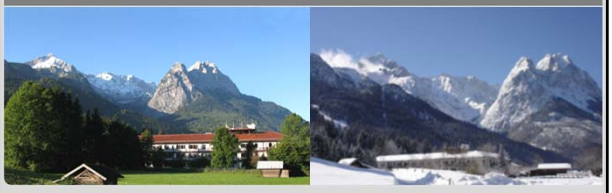
Assessment of air quality in urban conglomerations, mega cities and sensitive regions

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

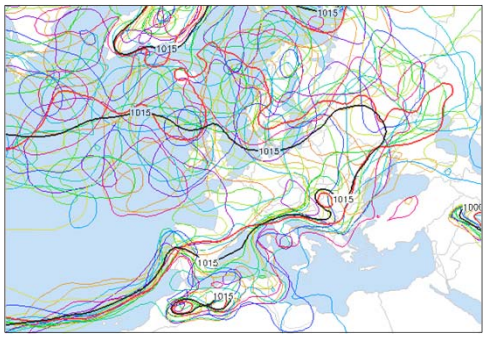
Peter Suppan

Karlsruhe Institute of Technology (KIT), Institute of Meteorology and Climate Research (IMK-IFU), Campus Alpin, Garmisch-Partenkirchen, Germany



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 worlds 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 (5th 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 ???
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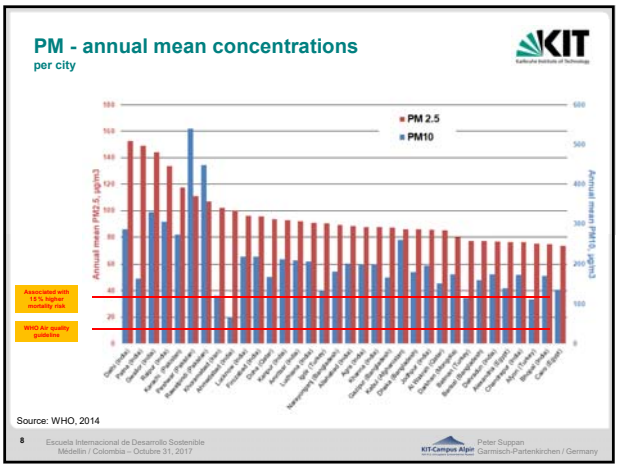
PM - annual mean concentrations
per city
PM 2.5
PM10
Annual mean PM2.5, µg/m3
Annual mean PM10, µg/m3
Associated with 15 % higher mortality risk
WHO Air quality guideline
Source: WHO, 2014
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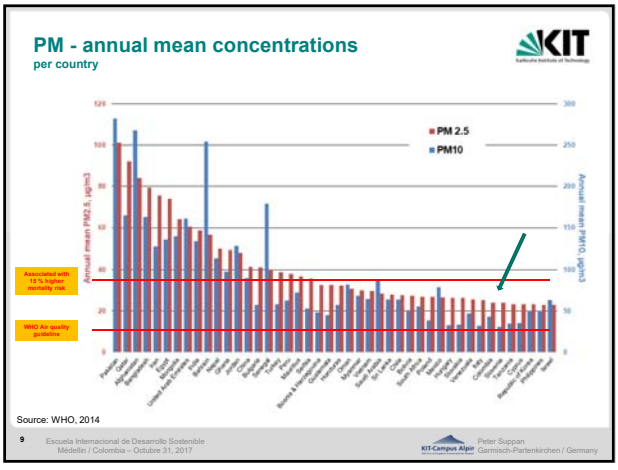
PM - annual mean concentrations
per country
PM 2.5
PM10
Annual mean PM2.5, µg/m3
Annual mean PM10, µg/m3
Associated with 15 % higher mortality risk
WHO Air quality guideline
Source: WHO, 2014
