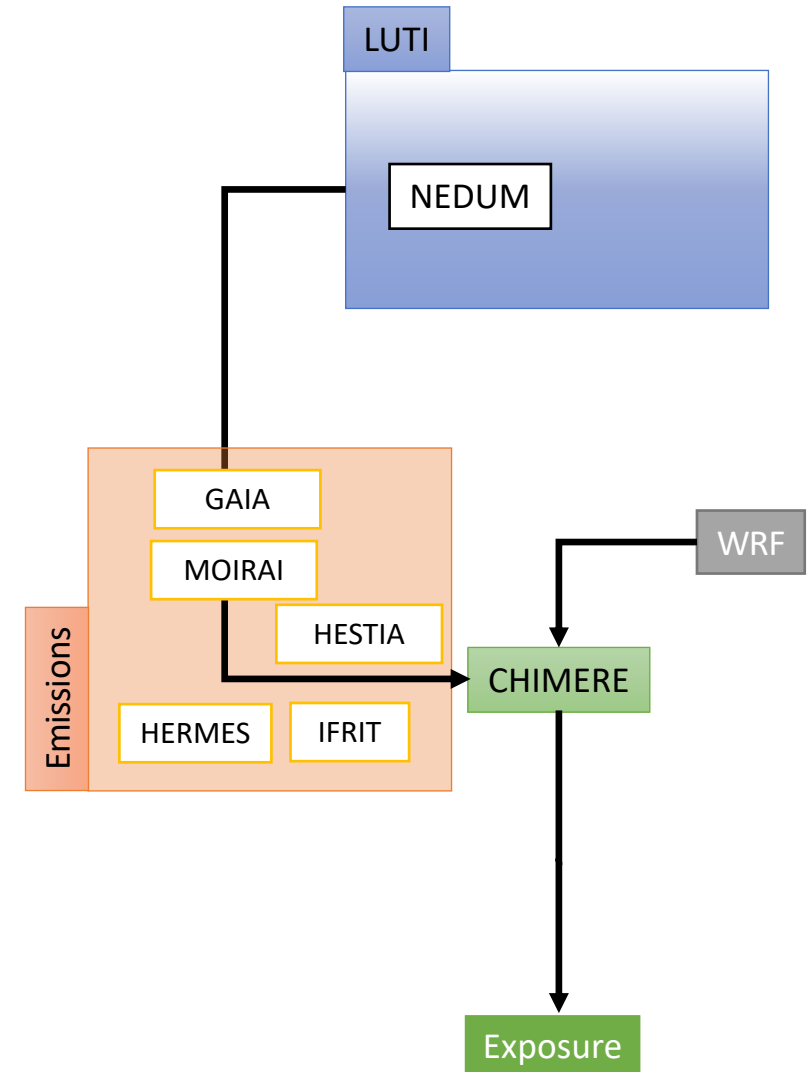


National domain  
15km X 15km

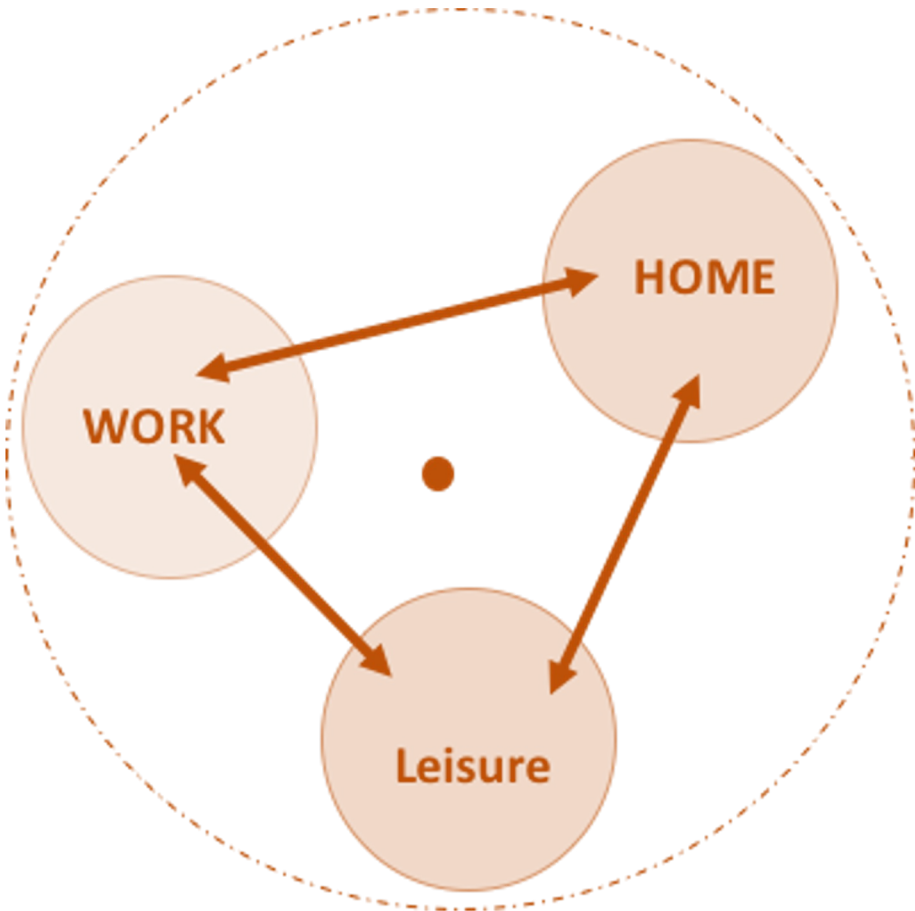


R and RMSE for NO<sub>2</sub> for rural Air-Base stations on the first week of January

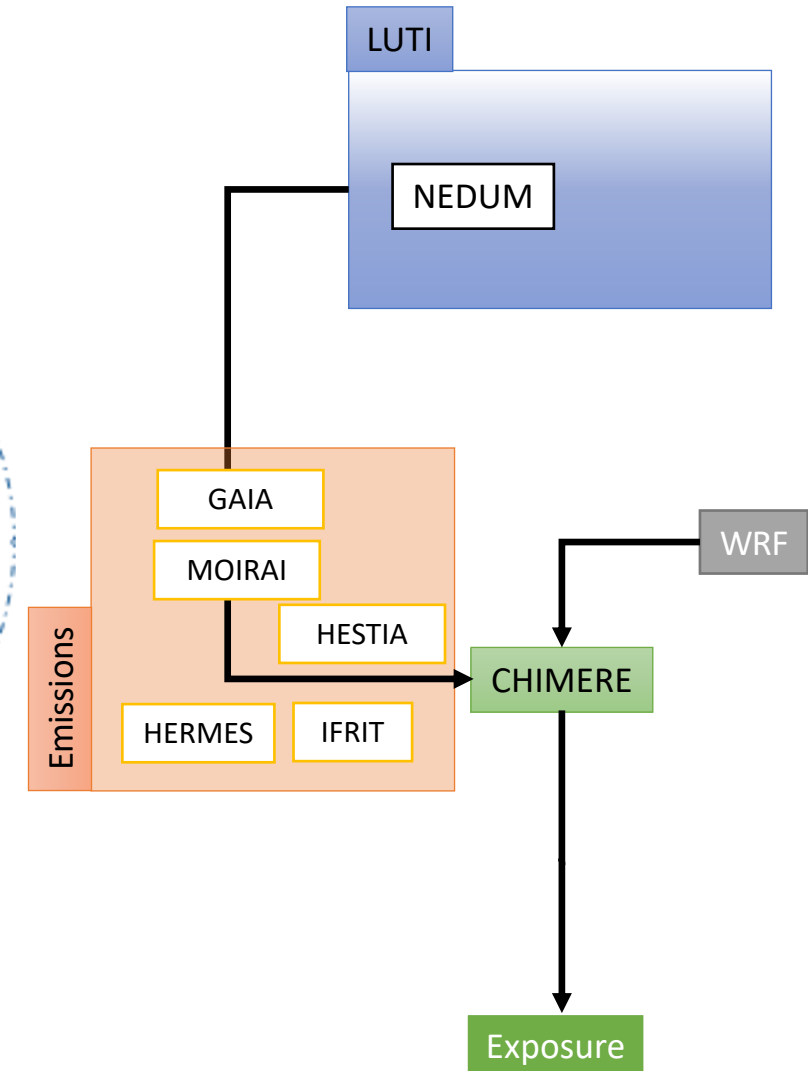
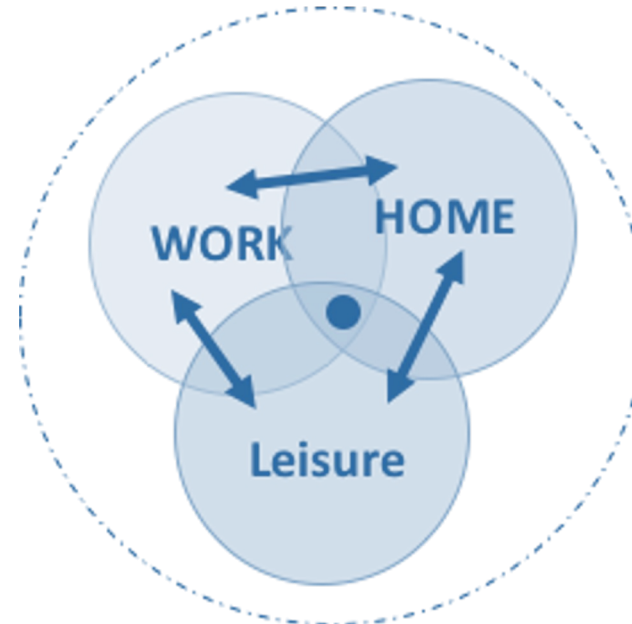
# Scenarios



