Assessment of air quality in urban conglomerations, mega cities and sensitive regions

A challenge for a sustainable development of urban agglomerations from a different point of view

Peter Suppan
City of Tomorrow
Complex System – like a knitting pattern …

… or a weather forecast ensemble – 5 days ahead
Overview

- Facts
- Current Situation
- Driving Forces
- Integrated Approach
- Global Context
- Future Challenges
Urban Settlements - Facts

- In 1900 about **3 %** of the world's population lived in cities; **33 %** in the 50s - since 2007 more than **50 %**; and **3 out of 5** in 2030

- **15 %** of the urban population live in Mega-Cities (>10 Mill.)

- **37% to 49%** of global CO$_2$-emissions are released by cities (5$^{th}$ IPCC Assessment Report)

- Urban emissions have a severe impact on air quality and regional climate (Hodzic et al. 2010, Kanakidou et al. 2012, Parrish & Zhu 2009)

- **70 %** of the world wide energy is needed by urban infrastructures (5th IPCC Assessment Report)

- About **75 %** of the material flow is realized in cities

- Climate change have/will have a strong impact on urban agglomerations (e.g. heat island effect) and related processes

- Air pollution levels in urban areas depend not only on local emissions but also on regional emissions (e.g. BVOC, Papiez et al. 2009)
Driving Forces

- Quality of life (→ health-related; atmosphere, water, biosphere, soil)
- Climate change (→ extreme weather)
- Demographic change (→ adaptation needs)
- Mobility (→ general mobility; modal split)
- Management of natural and anthropogenic risks (→ flooding; mudslides)
- Increasingly scarce resources (→ construction material)
- Sustainable development (→ city planning and construction)
Any other driving forces?
PM - annual mean concentrations per city

Associated with 15% higher mortality risk

WHO Air quality guideline

Source: WHO, 2014
PM - annual mean concentrations per country

Source: WHO, 2014
Mortality Effects Assessment – Example China


Prof. C. Arden Pope III, Thursday 8am
Associated with 15% higher mortality risk

WHO Air quality guideline
Rather Complex System — like a puzzle ...

Source: esotericastrologer.org
Driving forces

- Land Use Change

Mexico City
„Non-Anthropogenic“ Land Use Change

1: Beijing
2: Gobi Desert
3: Taklamakan Desert

Source: Stefan Norra (KIT/AGW)
„Anthropogenic“ Land Use Change

<table>
<thead>
<tr>
<th></th>
<th>Santiago de Chile</th>
<th>Mexico City</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Year</strong></td>
<td>2002</td>
<td>2005</td>
</tr>
<tr>
<td><strong>Population</strong></td>
<td>6,061,000</td>
<td>19,410,000</td>
</tr>
<tr>
<td><strong>Urbanized area (km²)</strong></td>
<td>641</td>
<td>1,800</td>
</tr>
<tr>
<td><strong>Population density (p / km²)</strong></td>
<td>9,500</td>
<td>10,800</td>
</tr>
<tr>
<td><strong>Population growth (% / y)</strong></td>
<td>~1.32</td>
<td>~1.28</td>
</tr>
</tbody>
</table>

Source: Poduje 2005 (Santiago de Chile)  
APERC 2007 (Mexico City)
Visual Effects

50 µg/m³

344 µg/m³

Photos: Matthias Tesche, IfT, Leipzig
Source Apportionment: Local Impact at Beijing

18.04.2006

Photos: Stefan Norra (KIT/AGW)
Impact on particles, e.g. PM$_{10}$

Beijing

Source: Stefan Norra (KIT/AGW)
Analysis on PM$_{2.5}$ and PM$_{10}$ source attribution

Impact of geogenic / anthropogenic emissions on local/regional air quality

Mesoscale-models can be used for mineral dust forecast in China

Classification of dust source types for dust event impact studies

PhD Thesis Stephanie Schrader, 2014: Analysis of the spatial distribution of airborne particles in the greater area of Beijing via modeling and satellite remote sensing
Identification of Particle Sources
Anthropogenic, Biogenic, Geogenic

Beijing

mean: 89 µg m⁻³

24 h PM₂.₅ threshold values:
WHO: 25 µg m⁻³
US-EPA: 35 µg m⁻³
China (Grade II): 75 µg m⁻³