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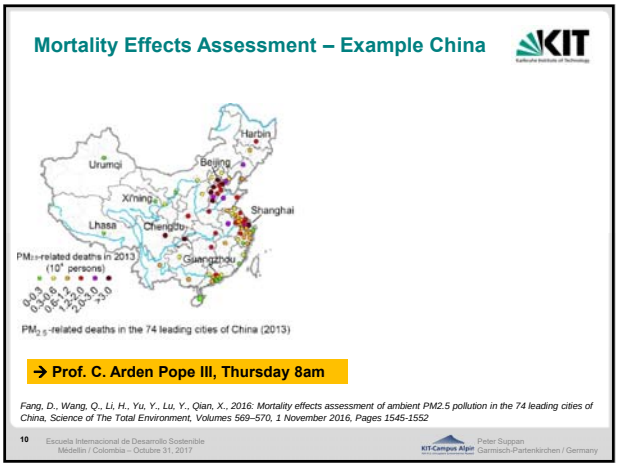
Mortality Effects Assessment – Example China
Harbin
Urumqi
Beijing
Xi'ning
Shanghai
Lhasa
Chengdu
Guangzhou
PM2.5-related deaths in 2013 (10^4 persons)
PM2.5-related deaths in the 74 leading cities of China (2013)
→ Prof. C. Arden Pope III, Thursday 8am
Fang, D., Wang, Q., Li, H., Yu, Y., Lu, Y., Qian, X., 2016: Mortality effects assessment of ambient PM2.5 pollution in the 74 leading cities of China, Science of The Total Environment, Volumes 569–570, 1 November 2016, Pages 1545-1552
10
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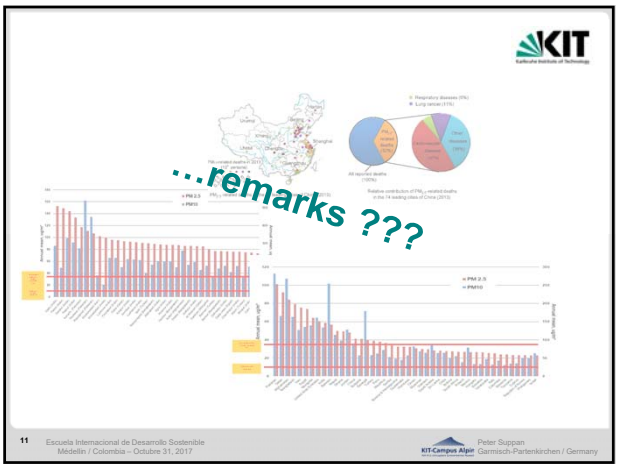
…remarks ???
11
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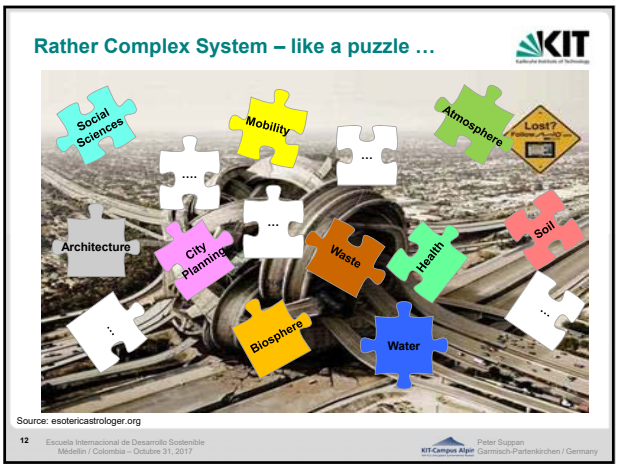
Rather Complex System – like a puzzle …
Social Sciences
Mobility
Atmosphere
Lost?
Architecture
City Planning
Waste
Health
Soil
Biosphere
Water
Source: esotericastrologer.org
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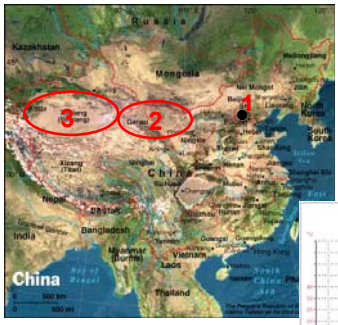
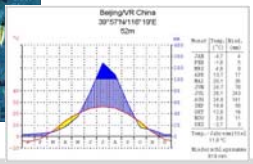
Driving forces