## SPRAWL



## COMPACT



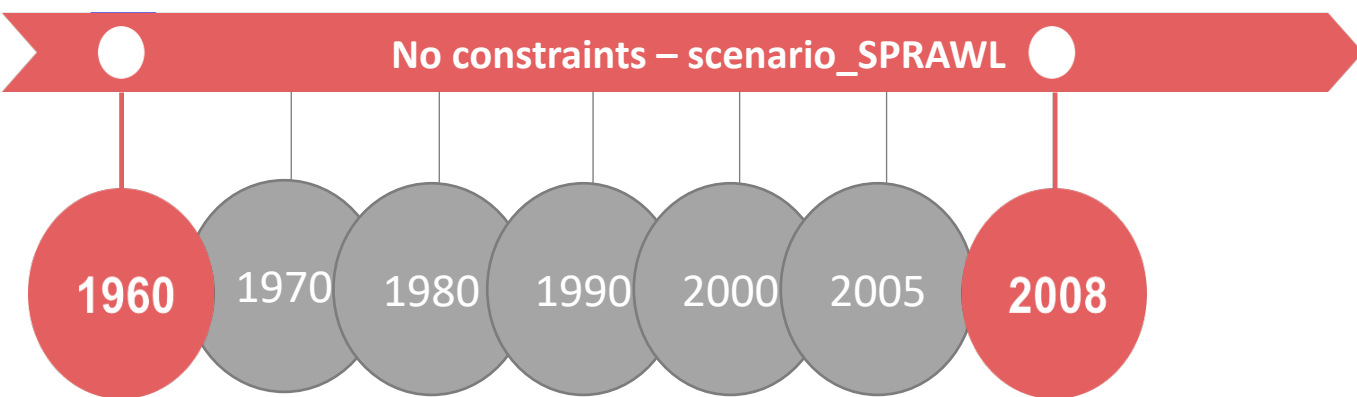
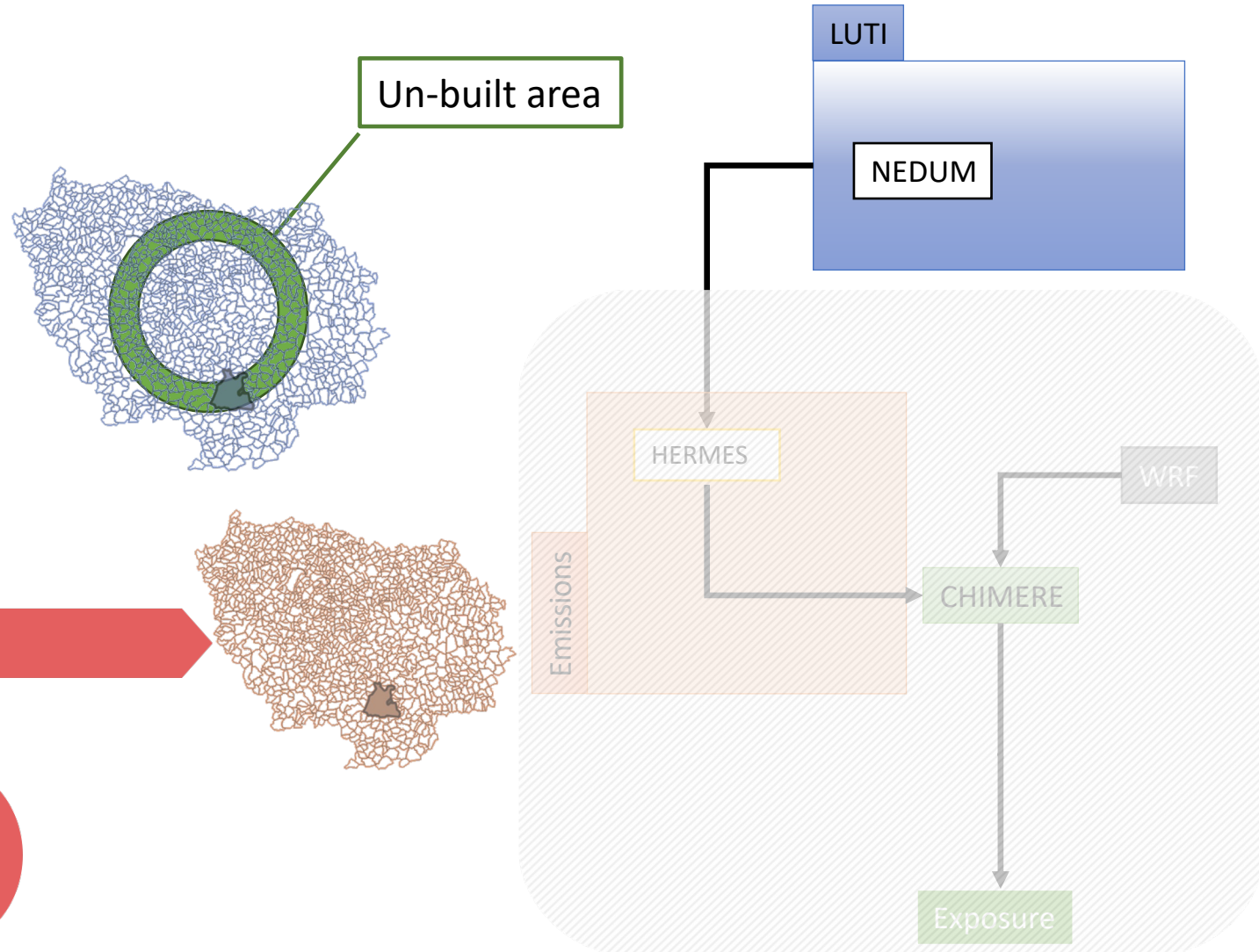
# Generation of land use scenarios

## Study on past urbanization

Reference situation in 1960 (On data census)

