Towards sustainable cities - linking urban structure and air quality

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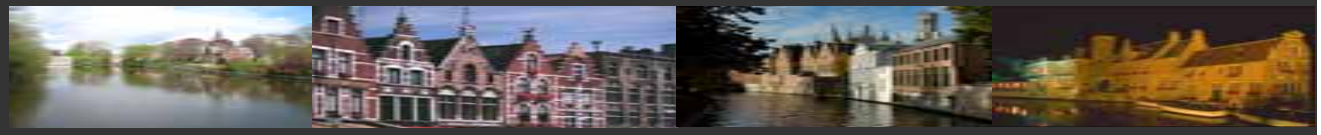


Innovative Methods in Sustainable Production 2008
Urban Growth and Air Pollution

Motivation

In Europe around 80% of the population lives in urban areas.

It’s expected that by 2030, around 60% of the world population will live in cities.

Motivation

Emissions from motorized vehicles and large point sources have been reduced…

… however, urban areas continue to show increasing signs of environmental stress…

Motivation

… thus, around 25% of the world population is exposed to excessive concentrations of gaseous and particulate pollutants.

Air quality in EU: ~100% of urban citizens are exposed to exceedences for PM, 44% for O_3 and 14% for NO_2.

Motivation

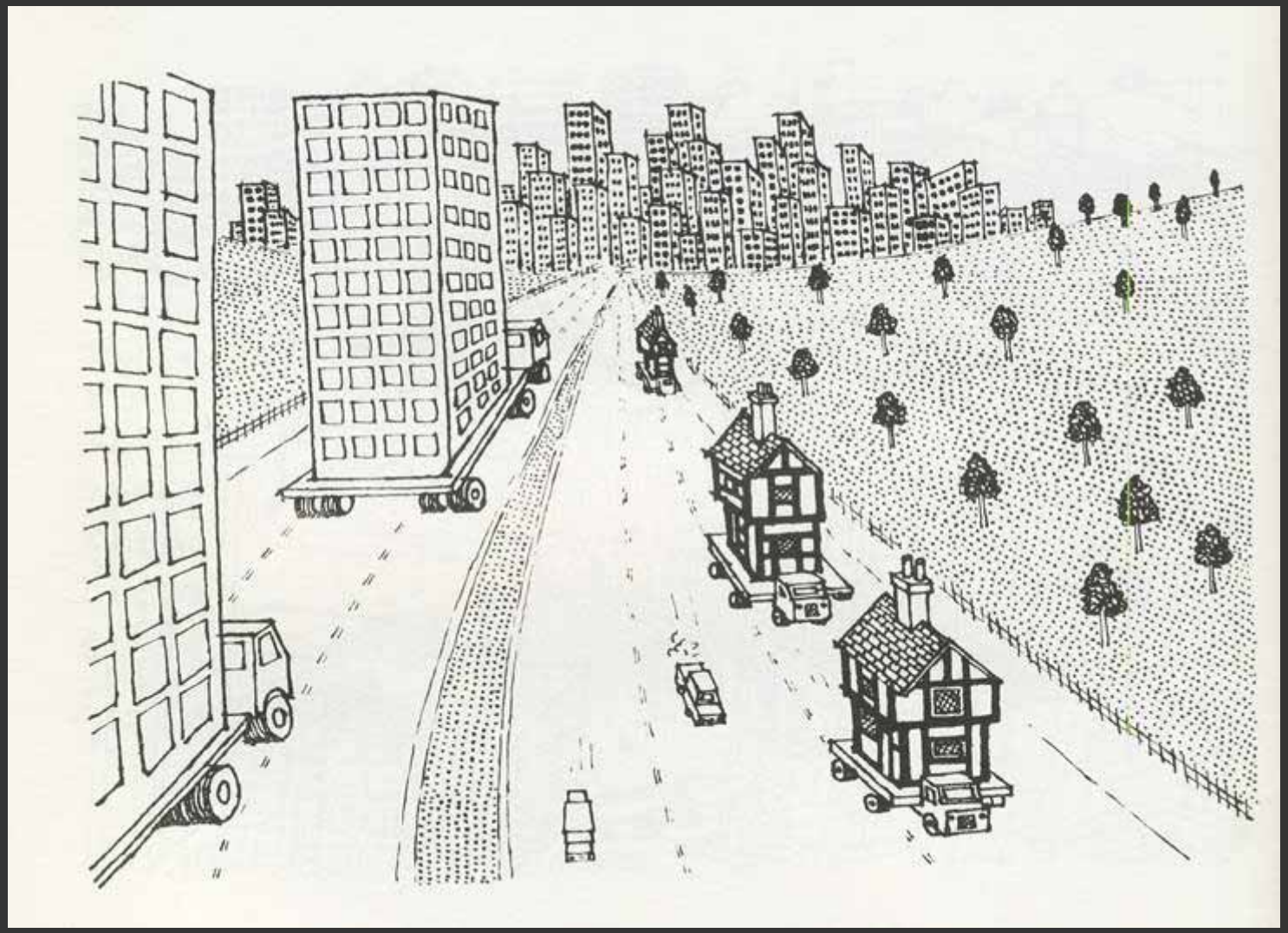
Technology options alone are unlikely to provide the solution…

… what about urban patterns?

What is their influence on air quality?
What is the more suitable urban form?

Current trend

Current trend



Current trend

Mexico city

“The sky under Mexico city is still blue, although many have never seen it”

Low-cost habitation complex, over 10 000 houses.

