Healthy Urban Air

A Catalogue of Urban Strategies towards better air quality in cities

S.Hoogewerf
06-04-2011
Structure of presentation

1. Inventarisation
   Why?
   What?

2. Solutions
   Model description
   Catalogue
   Subconclusion

3. Application
   Beijing

4. Conclusion
   Investment vs death toll
   Other cities
   Recommendations for the future city
1. Healthy City

- **Healthy City**
  - **Oxygen (O₂):** 1300L
  - **Activity:** 40min 1000 steps 20min
  - **Quality Air:** 100m²
  - **Nutrition:** 2000 calories

**Diseases and Causes**

<table>
<thead>
<tr>
<th>Disease</th>
<th>Percentage</th>
</tr>
</thead>
<tbody>
<tr>
<td>Communicable diseases</td>
<td>32,1%</td>
</tr>
<tr>
<td>Infections</td>
<td>19,1%</td>
</tr>
<tr>
<td>Respiratory infections</td>
<td>6,9%</td>
</tr>
<tr>
<td>Communicable conditions</td>
<td>58,8%</td>
</tr>
<tr>
<td>Noncommunicable conditions</td>
<td>29,3%</td>
</tr>
<tr>
<td>Injuries</td>
<td>9,1%</td>
</tr>
<tr>
<td>Cardiovascular diseases</td>
<td>2,1%</td>
</tr>
<tr>
<td>Ischaemic heart disease</td>
<td>1,5%</td>
</tr>
<tr>
<td>Injuries</td>
<td>0,3%</td>
</tr>
</tbody>
</table>

**23,7% = ill at any given time!**
1. Inventarisation

1. Inventarisation
   Why?
   What?

2. Solutions
   Model description
   Catalogue
   Subconclusion

3. Application
   Beijing

4. Conclusion
   Investment vs death toll
   Other cities
   Recommendations for the future city
1. Urgency
1. Urgency

- SO$_x$
- CO$_x$
- NO$_x$
- PM$_x$
- VOÇ's
- Toxic metals
- CFC's
- NH$_3$
- Radio actives
- Odours
- O$_3$
- PAN
1. Urgency

- Eye irritation
- Eye inflammation
- Impaired sight
- Respiratory diseases
- Cancers
- Chronic changes in respiratory systems
- Vitamin D efficiency
- Depression
- Impaired sight
1. Urgency

- Cardiovascular diseases
- Physiological changes
- Intrauterine growth restriction
- Cancers
1. Urgency

- Hospital admissions
- Emergency department visits
- Days of restricted activity

Death (up to 6 million/year)
1. Urgency

- Work absenteism
- School absenteism
- Medication
- Medical treatment
1. Urgency

= € 1,304,667,000,000

= -27% income

€1,890/capita globally


1. Urgency

\[
\begin{align*}
\text{€1,890/capita globally} &= 1.304.667.000.000 \\
\text{€700/capita globally} &= 483.210.000.000
\end{align*}
\]
1. Urgency

= € 1.304.667.000.000
= -27% income
€1.890/capita globally

= € 483.210.000.000
€700/capita globally

= € 9.664.200.000
= -2% income for past-school absenteeism
€140/capita globally
1. Urgency

= € 1.304.667.000.000
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= € 41.419.000.000
  €60/capita globally
  High income countries: €315/capita
1. Urgency

= €1,304,667,000,000
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= -2% income for past-school absenteeism
€140/capita globally/year

= €41,419,000,000
High income countries: €315/capita/year

= €1,838,960,200,000
€2,664/capita globally/year
1. AQ + health statistics

Fig. 1. Pyramid of health effects associated with air pollution

- Premature mortality
- Hospital admissions
- Emergency department visits
- Visits to doctor
- Restricted activity/reduced performance
- Medication use

Symptoms
- Physiological changes in cardiovascular system
- Impaired pulmonary function

Subclinical (subtle) effects

Severity of health effect

Proportion of population affected

- 4.5 million lost life years / year
- Up to 5 billion yearly
To calculate the expected number of deaths due to air pollution (E), we take the product of:

\[ E = \text{beta} \times B \times P \times C \]

where:
- \( E \) = expected number of premature deaths due to short-term exposure
- \( \text{beta} \) = percentage change in mortality per 10-\( \mu \)g/m\(^3\) change in PM10
- \( B \) = incidence of the given health effect (deaths per 1000 people)
- \( P \) = relevant exposed population for the health effect
- \( C \) = change in PM10 concentration (\( \mu \)g/m\(^3\) \times 0.1).
1. Air Pollutants