**Sprawl** city - Expansion of Paris with no specific constraint (LUTI)

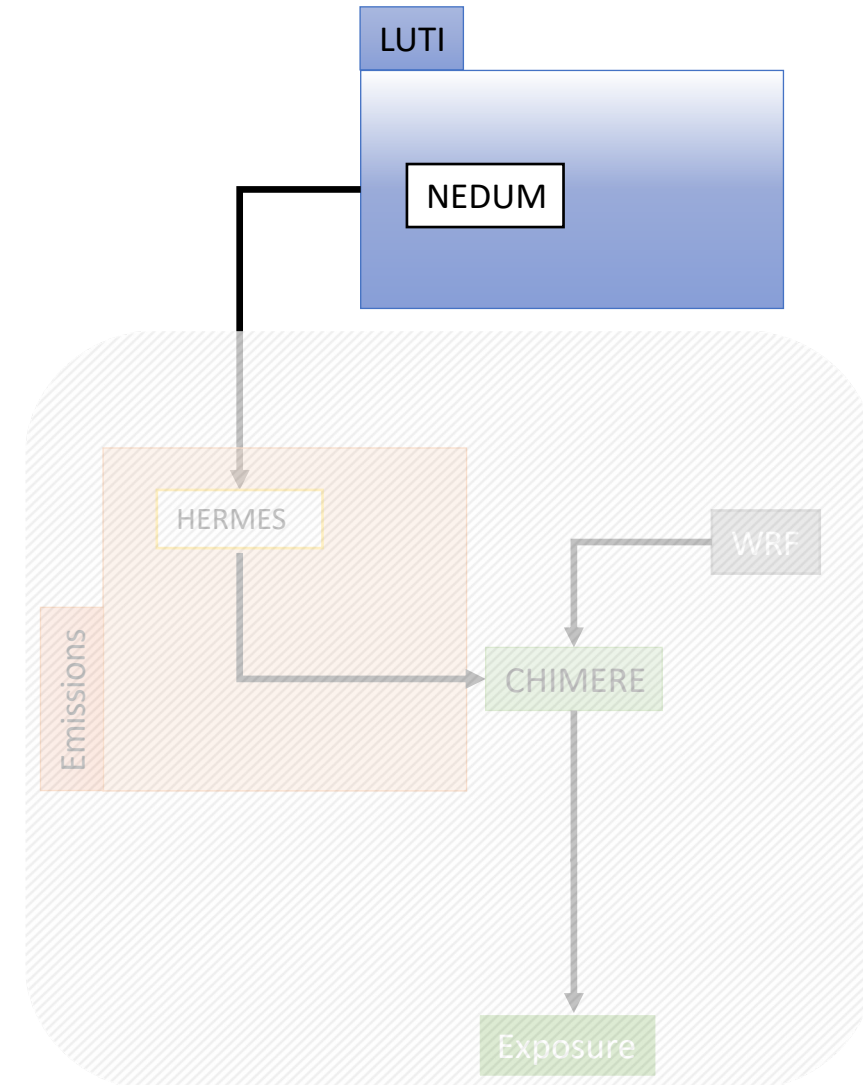
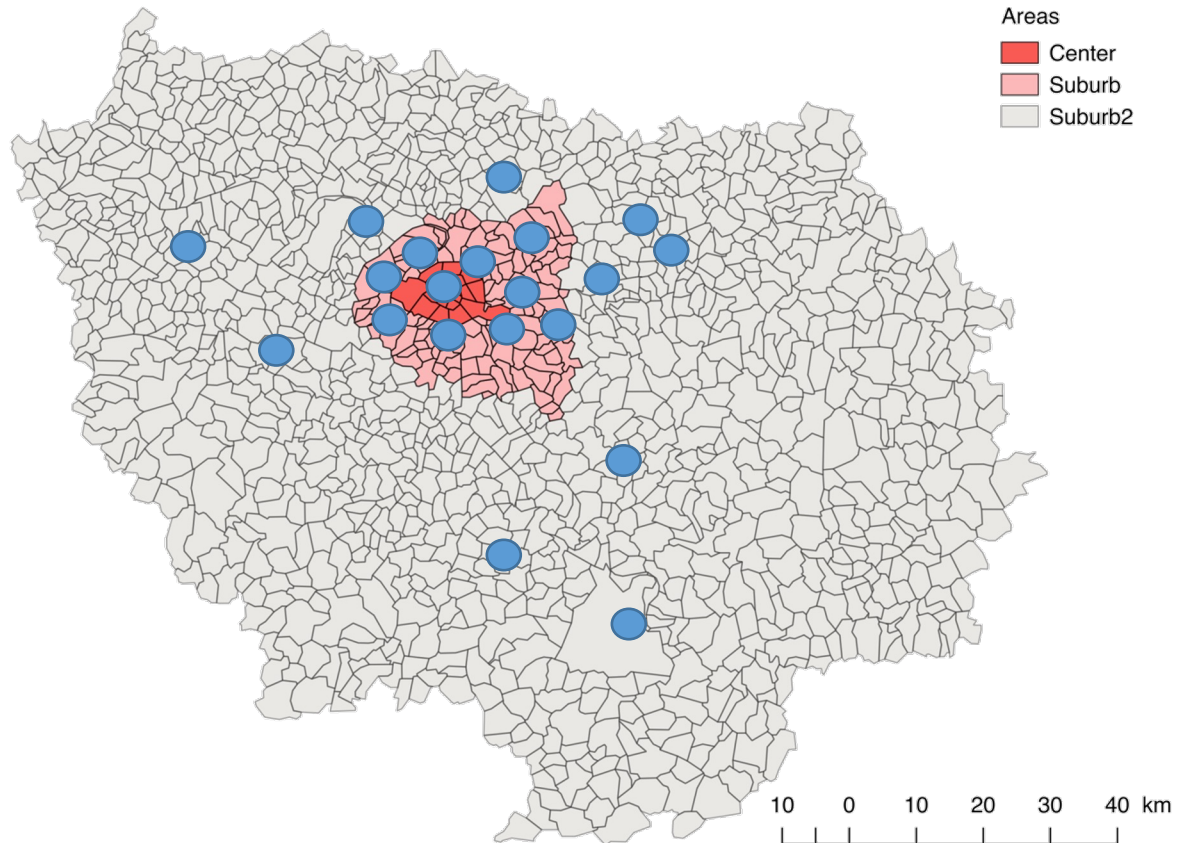
**Compact** city - Expansion of Paris with a green-belt (LUTI)



# Scenarios parametrization

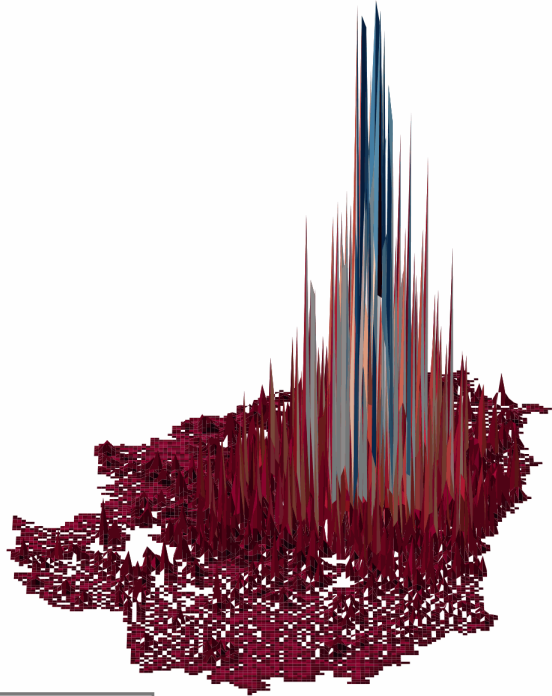
## Parameters fixed in time

- job centers location of 2008 ●
- Single average income per individual
- Transportation network of 2008