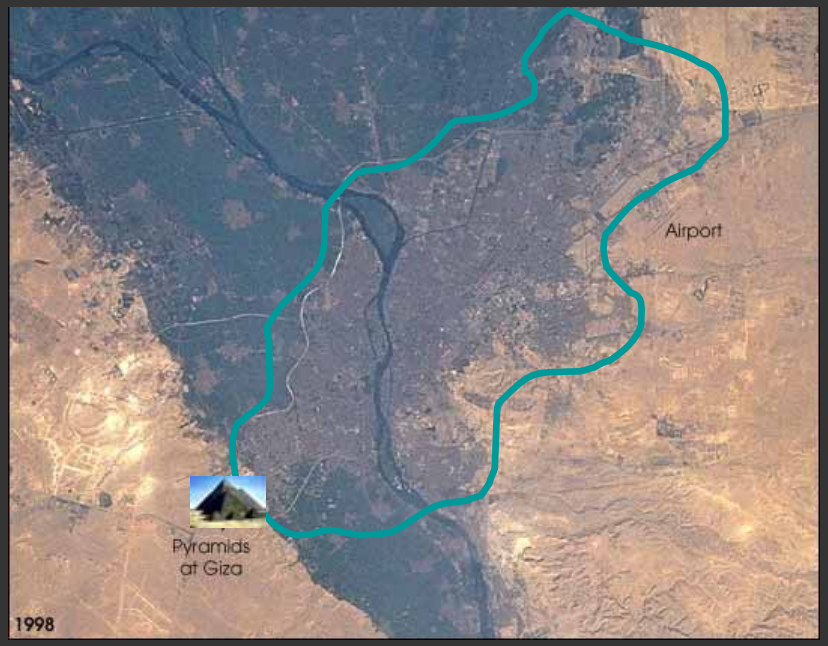
Current trend

American suburbs

"Suburb: a place that isn't city, isn't country, and isn't tolerable."
Mignon McLaughlin, *The Second Neurotic's Notebook*, 1966, writer.

Current trend

Cairo 1965–1998



Population: < 6 million

Urban area: < 200 km²

Population: > 10 million

Urban area: > 400 km²

Current trend

Jakarta, 1976–1989-2004

Population: 6 million

Population: 9 million

Population: 13 million

green: urbanized areas
red: vegetation areas

theories

Centrists

Compact city
Urban containment
High population densities
Mixed land use

Motorized trip reduction
Lower energy consumption
Lower emissions

Problems:
Overcrowded
Traffic congestion
Higher pollution

Is there another option?

decentrists

Disperse city
Low population densities
Large area requirements

More open space
Higher quality of life

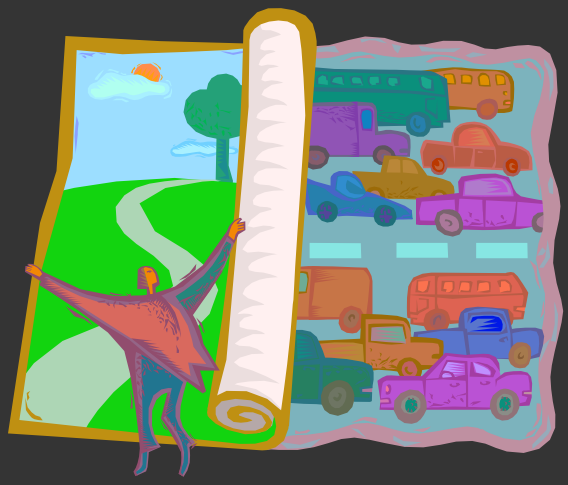
Problems:
Large resources consumption
High dependence on
motorized vehicles

evidence from world cities

Urban sprawl had origin in USA, early 20th with rapid low-density expansion of cities.

In Europe, the cities have traditionally been more compact → but
- modern transport systems,
- rapid economic growth,
- new types of housing,
- communication and tourism,

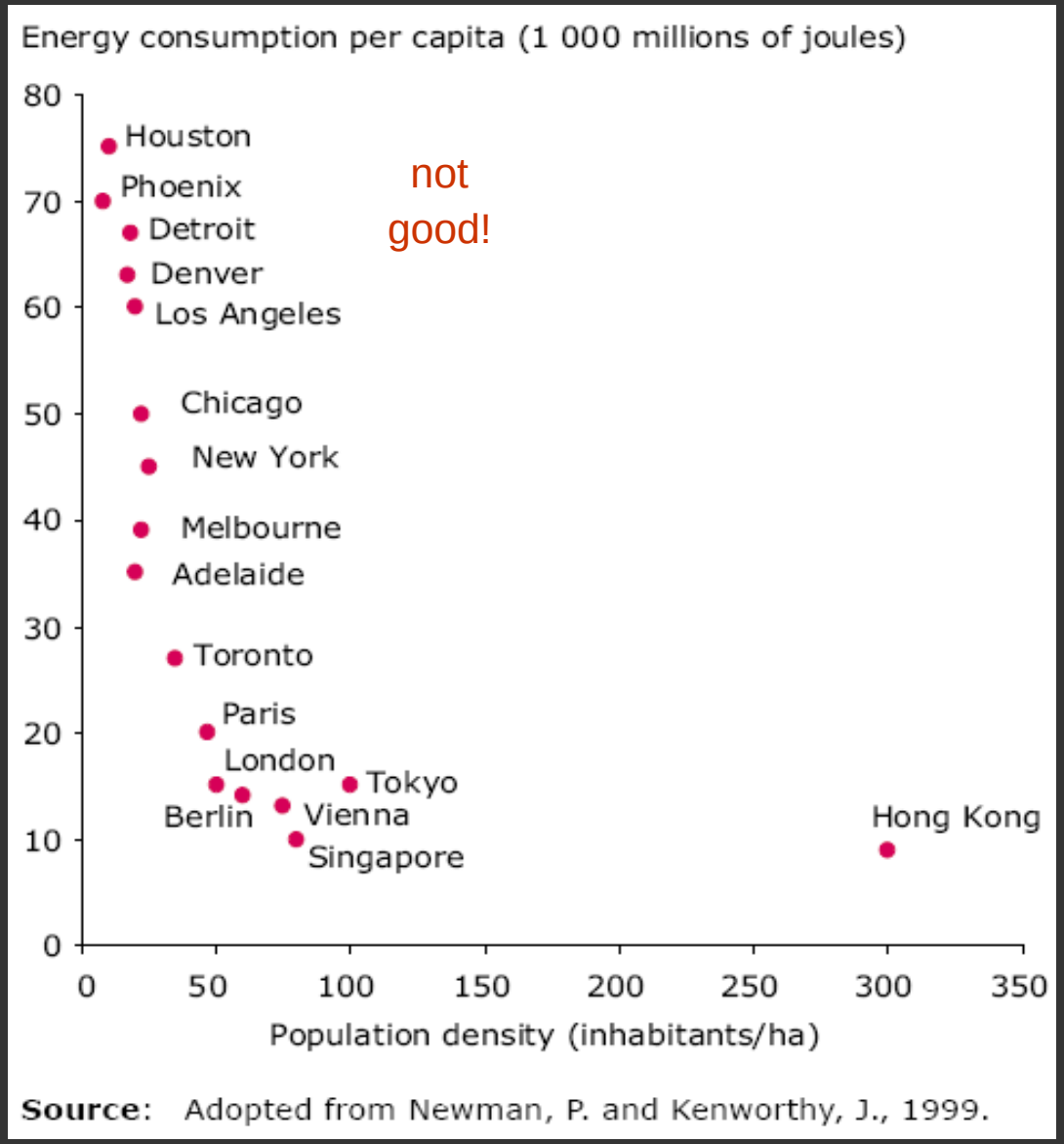
urban density have been decreasing.