- Land Use Change

„Non-Anthropogenic“ Land Use Change



1: Beijing
2: Gobi Desert
3: Taklamakan Desert

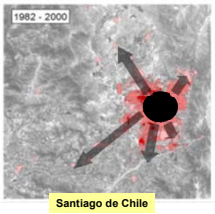


Source: Stefan Norra (KIT/AGW)

„Anthropogenic“ Land Use Change

	Santiago de Chile 2002	Mexico City 2005
Population	6.061.000	19.410.000
Urbanized area (km²)	641	1800
Population density (p / km²)	9.500	10.800
Population growth (% / y)	~1,32	~1,28

Source:
Podujle 2005 (Santiago de Chile)
APERC 2007 (Mexico City)

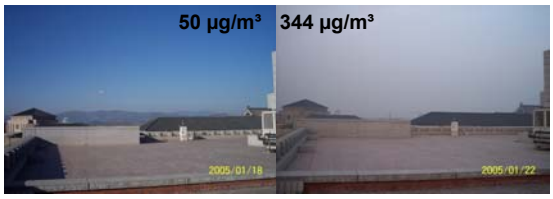


Santiago de Chile

Mexico City

Source:
U. Weiland, E. Banzhaf, A. Ebert, A. Kindler, R. Höfer (UFZ)

Visual Effects



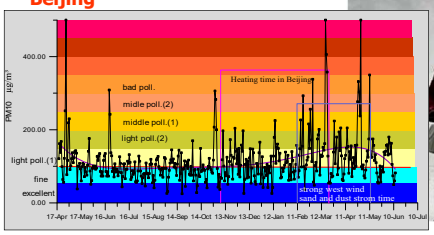
Photos: Matthias Tesche, IfT, Leipzig

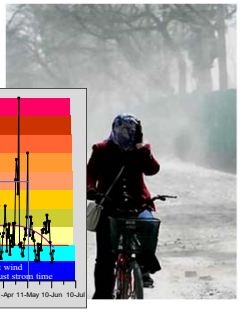
Source Apportionment: Local Impact at Beijing

Photos: Stefan Norra (KIT/AGW)

Impact on particles, e.g. PM_{10}

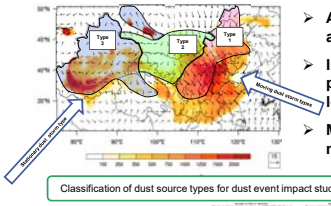
Beijing





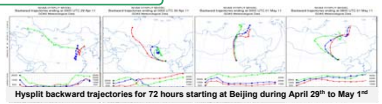
Source: Stefan Norra (KIT/AGW)

Source Apportionment



- 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



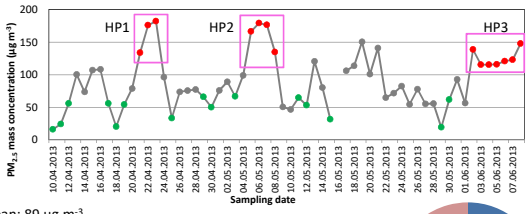
Hysplit backward trajectories for 72 hours starting at Beijing during April 29th to May 1st

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

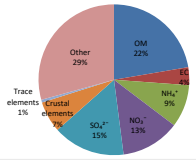
Beijing



mean: 89 µg m^{-3}

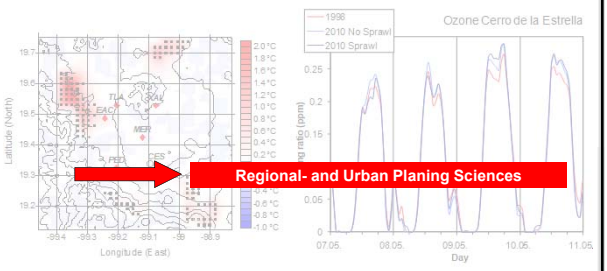
24 h $PM_{2.5}$ threshold values:
WHO: 25 µg m^{-3}
US-EPA: 35 µg m^{-3}
China (Grade II): 75 µg m^{-3}

Green: „Clean" days
Red: Smog-days



PhD Thesis: Rongrong Shen, 2015: Annual variation of chemical composition and source apportionment of particulate matter in Beijing