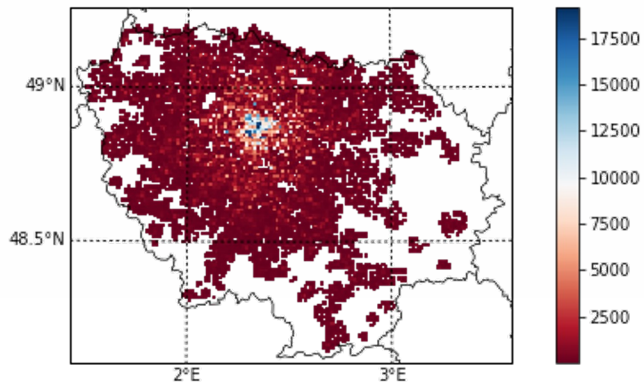


# Scenarios - Land-use transport outputs

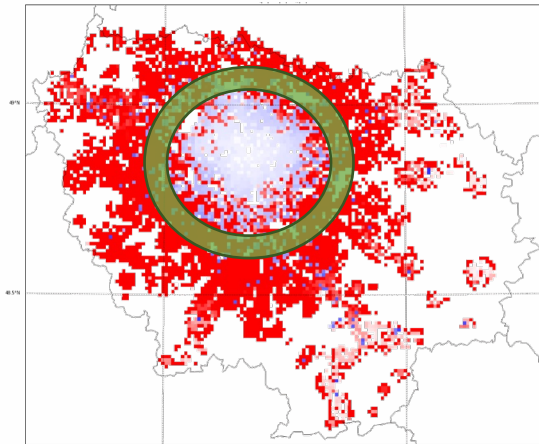
## households density



Scenario\_SPRAWL

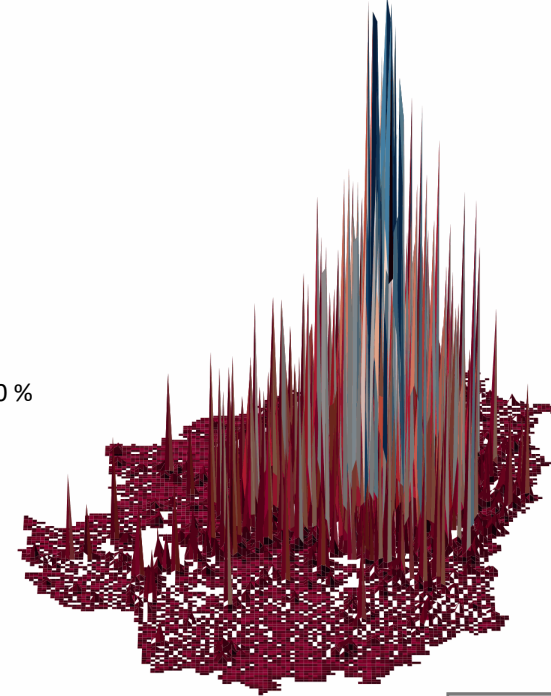
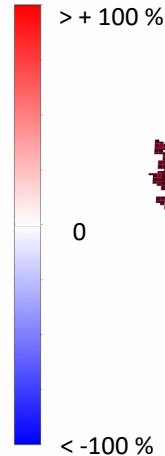


Number of households

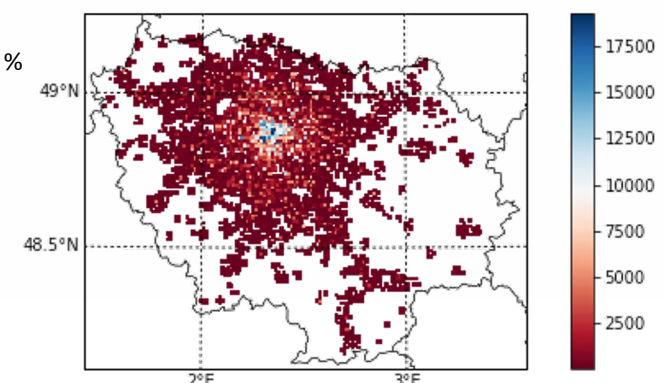


Absolute difference of households

**SPRAWL - COMPACT**



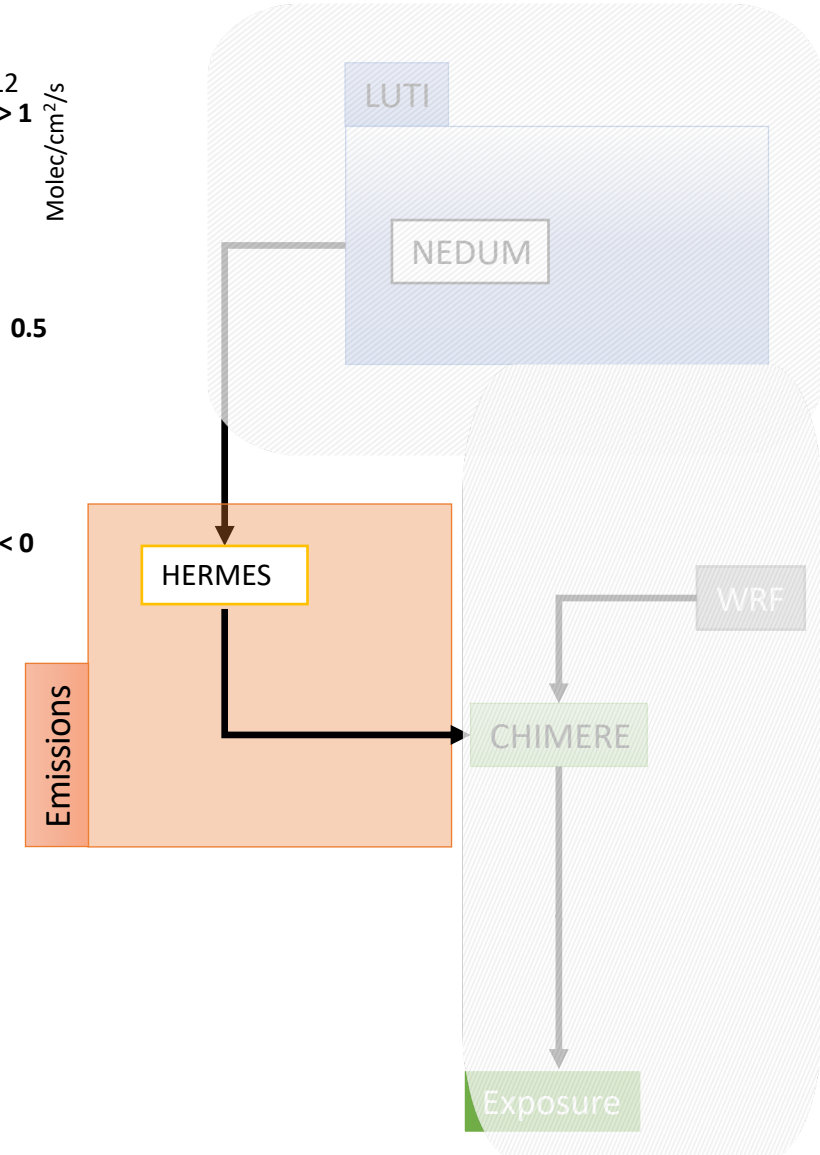
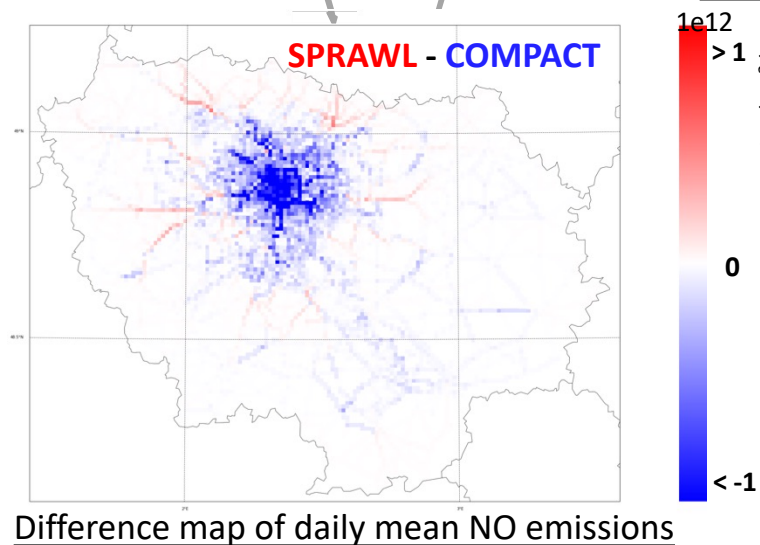
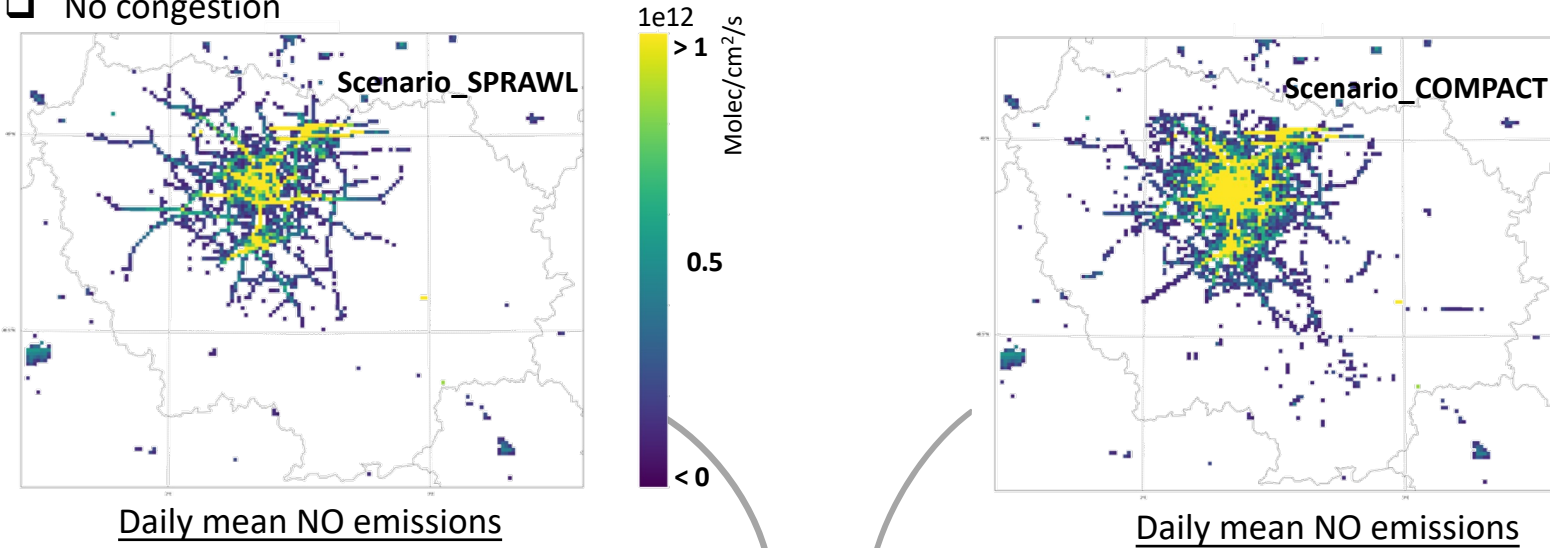
Scenario\_COMPACT