From 1980s to 1990s in EU-15
- urban population declined 2.8%
- built-up areas grown 9% → urban sprawl reality in EU

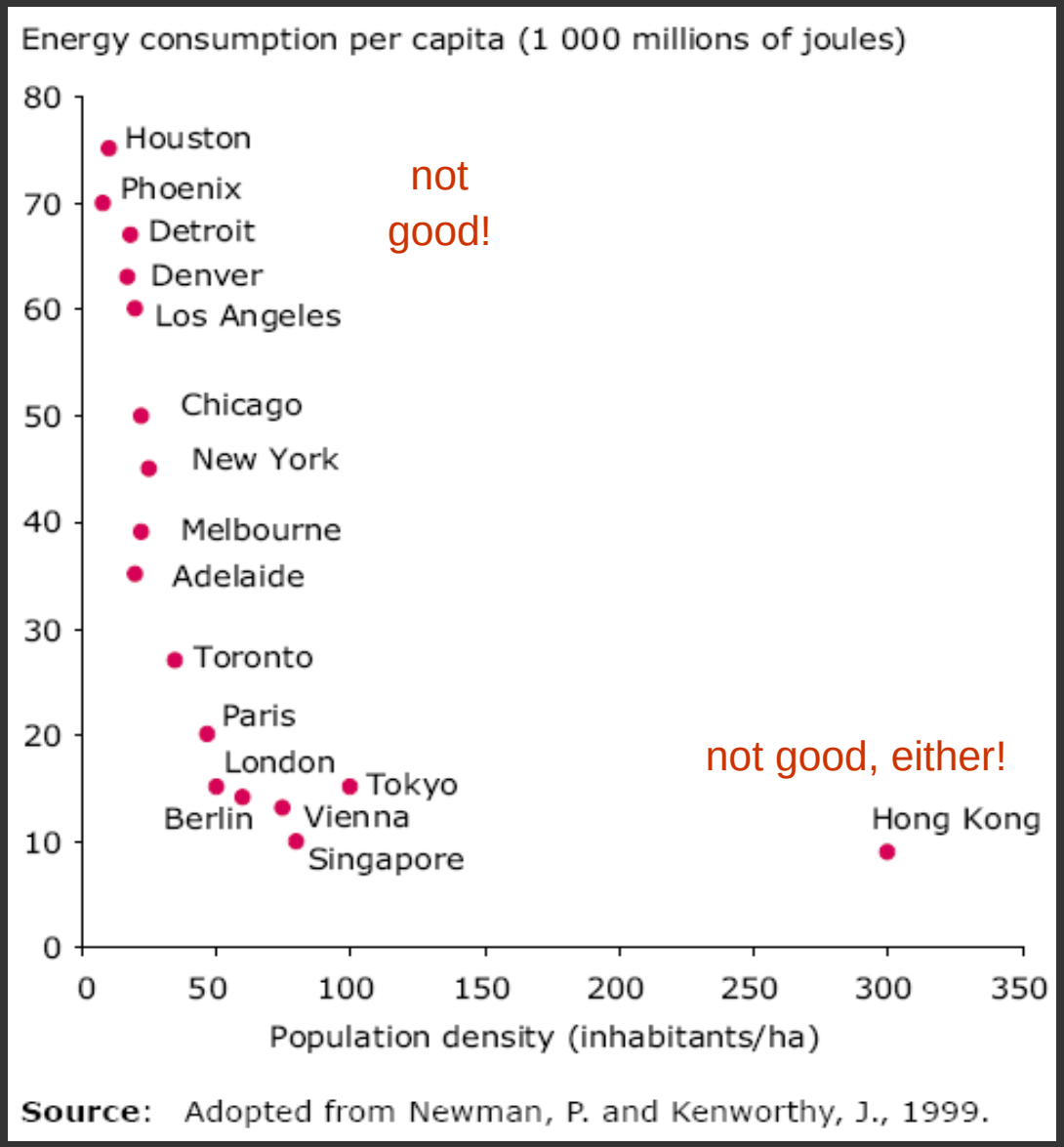
Consequences: high energy consumption rates associated with lower population densities → relation between land use and air quality.

Energy consumption vs. population density



Source: Adopted from Newman, P. and Kenworthy, J., 1999.