Air quality guidelines, Global update 2005; World Health Organization, 2006
1. Air Pollutants

Air quality guidelines, Global update 2005; World Health Organization, 2005
## 1. The Big 5

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<td>Sulfurdioxide</td>
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Air quality guidelines, Global update 2005; World Health Organization, 2005
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- Traffic
- Power plants
- Pulp mills
- Butane heaters
- Stoves
- Traffic (diesel)
- Power plants
- Industry
- Soil dust
- Sea salt
- NO$_x$, SO$_2$, NH$_3$, O$_3$
- Traffic
- Chemical plants
- Refineries
- Industry
- NO$_x$ + VOC’s
- Traffic
- Power plants
- Pulp mills
- Butane heaters
- Stoves
- Industry
- Smelting mineral ores
- Power plants
- Traffic

Air quality guidelines, Global update 2005; World Health Organization, 2009
## 1. Diseases

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<td>- Coughing, irritation of the airways, discomfort in the chest or when breathing.</td>
<td>- Reduced oxygen delivery to the body’s organs and tissues.</td>
<td>- Breathing problems with asthmatic children and adults who are active outdoors.</td>
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<td>- Asthma attacks.</td>
<td>- Faster or more shallow breathing.</td>
<td>- Visual impairment.</td>
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<td>- Decreased lung function.</td>
<td>- Aggravation of asthma, emphysema, and other respiratory diseases.</td>
<td>- Reduced work capacity.</td>
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<tbody>
<tr>
<td></td>
<td>1h</td>
<td>24h</td>
<td>1y</td>
<td>1h</td>
<td>8h</td>
</tr>
<tr>
<td>WHO</td>
<td>200</td>
<td>40</td>
<td>50</td>
<td>100</td>
<td>200</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>China I</td>
<td>120</td>
<td>80</td>
<td>40</td>
<td>120</td>
<td></td>
</tr>
<tr>
<td>China II</td>
<td>120</td>
<td>80</td>
<td>40</td>
<td>160</td>
<td></td>
</tr>
<tr>
<td>China III</td>
<td>240</td>
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China I: tourist, historical and conservation areas;
China II: residential urban and rural areas;
China III: industrial and heavy traffic areas.
### 1. The Big 5

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- Internal combustion engines
- Thermal power stations
- Pulp mills
- Butane heaters
- Stoves

- Diesel combustion engines
- Traffic
- Power plants
- Soil dust
- Sea salt
- Industry
- NO$_x$, SO$_2$, NH$_3$, O$_3$

- Vehicules
- Chemical plants
- Refineries
- Industry
- NO$_x$ + VOC's

- Internal combustion engines
- Thermal power stations
- Pulp mills
- Butane heaters
- Stoves

- Burnig fossil fuels
- Smelting mineral ores
- Burning oil and coal
- Power plants
- Industry

### Effects of NO$_2$

- Respiratory illness in young children.
- Harm lung function in people with existing respiratory illnesses.
- Increased susceptibility to respiratory infection.
- Alterations in the lung.

- Coughing, irritation of the airways, discomfort in the chest or when breathing.
- Premature aging of the lungs.
- Faster or more shallow breathing.
- Aggravation of asthma, emphysema, and other respiratory diseases.
- Increased risk of respiratory infections.
- Reduced oxygen delivery to the body's organs and tissues.
- Poisonous.
- Visual impairment.
- Reduced work capacity.
- Reduced manual dexterity.
- Poor learning ability.
- Difficulty in performing complex tasks.

- Tens of thousands of premature deaths every year.
- Increased emergency room visits.
- Asthma attacks.
- Decreased lung function.