Green: „Clean“ days
Red: Smog-days

Effect of Land Use Change

Temperature difference with and without urban sprawl

Diurnal variation of ozone concentrations considering land use change

Source: Forkel (IMK-IFU)
Driving forces

- Land Use Change
- Energy
Energy Consumption

... by Sources

<table>
<thead>
<tr>
<th></th>
<th>Industry</th>
<th>Transport</th>
<th>Residential</th>
</tr>
</thead>
<tbody>
<tr>
<td>Beijing</td>
<td>75%</td>
<td>8%</td>
<td>17%</td>
</tr>
<tr>
<td>Shanghai</td>
<td>83%</td>
<td>10%</td>
<td>7%</td>
</tr>
<tr>
<td>Seoul</td>
<td>38%</td>
<td>25%</td>
<td>37%</td>
</tr>
<tr>
<td>Tokio</td>
<td>41%</td>
<td>37%</td>
<td>22%</td>
</tr>
<tr>
<td>Mexiko City</td>
<td>38%</td>
<td>44%</td>
<td>18%</td>
</tr>
</tbody>
</table>


Source:
- Eurostat, European Union
- U.S. Energy Information Administration
Global Final Energy Consumption

Source: REN21, RENEWABLES 2017, GLOBAL STATUS REPORT
Bioenergy from Plants

Source: Crutzen et al., 2008
Bioenergy from Plants

GHG Emissions / GHG Savings

Source: Crutzen et al., 2008

Disciplines in Energy- & Technology Development

Increase of GHG-emissions

Reduction of GHG-emissions

Plant N content [g N kg$^{-1}$ DW]

Sugar cane

Wheat/Barley

Maize/root crops etc.

Rapeseed

CO$_2$-Eq-Bioenergy / CO$_2$-Savings

GHG Emissions

GHG Savings
Driving forces

- Land Use Change
- Energy
- Mobility
Traffic

Economical background of vehicle ownership
Vehicle purchase max GDP 3000-4000 $
Which will be reached in China in about 10-15 y

Source: World Bank, 2010
Traffic: Coupling of Scales

Exceeding of threshold values

Mesoscale modelling e.g. of NO$_2$

Disciplines in Traffic & Transportation Sciences

Source: EU-LIFE Project
Klagenfurt Graz Bozen

Microscale modelling e.g. of NO$_2$
Mobility

Exceeding of threshold values

...did we miss something???

Mesoscale modelling e.g. of NO$_2$

Microscale modelling e.g. of NO$_2$

Source: EU-LIFE Project
Klagenfurt Graz Bozen
Driving forces

- Land Use Change
- Energy
- Mobility
- Social Sciences
Development of Scenarios

Scenarios based on Development paths of social driving factors (→ til 2030)

- economical development, institutional framework conditions, demography, technical development, social systems of values

Business-as-usual (BAU)

Continuation of liberalization and privatization trends, persistence of strong market forces and weak public regulation activities, continuation of existing social protection measures and subsidy schemes for the poorest

Collective Responsibility (CR)

Characterized by social and environmental justice as principal goals of public regulation, strong regulation of market activities and large public investments, together with the embedding of technologies in society and decoupling of socioeconomic development from resource use

Market Individualism (MI)

Increasing individual freedom and freedom of action, markets as the dominant vehicle for all societal transactions, together with resources and services generation and distribution strongly subject to supply and demand principles.
Air Pollution Distribution

Annual mean NOx distribution for 2006 (only traffic emissions) in the Greater Region of Santiago de Chile


BAU - business as usual
MI - market individualism
CR - collective responsibility

~ 60% reduction
Annual mean NOx distribution for 2006 (only traffic emissions) in the Greater Region of Santiago de Chile

Social Sciences

...further implications on air quality???

~ 60% reduction

Driving Forces

- Land Use Change
- Energy
- Mobility
- Social Sciences
- Climate Change
Global Modelling Results

Impact of climate change on urban settlements

Resolution is still too coarse for regional interpretation
Regional Climate Change Impact

High resolution climate-chemistry simulations - Mexico -

Source: Forkel (IMK-IFU)
Climate Change: Challenge for Cities

- 37% to 49% of global CO₂-emissions are released by cities
- 70% of the world wide energy is needed by urban infrastructures

Limitation of global temperature increase below 2°C, preferably 1.5°C.