Energy consumption vs. population density



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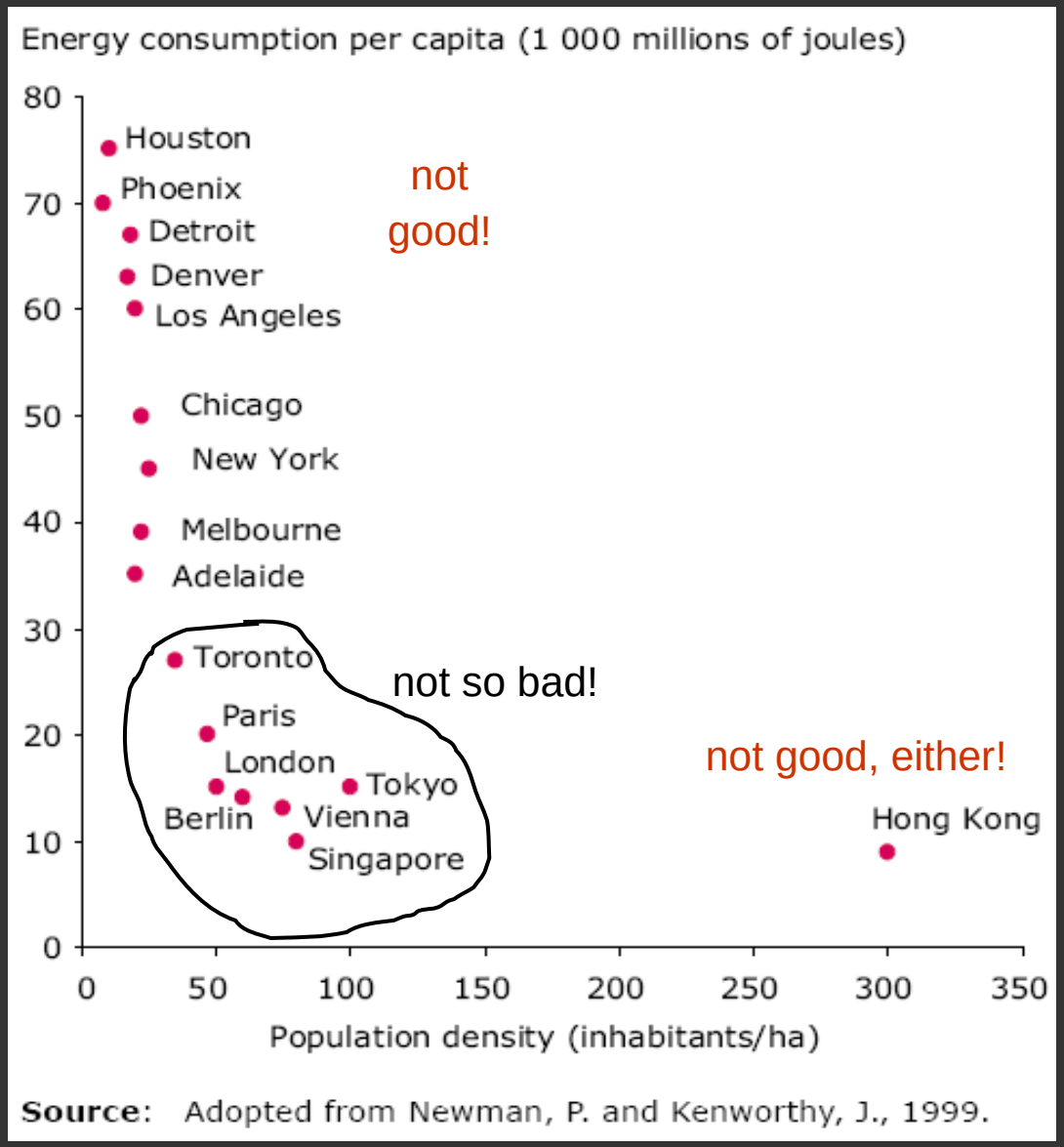
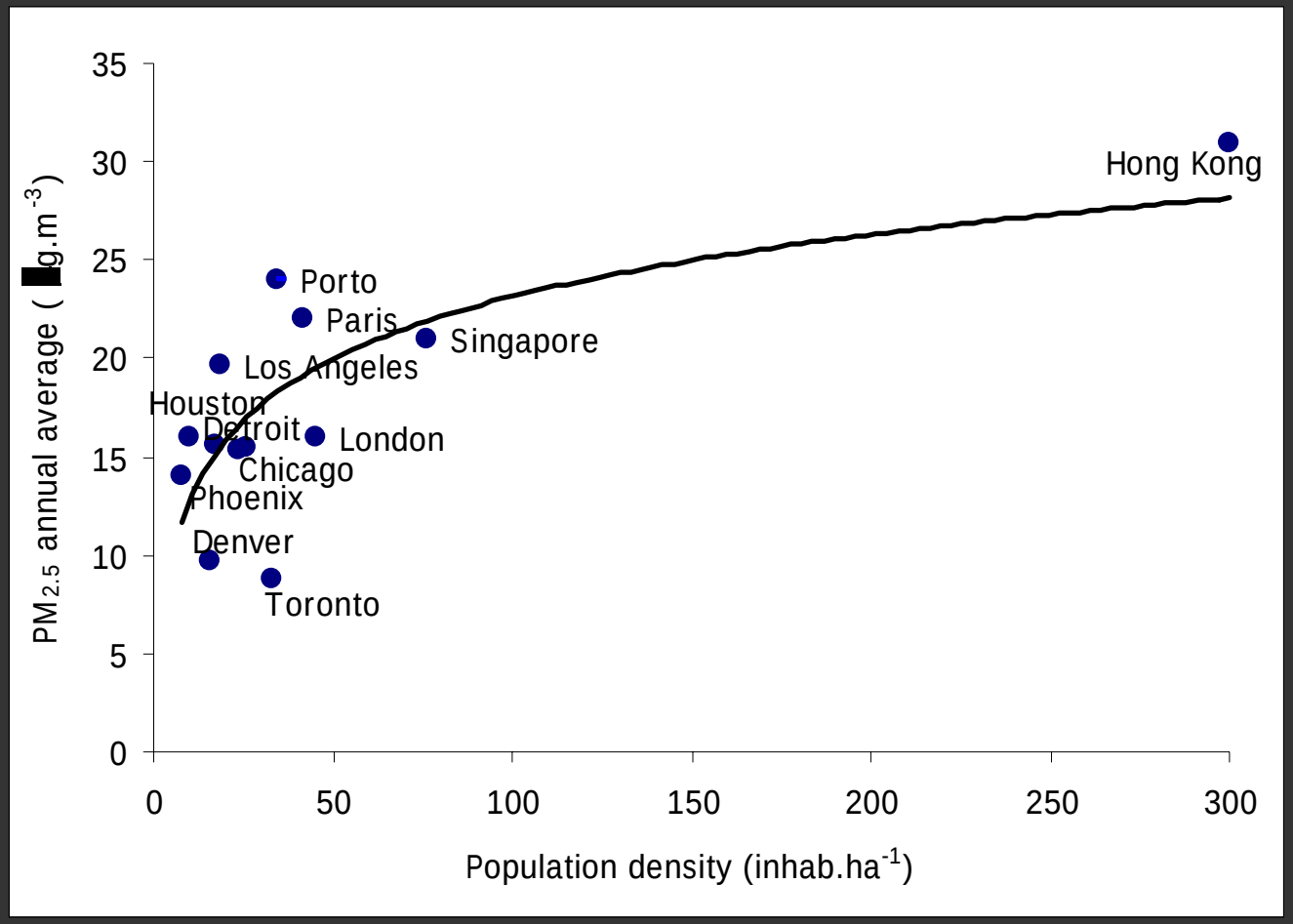
Energy consumption vs. population density



Source: Adopted from Newman, P. and Kenworthy, J., 1999.