Effect of Land Use Change



Regional- and Urban Planing Sciences

Temperature difference with and without urban sprawl

Diurnal variation of ozone concentrations considering land use change

Source: Forkel (IMK-IFU)

Driving forces

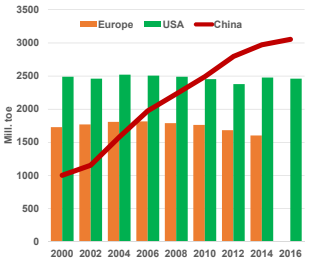
- Land Use Change
- Energy

Energy Consumption

… by Sources

	Industry	Transport	Residential
Beijing	75%	8%	17%
Shanghai	83%	10%	7%
Seoul	38%	25%	37%
Tokio	41%	37%	22%
Mexiko City	38%	44%	18%

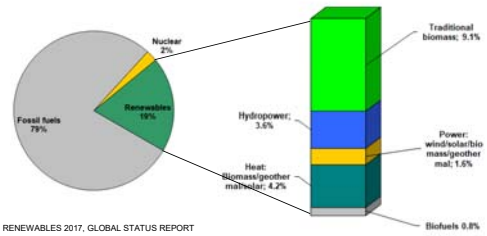
… by Regions



Source: APERC 2007, Shobhakar Dhakal (2004). Urban Energy Use and Greenhouse Gas Emissions in East Asian Megacities

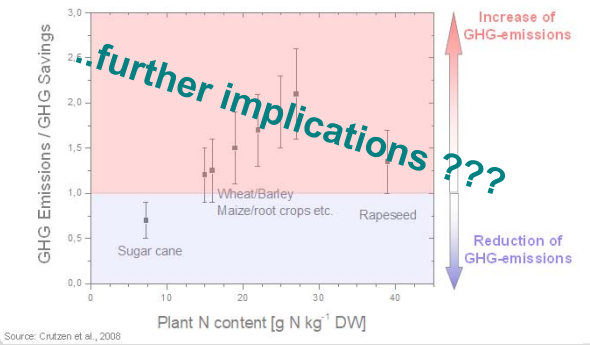
Source:
- Eurostat, European Union
- U.S. Energy Information Administration
- www.statista.com, https://yearbook.enerdata.net/total-energy/

Global Final Energy Consumption



Source: REN21, RENEWABLES 2017, GLOBAL STATUS REPORT

Bioenergy from Plants



Source: Crutzen et al., 2008

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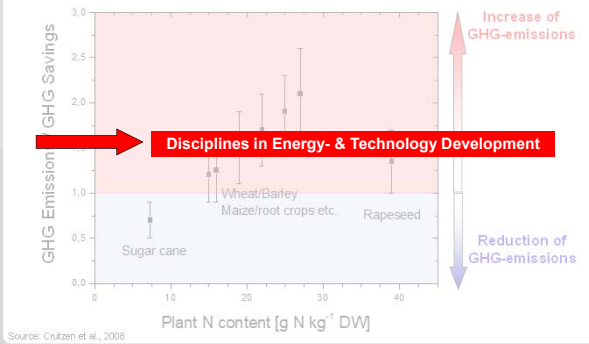
Bioenergy from Plants



Source: Crutzen et al., 2008

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Driving forces

- Land Use Change
- Energy
- Mobility

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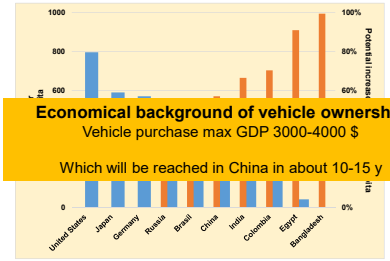
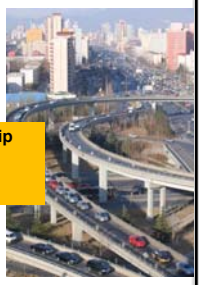
Traffic