Source: Fuss et al 2014; CDIAC: Global Carbon Budget 2015
Climate Change: Other Impacts

- Impact on global climate (and weather)
- Modification of atmospheric radiation
- Feedback mechanisms between particles – clouds – temperature
Integrated Approach

- Land use change
- Energy
- Mobility
- Social science
- Climate change

- Air quality & well being
- Health impact
- Economical benefit
- Land use change
- Energy
- Mobility
- Social science
- Climate change

- Air quality & well being
- Health impact
- Economical benefit

...did we miss a faculty or science community???
...well being...
Health and Quality of Life Issue

Heat waves and mortality

Source: Vandentorren et al. 2004
Urban Heat Island (UHI): Phenomena

- "Urban Heat Island" (UHI) refers to the tendency for a city or town (urbanized areas) to remain **warmer than its surroundings**.

- The **annual mean temperature** of a large city may be 1°–2°C warmer than the surrounding areas, and on individual calm, clear **nights** may be up to 12°C warmer (→ Heat Island Intensity).

- **Closed isotherms** indicating an area of the surface (→ island) that is relatively warm; most commonly associated areas of human disturbance such as towns and cities (urbanized areas).

- The warmth extends vertically to form an **urban heat dome** in near calm, and an **urban heat plume** in more windy conditions.

Source: Lawrence Berkeley National Lab.
Source: NASA Global Hydrology and Climate Center
UHI: Intensity and Magnitude

Source: Chow & Roth, 2006

Source: EPA, 2009
UHI: Mitigation Measures …

- Increasing albedo
  reflectivity of surfaces / buildings, …

- Increasing vegetation cover
  green roofs, parks, avenue trees, …

- Decreasing runoff
  open water spaces, ponds, control of impervious surface areas, …

- Decreasing anthropogenic heating
  air conditioning, industrial facilities, …

- Increasing structural and natural shading
  ancient city structures

Photo: Mstyslav Chernov
Particles & Health

344 µg/m³
2005/01/22
Foto: S. Norra

50 µg/m³
2005/01/18
Foto: Matthias Tesche, IfT

Geogenic

Urban Particles

Anthropogenic

Adverse Health Effects: Santiago de Chile

Mortality Risks per 10 µg/m³ PM$_{10}$

Franck, U., Leitte, A., Suppan, P., 2014: Respiratory diseases in Santiago de Chile are related to multiple airborne exposures more than to exposure by a single pollutant. Science of the Total Environment

Escuela Internacional de Desarrollo Sostenible
Medellin / Colombia – Octubre 31, 2017
Economical Benefit

Reduction benefit is 10 times higher as for ozone, e.g. Mexico City about $2 Bill.

Source: M. Krzyzanowski & H-G. Mucke, WHO update by Jordan et al, CEPAL
Summary: Integrated Approach

Urban Development

Measurement Data

Emission Data

Air Quality & Climate Change Approach

Air Pollutants - Mortality rates

Elements at Risk

Governance

Health Impact

Stakeholder

Mortality

Subclinical Effects

Scenario

WRF Chem

GRAL Chem

Air Quality

Traffic Data

Approach

Emission Data

Urban Development

Measurement Data

Emission Data

Air Quality & Climate Change Approach

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Mortality

Subclinical Effects

Scenario
Maximal daily risk increase per 10 µg/m³ PM10

<table>
<thead>
<tr>
<th>Disease Group</th>
<th>Maximal Daily Risk Increase</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hypertensive diseases</td>
<td>8.4</td>
</tr>
<tr>
<td>Ischemic heart diseases</td>
<td>6.3</td>
</tr>
<tr>
<td>Influenza and pneumonia</td>
<td>7.4</td>
</tr>
<tr>
<td>Other heart diseases</td>
<td>8.2</td>
</tr>
<tr>
<td>Chronic lower resp. dis.</td>
<td>8.9</td>
</tr>
</tbody>
</table>

**Measurement Data**

<table>
<thead>
<tr>
<th>Indicator</th>
<th>Scenario</th>
<th>Stakeholder</th>
<th>Health Impact</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fine particles &gt; 10 nm / cm³</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Coarse particles &gt; 300 nm / cm³</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Ozone [ppb]</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Approach**

- Air Quality & Climate Change
- Stakeholder Engagement
- Health Impact
- Subclinical Effects

**Emission Data**

- Elements at Risk
- Air Pollutants

**Urban Development**

- Land use change
- Energy
- Mobility
- Climate change
- Air quality & well being
- Governance
- Economic benefit

**Emissions from fossil fuels and cement (GtCO₂/yr)**

- Data: CDP-CC, etc.
- Emissions reduction targets
- Greenhouse gas emissions
- Policy measures
- Mitigation strategies

**Concept of bringing disciplines together**
... within a Research Program (2007-2011)

Risk Habitat Megacity

¿sostenibilidad en riesgo?