$PM_{2.5}$ annual average vs. population density

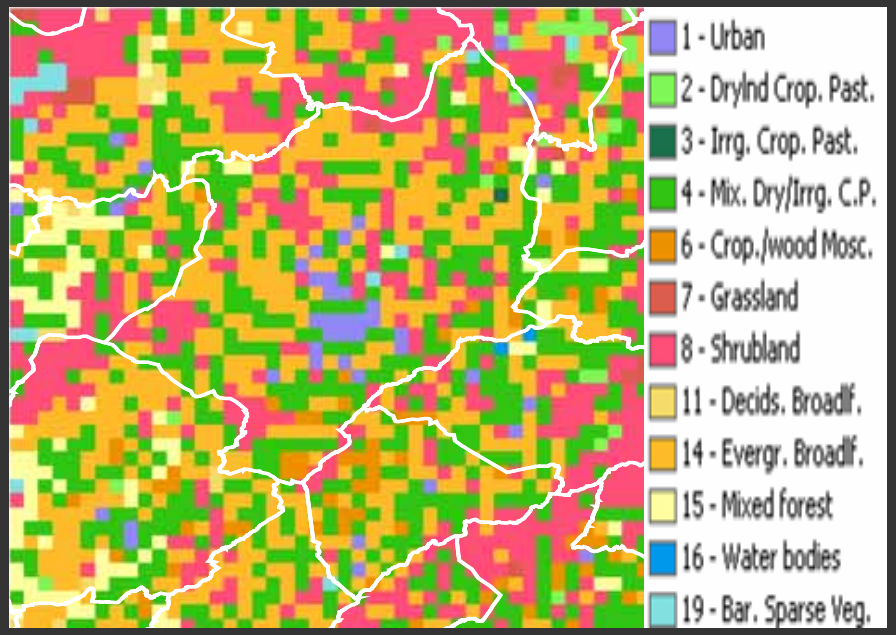


$PM_{2.5}$ annual averages tend to increase with population density (correlation r^2=0.5).

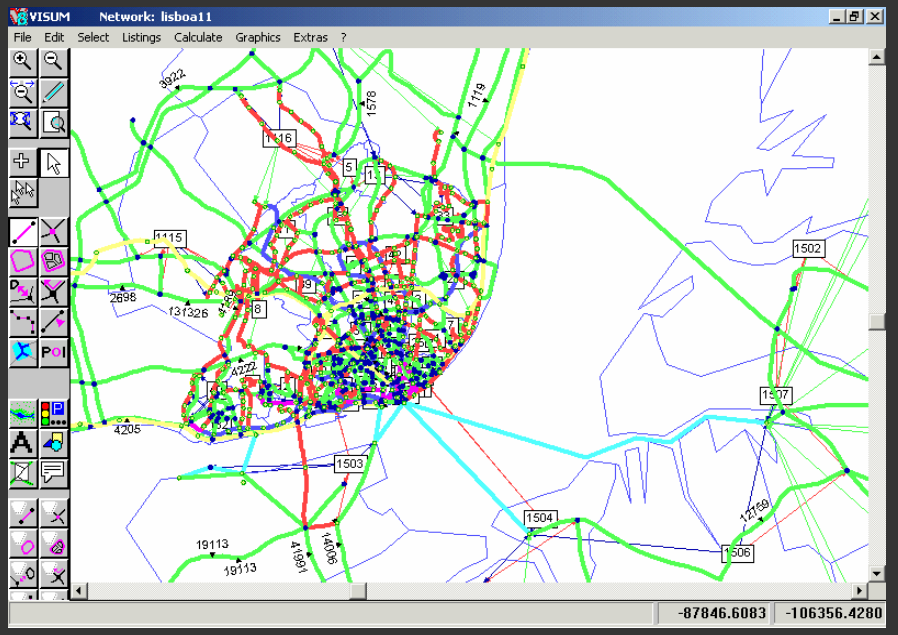
Modelling

Can we test this?

land use models



transportation models



What about air quality?

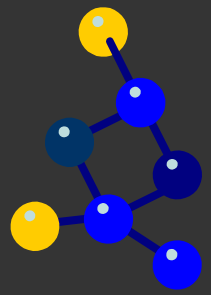
air quality Modeling

emissions

Urban structure

shape, population density, land use

transport and dispersion



chemical reactions

air quality

exposure

Modelling

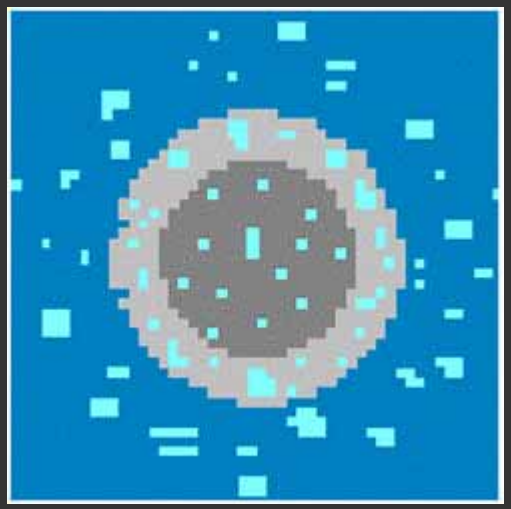
Question: how does urban structure affect air quality and consequently human exposure and health**?**

Method:

- three idealized cities have been created, considering different urban structures and land use.
- for all the land use categories (urban, suburban, and rural) different population densities have been assumed and 3 million inhabitants were distributed throughout the cities.
- transport emissions have been calculated considering different mileages and average velocities for different land use categories.