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

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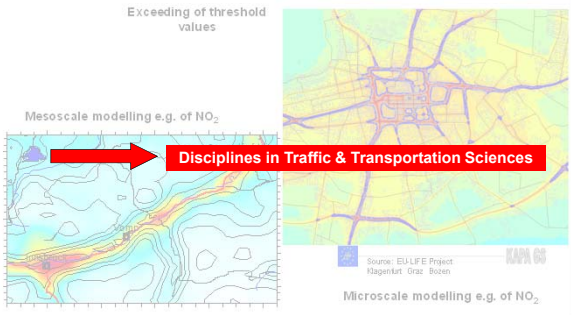
Traffic: Coupling of Scales



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Mobility

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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)

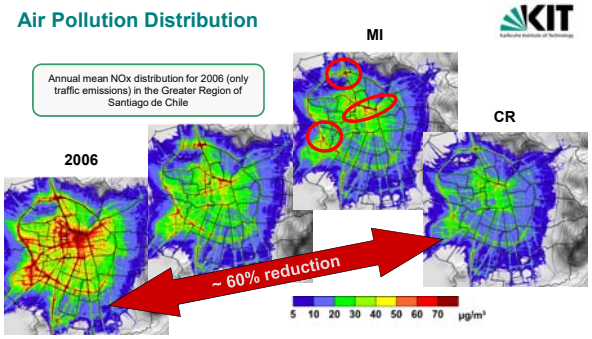
Characterized by social and environmental justice as principal goals of public regulation, strong regulation of market activities and large public investments, together with the embedding of technologies in society and decoupling of socioeconomic development from resource use

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

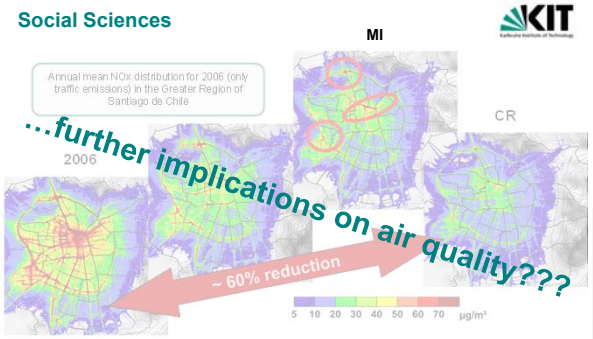
Annual mean NOx distribution for 2006 (only traffic emissions) in the Greater Region of Santiago de Chile



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

Social Sciences

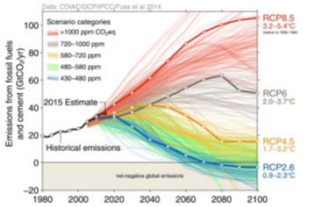
Annual mean NOx distribution for 2006 (only traffic emissions) in the Greater Region of Santiago de Chile



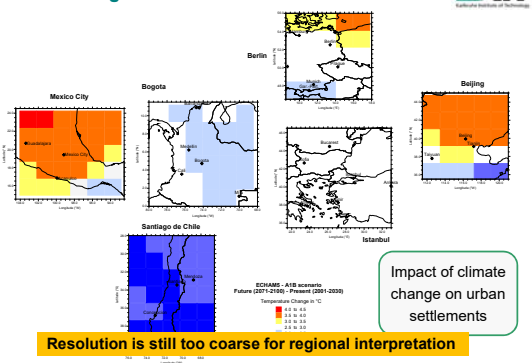
BAU - business as usual
MI - market individualism
CR - collective responsibility

Driving Forces

- Land Use Change
- Energy
- Mobility
- Social Sciences
- Climate Change



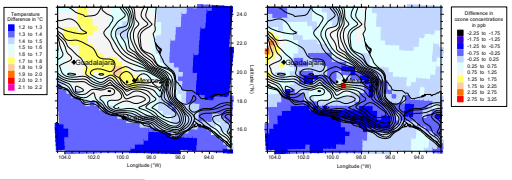
Global Modelling Results



Impact of climate change on urban settlements

Resolution is still too coarse for regional interpretation

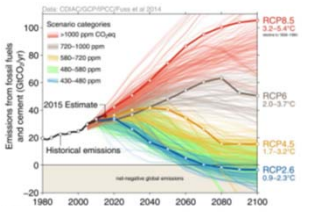
Regional Climate Change Impact



High resolution climate-chemistry simulations
- Mexico -

Source: Forkel (IMK-IFU)