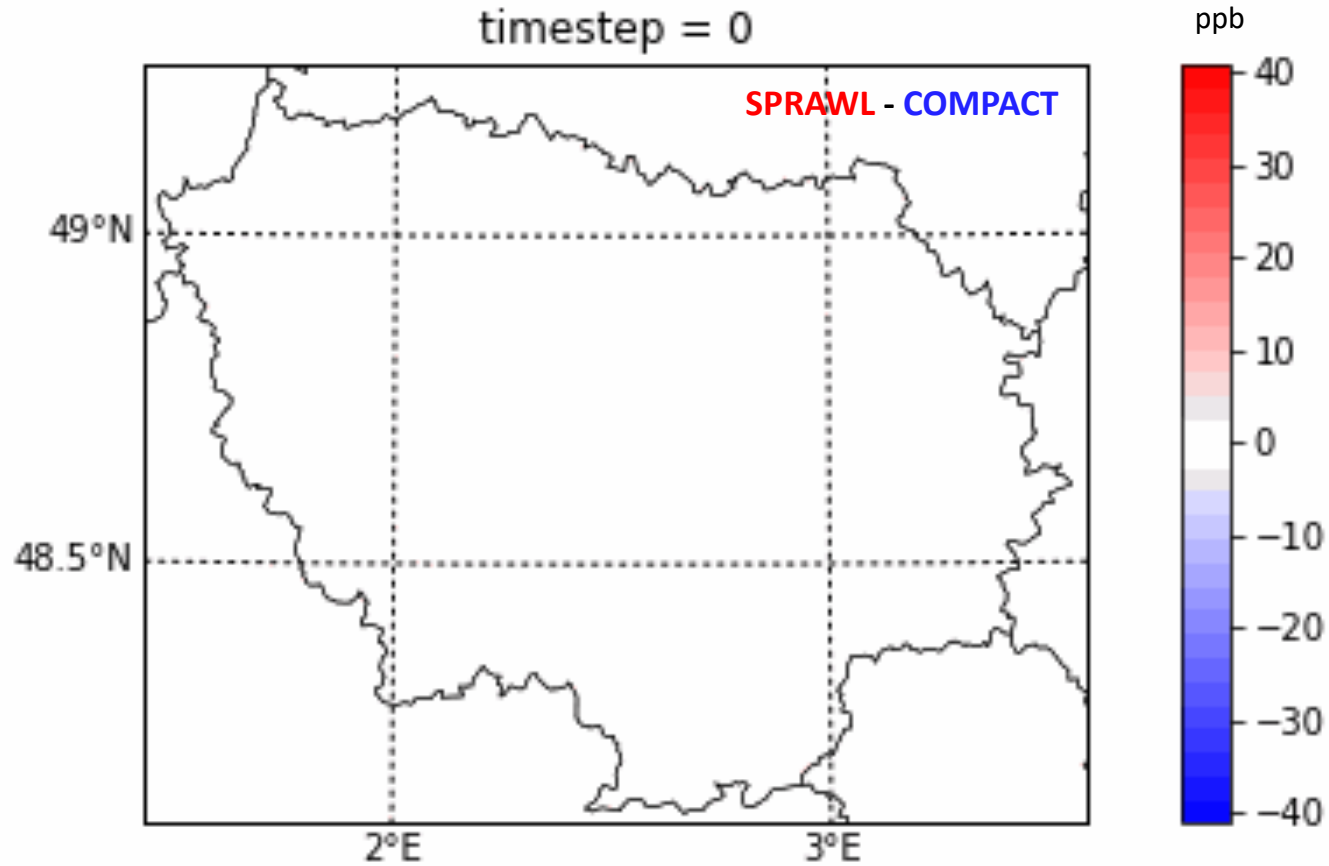
Number of households

# Scenarios - Road emissions outputs

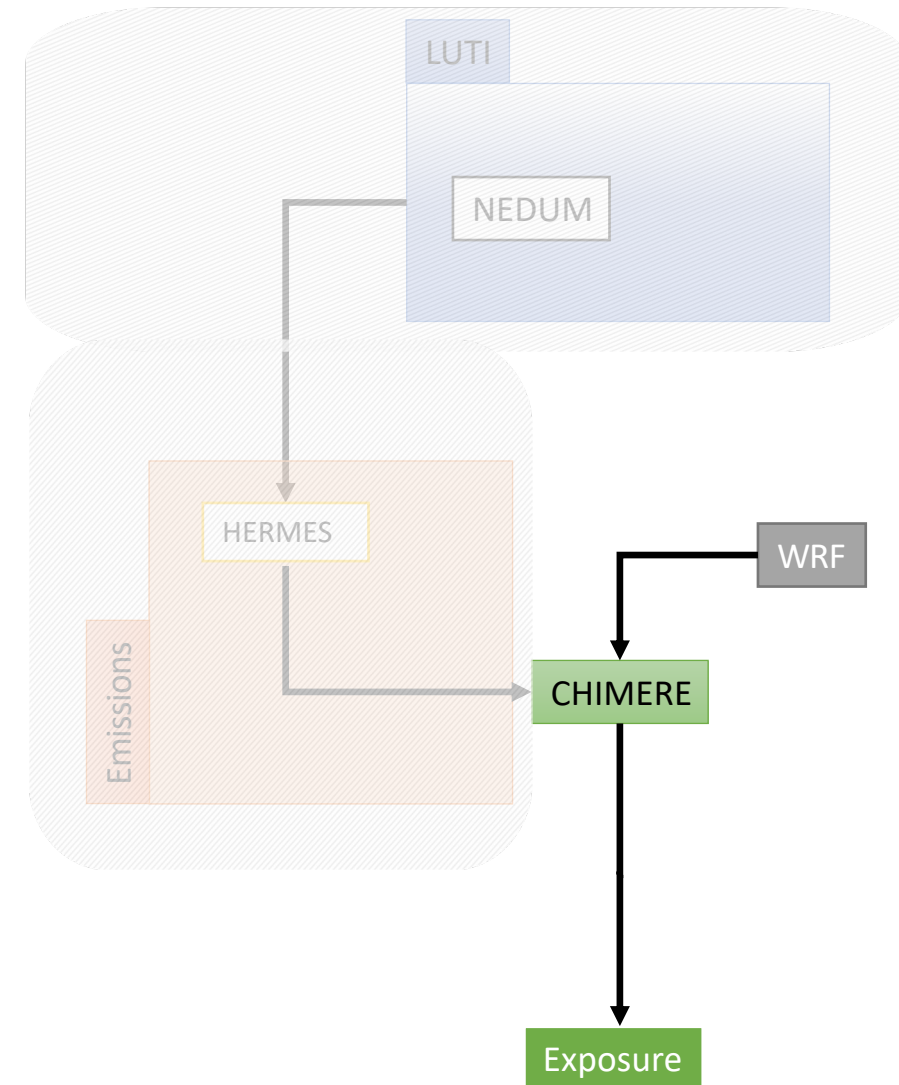
- Car fleet of 2008 (Census data)
- No congestion