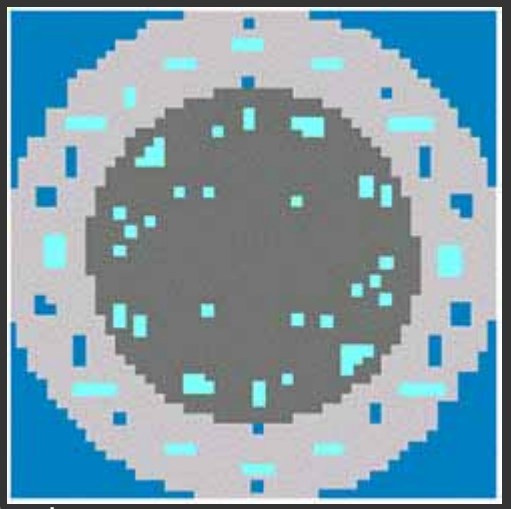
Modelling

Compact city



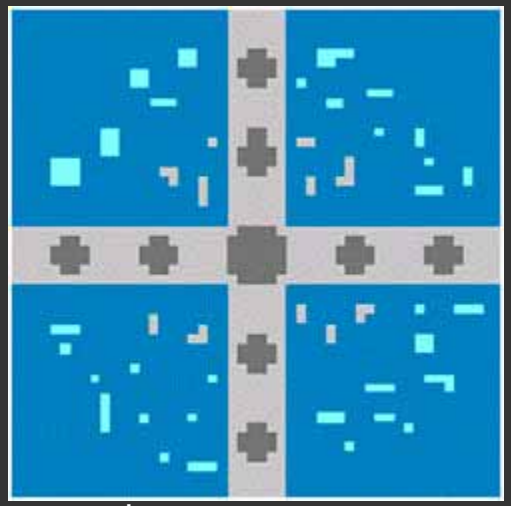
- high population density
- low area requirements
- mixed land uses (complementary functions located closed together: housing, shopping, offices)
- reduce of travel length and number of trips

disperse city



- low population density
- large area requirements
- separation into distinct zones for residential, commercial and industrial uses
- high dependence on motorized vehicles

Corridor city

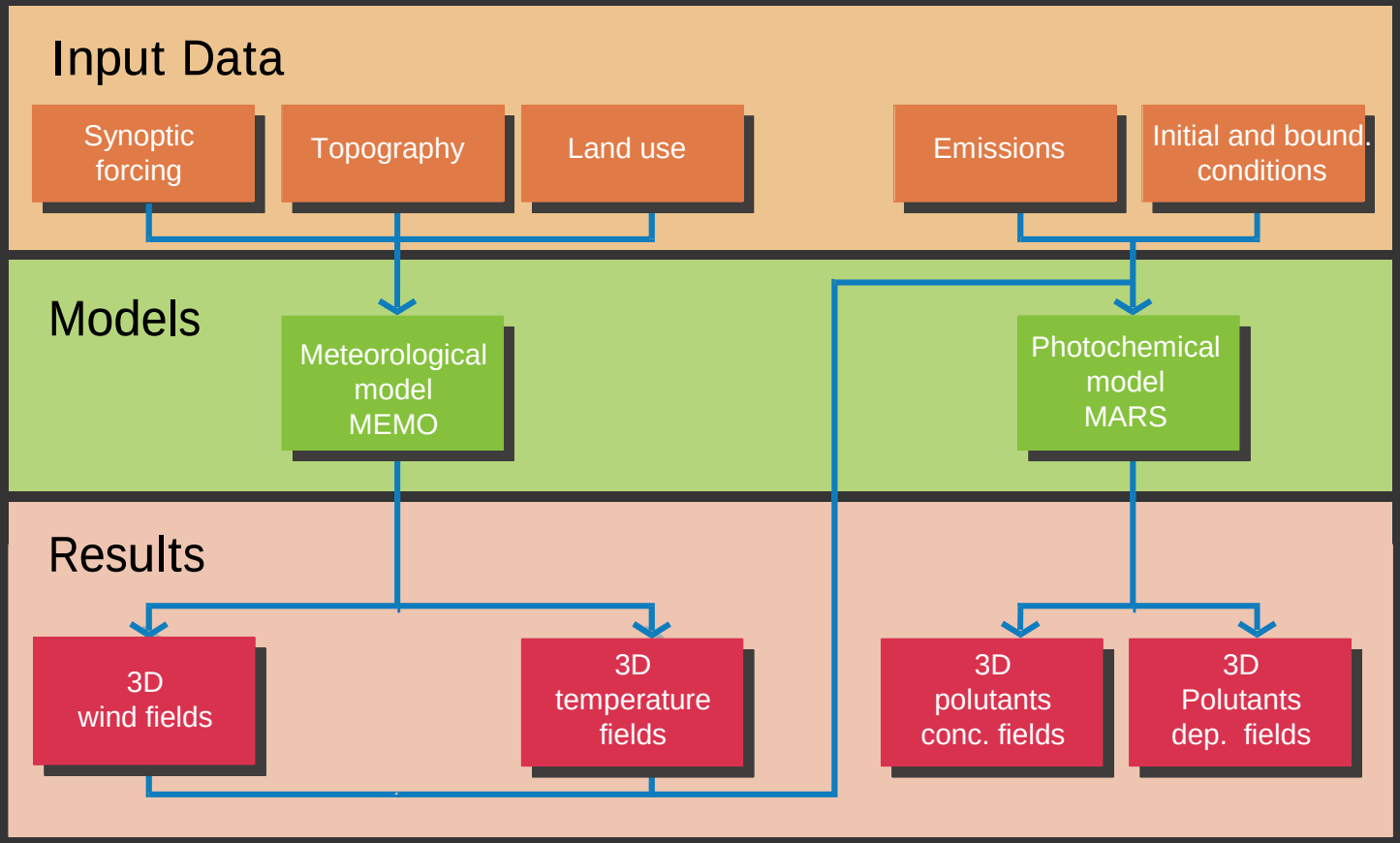


- growth in linear corridors with origin in the centre
- supported by high quality transport infrastructures
- “network city” offering partly unmixed, partly mixed functions