Climate Change: Challenge for Cities



- 37% to 49% of global CO_2-emissions are released by cities
- 70 % of the world wide energy is needed by urban infrastructures

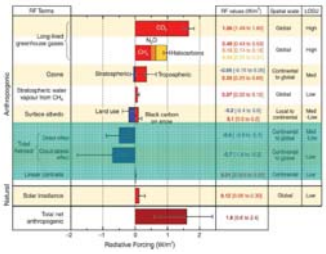
5th IPCC Assessment Report

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

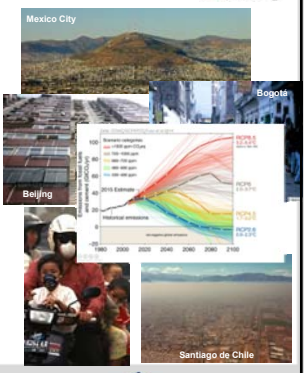
- **Impact on global climate (and weather)**
- **Modification of atmospheric radiation**
- **Feedback mechanisms between particles – clouds – temperature**



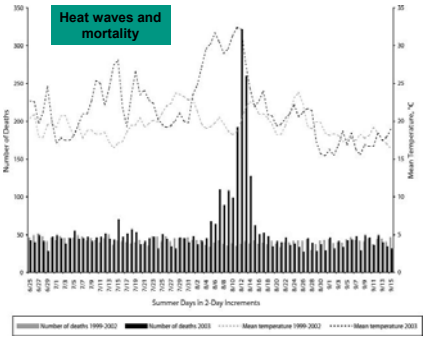
Integrated Approach

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

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



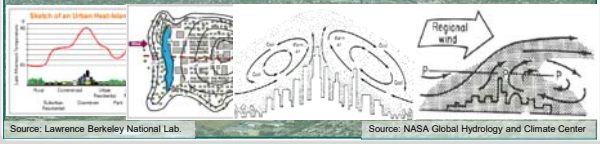
Health and Quality of Life Issue



Source: Vandentorren et al. 2004

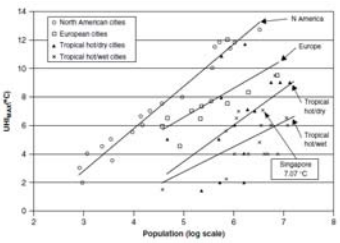
Urban Heat Island (UHI): Phenomena

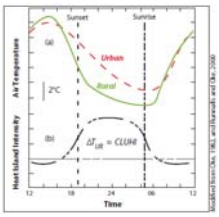
- "Urban Heat Island" (UHI) refers to the tendency for a city or town (urbanized areas) to remain **warmer than its surroundings**.
- The **annual mean temperature** of a large city may be **1°–2°C warmer** than the surrounding areas, and on individual calm, clear **nights** may be up to **12°C warmer (→ 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





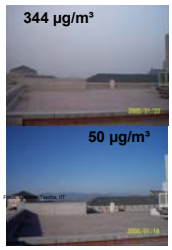
Source: Chow & Roth, 2006 Source: EPA, 2009

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



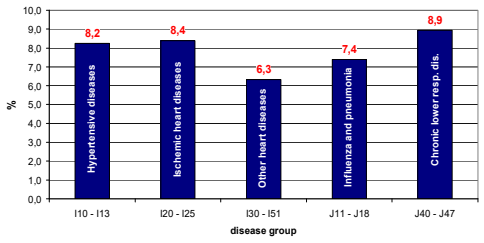
Geogenic

Urban Particles

Anthropogenic

Shao, L., Hu, Y., Shen, R., Schäfer, K., Wang, J., Wang, J., Schnelle-Kreis, J., Zimmermann, R., BéruBé, K., Suppan, P.: Seasonal variation of particle-induced oxidative potential of airborne particulate matter in Beijing, Science of the Total Environment 579 (2017) 1152–1160

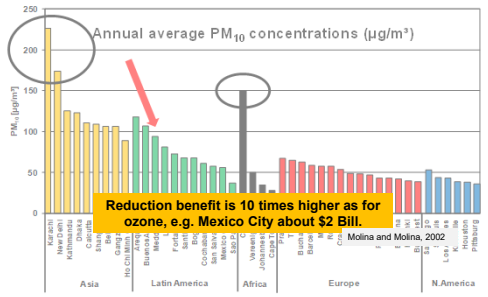
Adverse Health Effects: Santiago de Chile