# Scenarios – CTM outputs

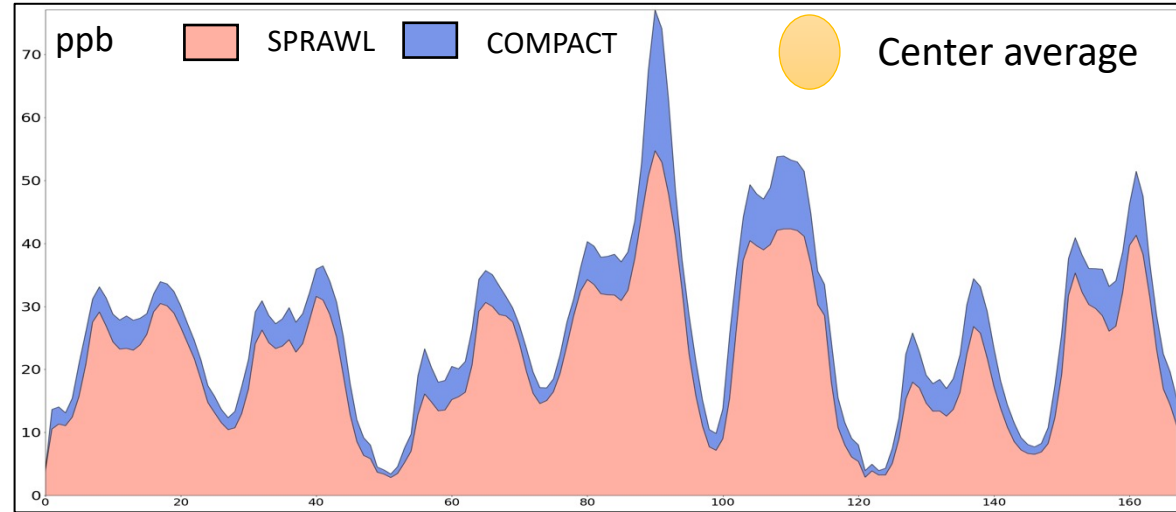
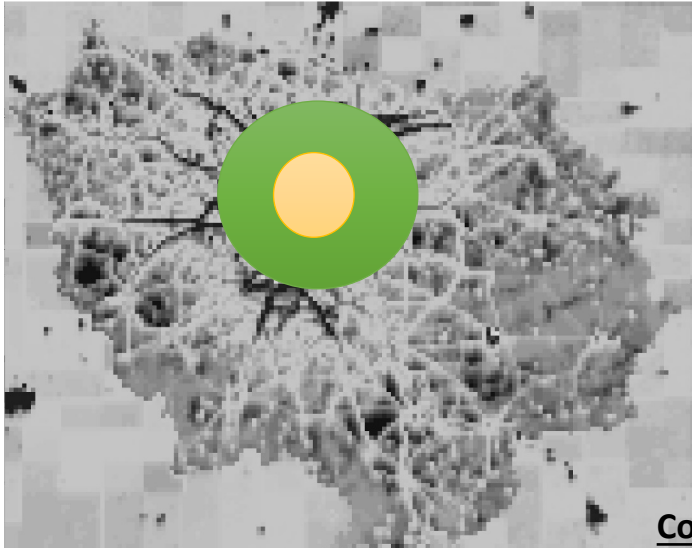


NO2 difference concentration

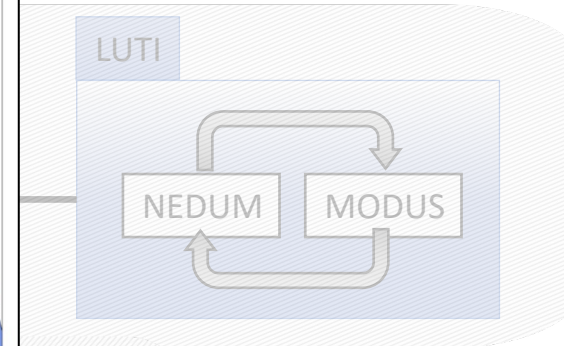




# Scenarios – CTM outputs time series

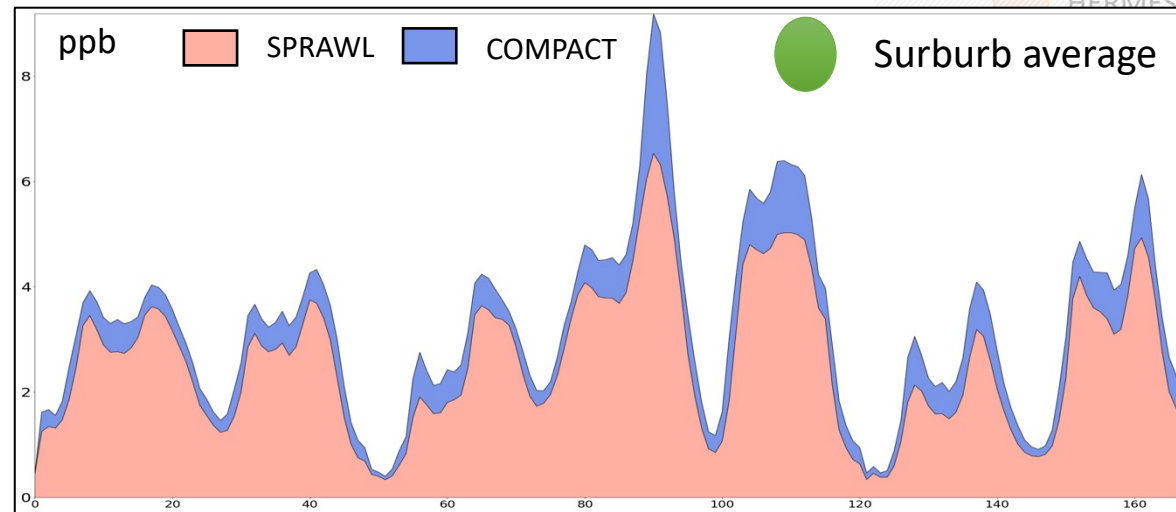


**Concentration of NO2 during a week (January 2009 - Average of all meshes in the center area)**

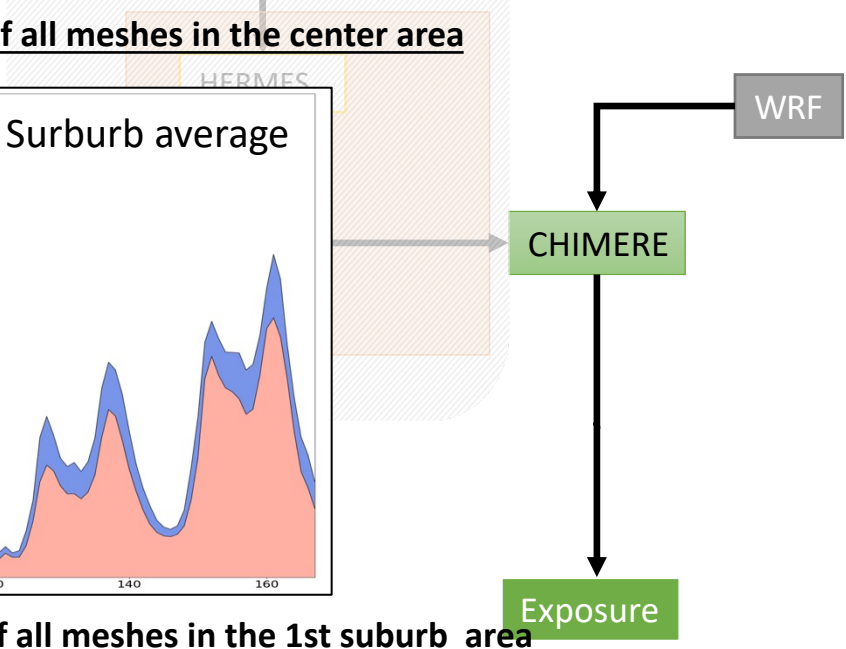


- Center zone
- Suburb zone

*concentration appears higher, in average, in the compact scenario (With the previous hypothesis)*