urban area suburban area green area rural area

Modelling

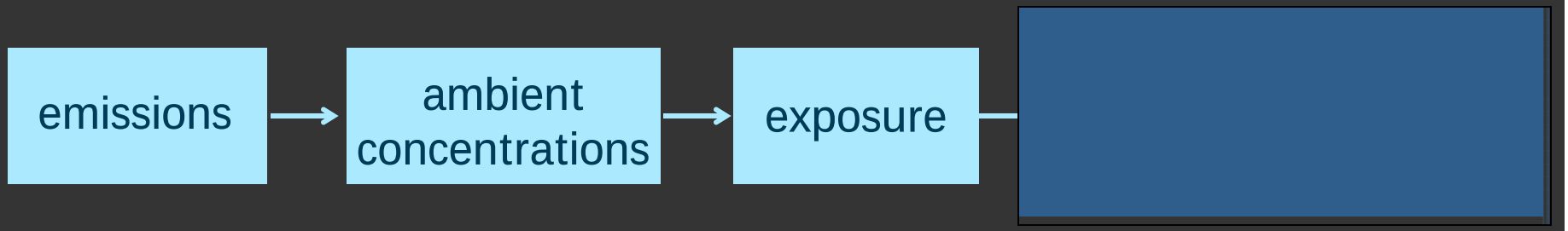
air quality



Application:
- domain: 200 km x 200 km
- horizontal grid resolution: 2 km x 2km
- synoptic situation: Iberian Peninsula typical summer day

exposure

Health effects as a chain of events…



total exposure for person *i* over the specified period of time

$$E_i = \sum_j^J C_j t_j$$

pollutant concentration in microenvironment *j*

residence time of the person *i* in microenvironment *j*

total population exposure

$$E_{pop} = \sum_i^N E_i$$

microenvironments: residences, office, school, outdoors…

Modelling

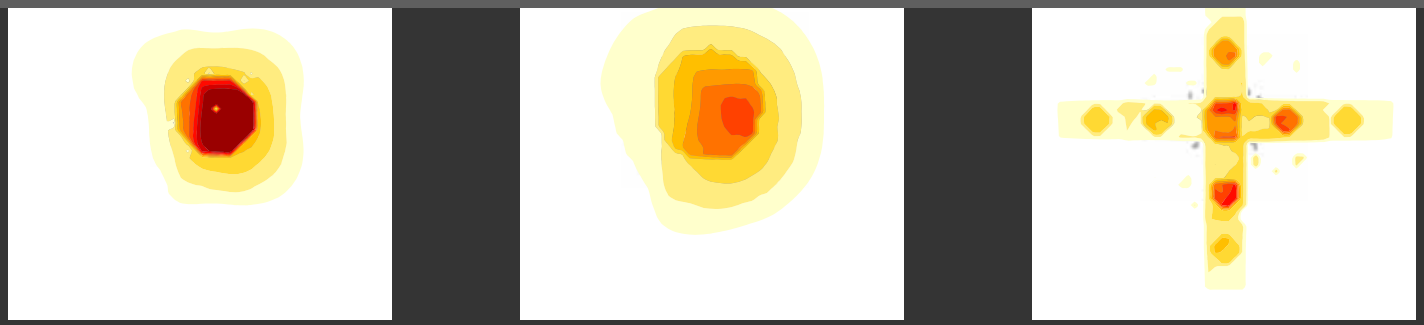
O_3 concentration fields [µg.m^{-3}] and **population exposure** [inhab. µg.m^{-3}] for each city at 14:00 UTC

Compact city | disperse city | Corridor city

conc

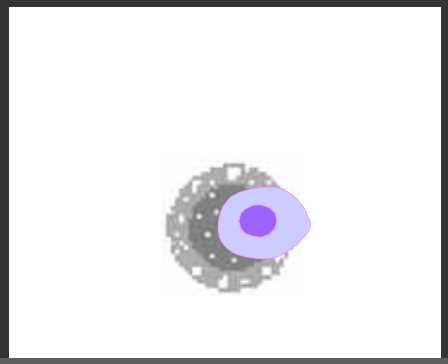
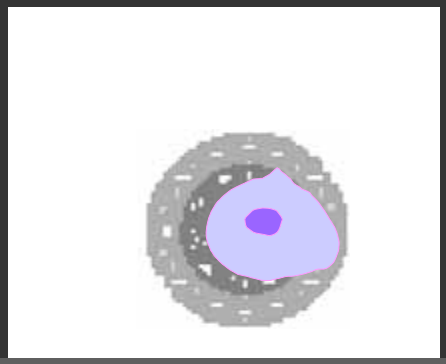
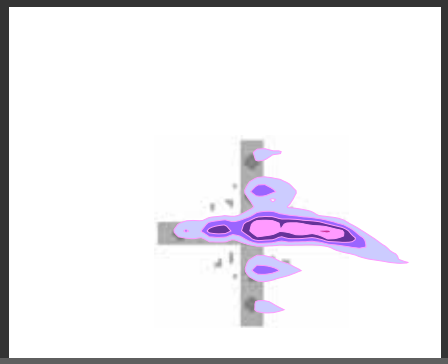
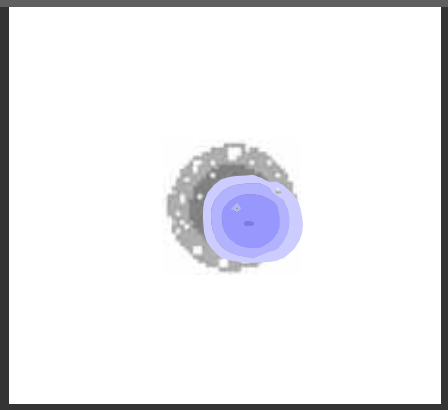
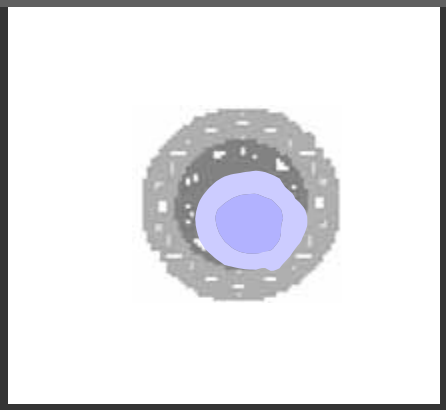
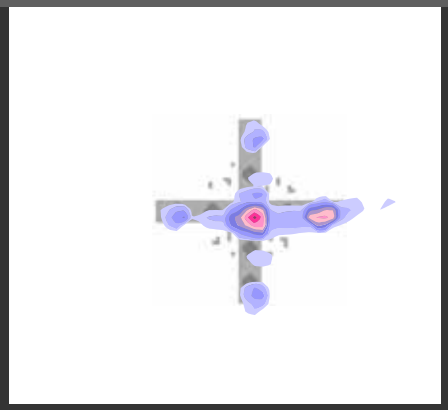
- higher O_3 concentrations and larger areas are reached in Disperse (170 µg.m^{-3}) and Corridor (160 µg.m^{-3}) cities.
- maximum exposure value for Corridor city, but Compact city evidences a larger area of higher population exposures