Source: http://www.ufz.de/risk-habitat-megacity/index.php?de=15003
A little bit less complex
.... or like this:
How do we want to live tomorrow?
Global Context:
2030 Agenda for Sustainable Development

adopted at the UN Sustainable Development Summit September 25–27, 2015 in New York

Source: www.un.org
Global Context:
Towards a New Urban Agenda

HABITAT I 1976
WORLD URBAN POPULATION
37.9%

In 1976 the first Habitat Conference in Vancouver
• recognized the need for sustainable human settlements and
• the consequences of rapid urbanization, especially in the developing world.

➔ Creation of the United Nations Center for Human Settlements (UNCHS-Habitat)

Source: http://habitat3.org/the-new-urban-agenda
Global Context:
2030 Agenda for Sustainable Development
THE GLOBAL CONTEXT

Cities today occupy approximately only 2% of the total land, however:

- 70% Economy (GDP)
- Over 60% Global Energy Consumption
- 70% Greenhouse Gas Emissions
- 70% Global Waste

Source: http://habitat3.org/the-new-urban-agenda
Perspective 1 – Heat-Resilient Cities

Traditional ideas

Photo: Holger Reineccius

Beni Izguen, Algerien
Perspective 2 – Whiter and Cooler Cities
Traditional ideas

Santorini Island, Greece

Photo: Mstyslav Chernov,
http://upload.wikimedia.org/wikipedia/commons/c/c1/Oia_%28panoramic_cityscape%29__Santorini_island_%28Thira%29%2C_Greece.jpgn.jpg
Perspective 3 – Multiple Use of Traffic Lines
Restructuring existing cities

Source: www.fosterandpartners.com
Perspective 4 – Housing and Urban Green (Vertical Forests) 
Restructuring existing cities

Source: www.stefanoboeriarchitetti.net
Perspective 5 – new architecture for housing, greening, traffic, energy, society
Restructuring existing cities

Source: www.nationale-plattform-zukunftsstadt.de
Perspective 6 – Completely New Designed Cities – Masdar City - Planning new cities

Source: www.fosterandpartners.com
Challenges & Future Perspective
Airborne Measurements

UAV or drone (hexacopter)

1. Air temperature and humidity sensors
2. Teflon tube
3. Tube extension above hexacopter
Smart networks

(a)

(b)

Smart Air Quality Network

funded by the German Ministry of Traffic and Digital Infrastructure

Figure 1. (a) Sharp GP2Y1010 dust sensor and operation principle, and (b) prototypical implementation with modified emitter-receptor configuration embedded in the back shell of an otherwise unaltered phone.

Source: Emeis (IMK-IFU)
Urban-Rural Interactions
Cities as Reaction Vessels

Internal processes and exchange with surrounding compartments of the Earth system

- urban wind and radiative regimes
- secondary circulations and matter transports
- urban heat island(s)
- natural and biogenic emissions (inside and outside of cities)
- anthropogenic emissions
- air chemistry, aerosol formation
- impact on local and regional air quality
- impact on regional and global climate
- source apportionment

Source: http://mce2.org/wmogurme/
Summary

Aerosol Chemistry & Physics

Impact of anthropogenic - biogenic emissions on urban climate – health – air quality

Mitigation & Adaptation strategies
Overcoming the Scales

...from measurements to modeling
...from the micro to the macro scale and vice versa
A holistic and interdisciplinary approach is the main goal for a successful sustainable development of cities and a step forward for improving the air quality...

...but there is an absolute need of in-depth research in each discipline

Complex processes can only be described and assessed by multi-scale modeling

Also the scenario development (mitigation & adaptation) needs multidisciplinary views and approaches

High quality standards are needed not only for the urban level but also for the regional surrounding of cities

„It is now understood that the battle against climate change will likely be won - or lost - in cities......targeted research at the city level is needed to enable policy makers to understand the magnitude of the impacts ...... (World Bank 2008)“
... or can we do it more easier?
Muchas gracias por su atención
and best regards from Germany