Mortality Risks per 10 µg/m³ PM_{10}

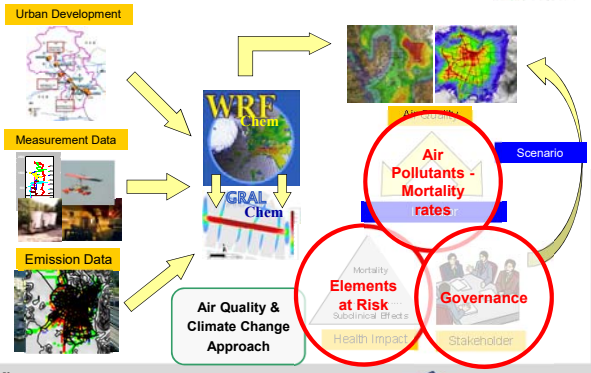
Franck, U., Leitte, A., Suppan, P., 2014: Respiratory diseases in Santiago de Chile are related to multiple airborne exposures more than to exposure by a single pollutant. Science of the Total Environment

Economical Benefit



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

Summary: Integrated Approach

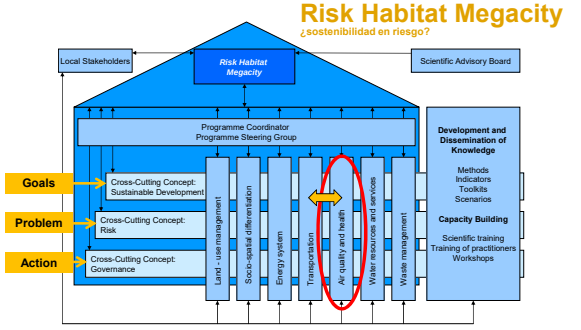


...concept of bringing disciplines together...

... within a Research Program (2007-2011)

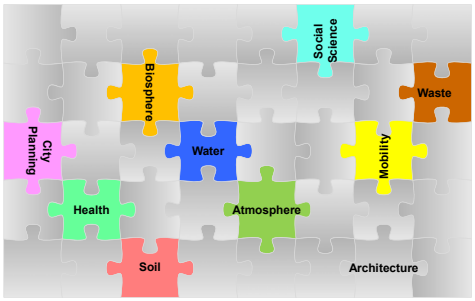
Risk Habitat Megacity

¿sostenibilidad en riesgo?

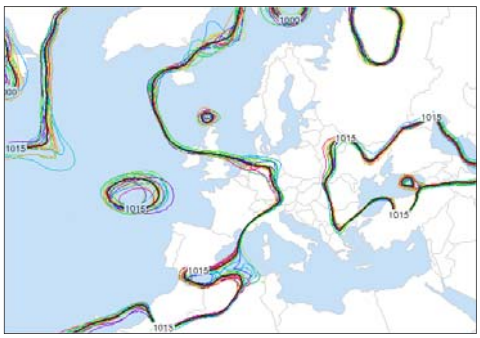


Source: http://www.ufz.de/risk-habitat-megacity/index.php?de=15003

A little bit less complex



.... or like this:



How do we want to live tomorrow?

Source: Ziegahn, KIT

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

Source: http://habitat3.org/the-new-urban-agenda

Quito, October 17-20, 2016

Perspective 1 – Heat-Resilient Cities
Traditional ideas

Beni Izguen, Algerien

Photo: Holger Reineccius
http://en.wikipedia.org/wiki/File:Beni-Izguen.jpg

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.jpg.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

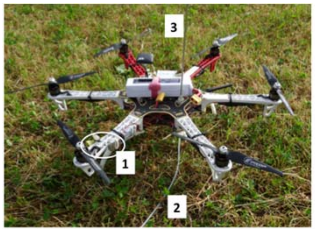
Source: www.nationale-plattform-zukunftsstadt.de

Perspective 6 – Completely New Designed Cities – Masdar City -
Planning new cities