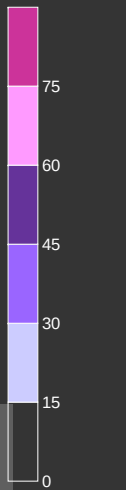
expo

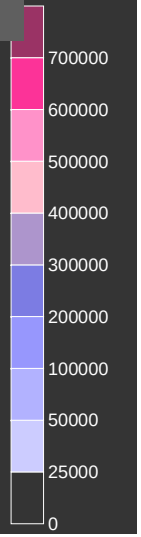


Modelling

NO_2 concentration fields [µg.m^{-3}] and **population exposure** [inhab. µg.m^{-3}] for each city at 22:00 UTC

	Compact city	disperse city	Corridor city
conc			
expo			

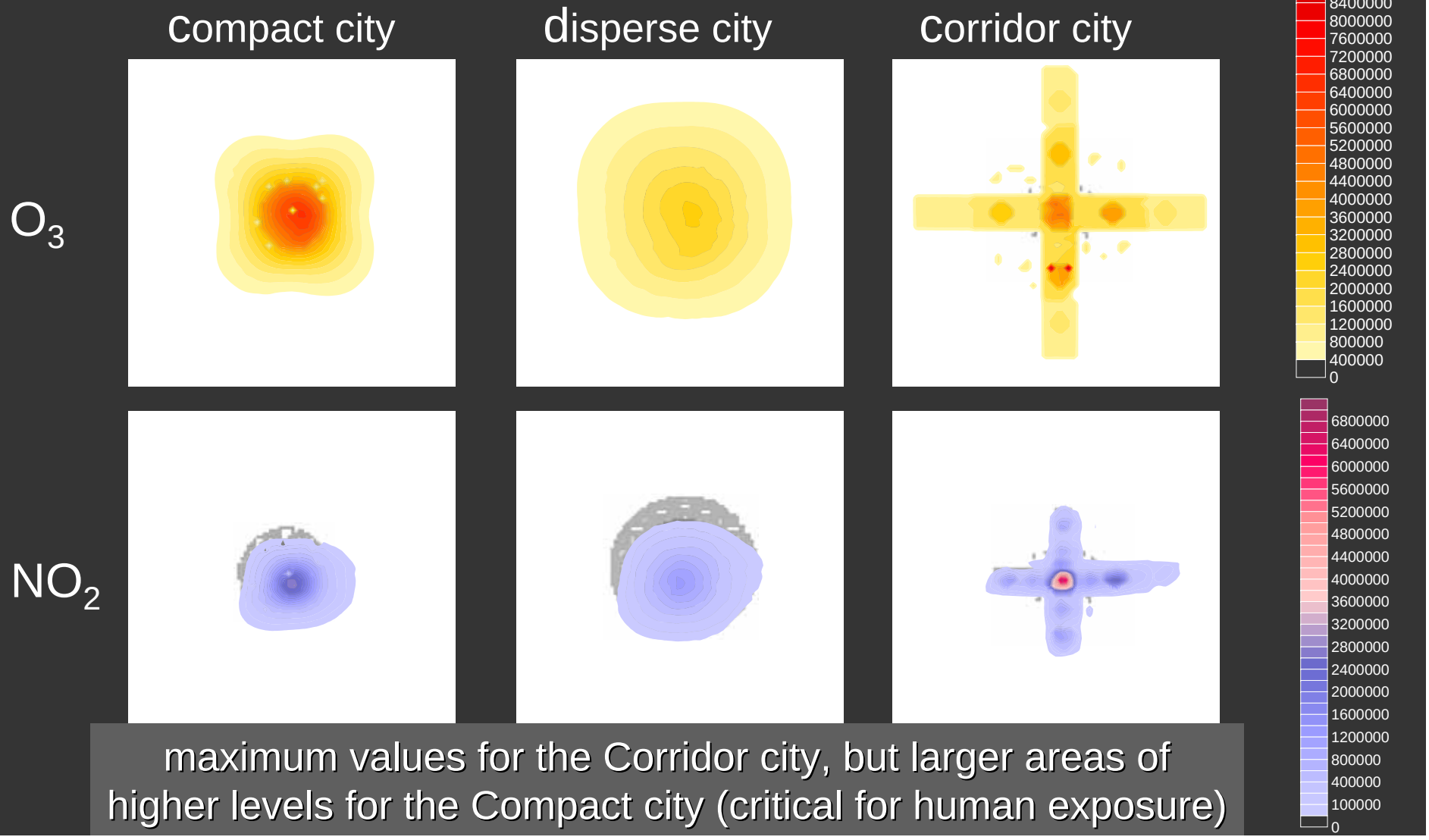




- Corridor city presents the worst situation, with maximum concentrations around 80 µg.m^{-3}, and maximum exposures.

Modelling

Daily total population exposure [inhab. µg.m^{-3}]



maximum values for the Corridor city, but larger areas of higher levels for the Compact city (critical for human exposure)

Conclusions

The need to integrate air quality aspects, including modelling, in the urban structure debate is evident.

Urban structure influences air quality, however the link is not direct.

Compact cities with mixed land-use provide better air quality compared to disperse cities

In terms of population exposure, the compact city presents the worst scenario, due to the higher population densities in areas affected by high concentrations.

In the last decades, in general, the way our cities have evolved is not in accordance with the concept of sustainable development.

There is a need to define more efficient urban spaces, at the energy and environmental levels, decreasing GHG and pollutants emissions.