**Concentration of NO2 during a week (January 2009) - Average of all meshes in the 1st suburb area**



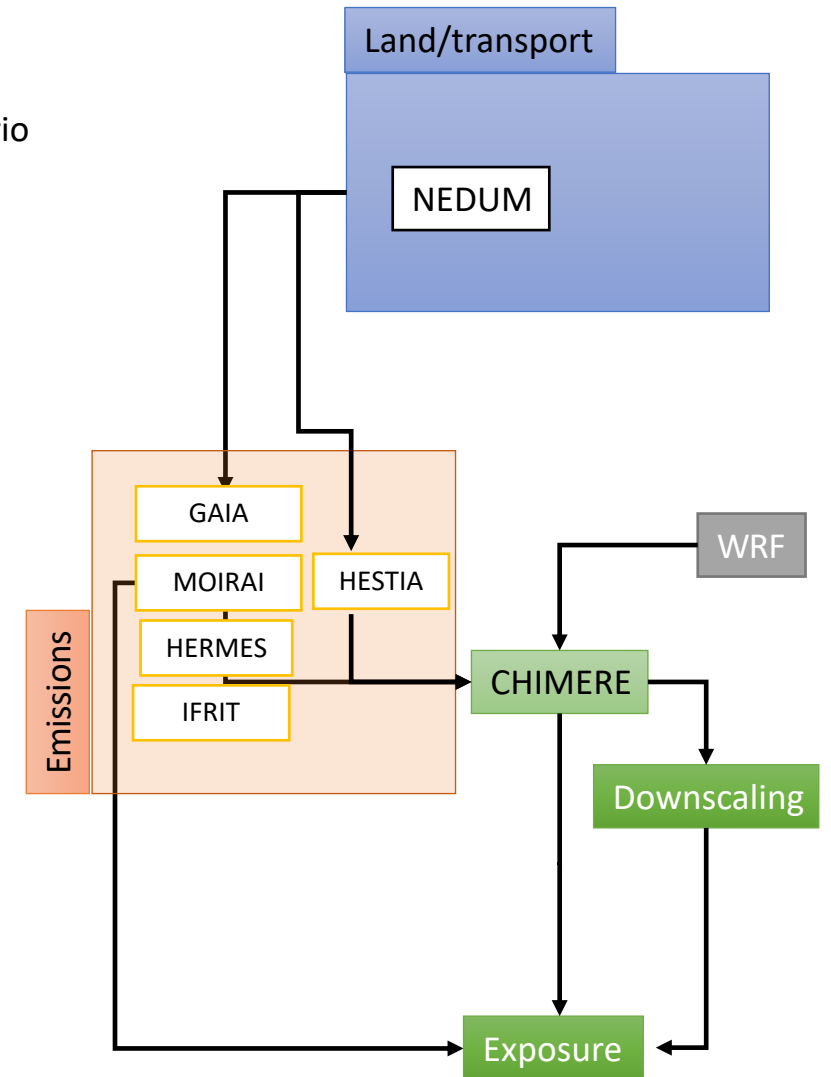
## Conclusion

- ❑ Operational modeling chain
- ❑ Sensitivity in terms of air quality
- ❑ In the center of the city, pollutants concentration appears higher, in average, in the compact scenario
- ❑ Simplified modeling of the city – Change modal split sensibility

## Ongoing

### Downscaling

- ❑ Modelling at a smaller scale

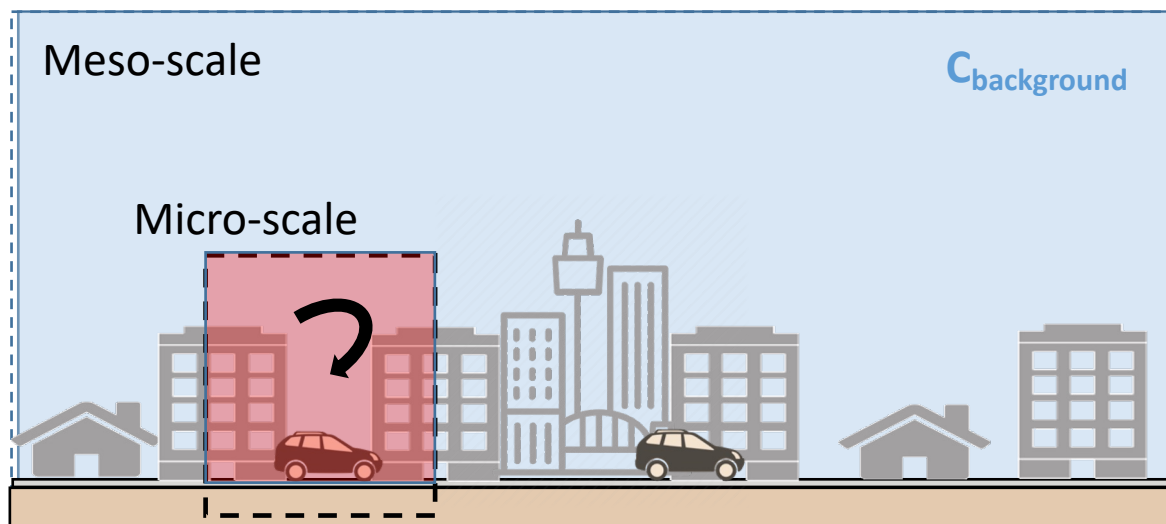


## Downscaling

Extrapolation of CTM mesoscale to micro-environments

Work in progress...

- Learning Capacity / Extrapolation
- Potential for transposition to other sites / Standard micro-environments

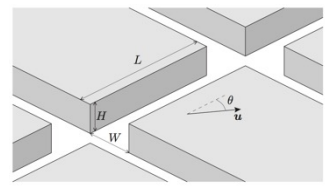


1km resolution

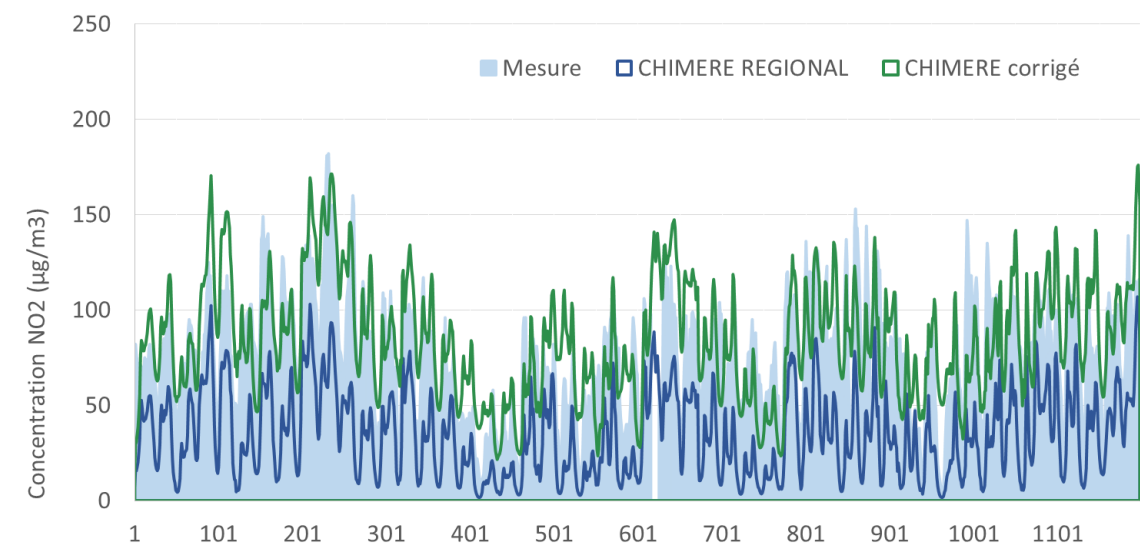
$$C_{\text{micro-environnement}} = C_{\text{regionale}} + C_{\text{increment}}$$