Source: www.fosterandpartners.com

Challenges & Future Perspective

Airborne Measurements



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

UAV or drone (hexacopter)

Smart networks

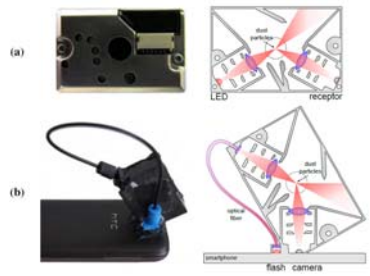


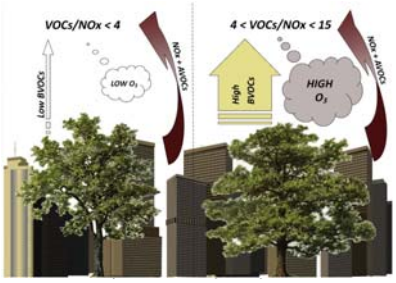
Figure 1. (a) Sharp GP2Y1010 dust sensor and operation principle, and (b) prototypical implementation with modified emitter-receptor configuration embedded in the back shell of an otherwise unaltered phone.

Source: Emeis (IMK-IFU)

Smart Air Quality Network

funded by the German Ministry of Traffic and Digital Infrastructure

Biogenic Emissions

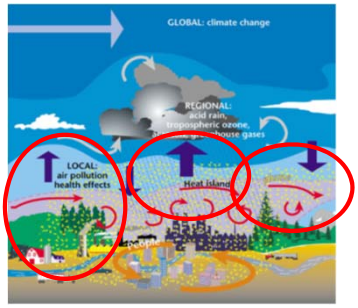


BVOC Emissions from vegetation have have a strong impact on air quality

Churkina G, Grote R, Butler TM, Lawrence M. 2015. Natural selection? Picking the right trees for urban greening. Environmental Science & Policy, 47: 12-17.

Urban-Rural Interactions

Cities as Reaction Vessels



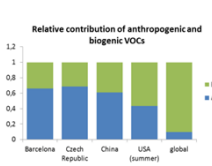
Internal processes and exchange with surrounding compartments of the Earth system

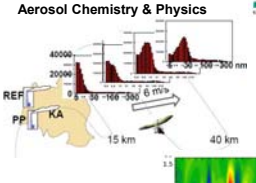
- urban wind and radiative regimes
- secondary circulations and matter transports
- urban heat island(s)
- natural and biogenic emissions (inside and outside of cities)
- anthropogenic emissions
- air chemistry, aerosol formation
- impact on local and regional air quality
- impact on regional and global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

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

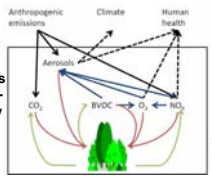
Summary

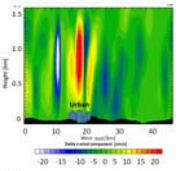
Aerosol Chemistry & Physics





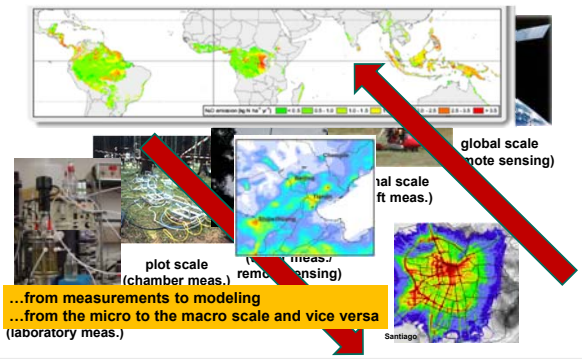
Impact of anthropogenic - biogenic emissions on urban climate – health – air quality





Mitigation & Adaptation strategies

Overcoming the Scales



…from measurements to modeling
…from the micro to the macro scale and vice versa
(laboratory meas.)

Summary

- 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 a 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 ?
?
73
Escuela Internacional de Desarrollo Sostenible
Médellin / Colombia – Octubre 31, 2017
KIT-Campus Alpin
Peter Suppan
Garmisch-Partenkirchen / Germany


Muchas gracias por su atención
and best regards from Germany