$$C_{\text{increment}} = [\sin(\theta) + 1] * [x_1 C_{\text{background}} + x_2 H/WL * \text{emis}/w_{\text{speed}}]$$

$$C_{\text{micro-environnement}} = x_1 (\text{wind, confinement}) C_{\text{background}} + x_2 (\text{wind, confinement}) C_{\text{regionale}}$$



Moussiopoulos et al. (2014)



## Conclusion

- Operational modeling chain
- Sensitivity in terms of air quality
- In the center of the city, pollutants concentration appears higher, in average, in the compact scenario
- Simplified modeling of the city – Change modal split sensibility

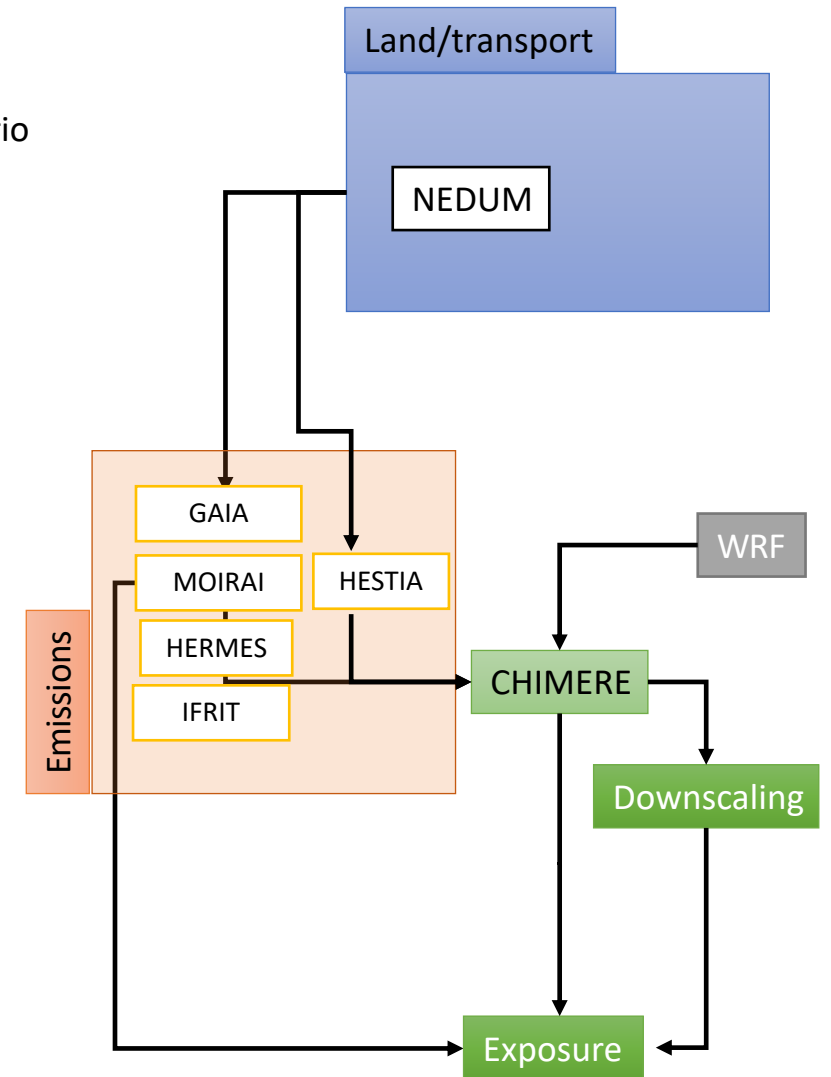
## Ongoing

### Downscaling

- Modelling at a smaller scale

### Individual exposure

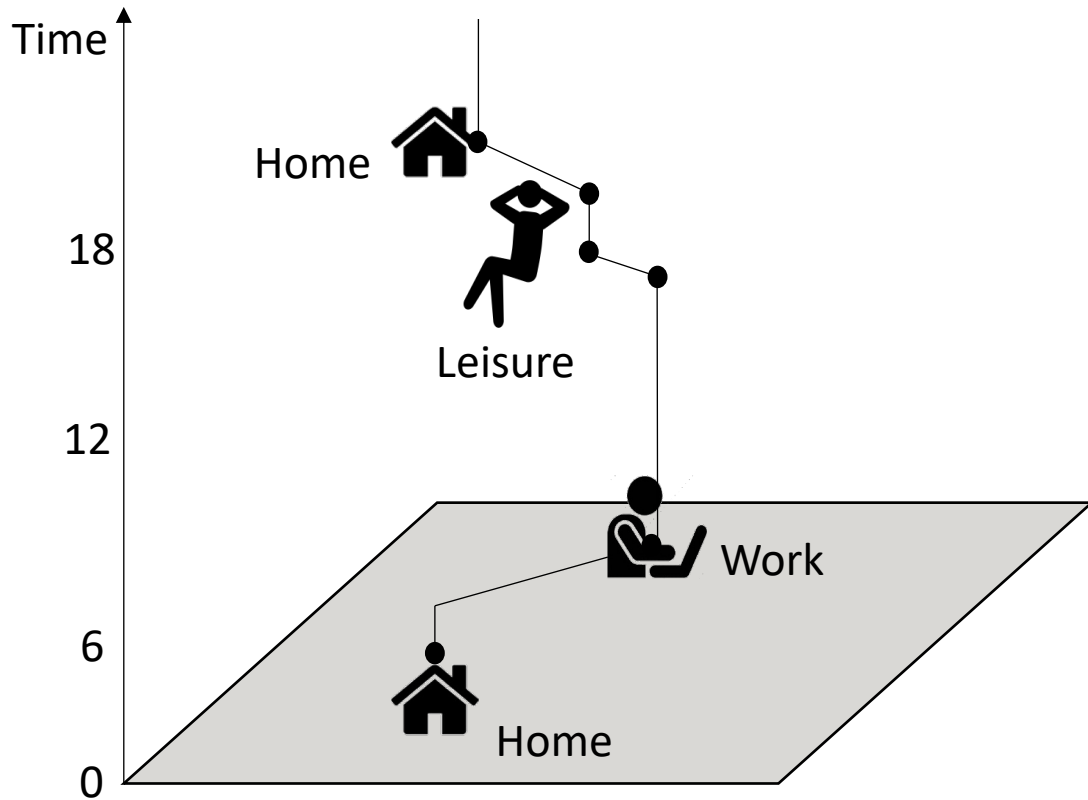
- Time geography exposure (Work in progress...)



## Individual exposure

Time geography exposure (Work in progress...)

- ❑ MOIRAI + CHIMERE (Downscaling)



Individual daily movement trajectory

$$\text{Individual Exposure}_i = \sum C_{\text{environment}} \cdot \text{time}_{\text{Spend}}$$

## Conclusion

- Operational modeling chain
- Sensitivity in terms of air quality
- In the center of the city, pollutants concentration appears higher, in average, in the compact scenario
- Simplified modeling of the city – Change modal split sensibility

## Ongoing

### Downscaling

- Modelling at a smaller scale

### Individual exposure

- Time geography exposure (Work in progress...)

### Interaction on the LUTI

- In progress

### Deposition

- In progress