### Reductions

- Car exhaust filters
- Electric cars
- Façade filters
- Gas masks

- Car exhaust filters
- Electric cars
- Gas masks
- New mountain
- Industry emission cut
- Policy making
- Exodus of industry
- Fresh air tubes

### WHO Standards

<table>
<thead>
<tr>
<th>NO$_2$</th>
<th>PM$_{10}$</th>
<th>O$_3$</th>
<th>CO</th>
<th>SO$_2$</th>
</tr>
</thead>
<tbody>
<tr>
<td>1hour</td>
<td>100 200 40 24hours</td>
<td>200 40 8hours</td>
<td>40 200 8hours</td>
<td>40 200 8hours</td>
</tr>
</tbody>
</table>

- Reduction from 70 to 20 µg/m$^3$ means 15% less deaths

### Prevention

- Car exhaust filters
- Electric cars
- Façade filters
- Gas masks

- Car exhaust filters
- Electric cars
- Gas masks
- New mountain
- Industry emission cut
- Policy making
- Exodus of industry
- Fresh air tubes

### Breathing problems with asthmatic children and adults who are active outdoors.

- Wheezing, chest tightness and shortness of breath.
- Respiratory illness.
- Alterations in the lungs' defenses.
- Aggravation of existing cardiovascular disease.

### Table:

<table>
<thead>
<tr>
<th>Class</th>
<th>NO$_2$ 1hour</th>
<th>PM$_{10}$ 24hours</th>
<th>O$_3$ 1hour</th>
<th>CO 1hour</th>
</tr>
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### Class I:
- Tourist, historical and conservation areas;
- Class II: residential urban and rural areas;
- Class III: industrial and heavy traffic areas.

### β

- Daily mortality rises by 0.3% and that for heart diseases by 0.4 %, per 10 µg/m$^3$ increase in ozone exposure.

- 06.04.2011
- Sjoerd Hoogewerf
Create a CATALOGUE with URBAN STRATEGIES that work towards reducing air pollution in cities.

By reducing air pollution we can reduce the loss of life years/healthy life years.

The air quality of every city should be as the air quality guidelines of the World Health Organization prescribe.
2. Solutions

1. Inventarisation
   Why?
   What?

2. Solutions
   Model description
   Catalogue
   Subconclusion

3. Application
   Beijing

4. Conclusion
   Investment vs death toll
   Other cities
   Recommendations for the future city
2. Generic city

- Mountain ranges
- Sea side
- Industry
- Dominant wind direction

Generic City

- 45.080x41.980m = 1892km²
- 1,000,000 inhabitants
- 200x100x21m blocks: 69710 blocks
- 1 block = 14 persons
- 400x200x21m industry blocks: 510 blocks
2. City model
2. City model
2. City model
2. City model

- 0-21m
- 21-42m
- 24-457m
- 457+m

- 21-42m
- 0-21m
## 2. Categories

<table>
<thead>
<tr>
<th>Prevent</th>
<th>Filter</th>
<th>Ventilate</th>
<th>Shift</th>
</tr>
</thead>
<tbody>
<tr>
<td>- Electric cars</td>
<td>- Gas masks</td>
<td>- Street ventilators</td>
<td>- Extreme zoning</td>
</tr>
<tr>
<td>- Exodus of industry</td>
<td>- Façade filters</td>
<td>- Special street profiles</td>
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</tr>
<tr>
<td>- Industry emission cut</td>
<td>- Car exhaust filters</td>
<td>- New mountains</td>
<td>- New mountains</td>
</tr>
<tr>
<td>- Behavioural restrictions</td>
<td>- Tree filters</td>
<td>- Funneling towers</td>
<td>- Behavioural restrictions</td>
</tr>
<tr>
<td></td>
<td>- Algae lakes</td>
<td>- Fresh air tubes</td>
<td></td>
</tr>
<tr>
<td></td>
<td>- Falling water</td>
<td>- $1 billion vaccum cleaner</td>
<td></td>
</tr>
<tr>
<td></td>
<td>- Road roof</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>- Air purifying dress</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
2. Catalogue layers

Prevent  Filter  Ventilate  Shift

- Exodus of industry
- Industry emission cut
- Electric cars
- Behavioural restrictions
- Tree filters
  - Algae lakes
  - Falling water
- Gas masks
  - Façade filters
  - Car exhaust filters
  - Road roof
  - Crowdsourcing
- Funneling towers
- $1 billion vaccum cleaner
- Fresh air tubes
- Street ventilators
  - Special street profiles
  - New mountains
- Behavioural restrictions
- New mountains
- Extreme zoning
- Exodus of industry
2. Catalogue

- Extreme zoning
- Fresh air tubes
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- Funneling towers
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- Road roof
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- Façade filter
- Algae lakes
- Behavioural restrictions
- Car exhaust filters
- Tree filters
2. Electric Cars

- Category: Prevent
- Strategy/Product: Electric cars
- Program added: 0 m³
- Price per capita: € 5.700

Existing Technical Information

http://www.drive-ec1.nl/images/PDF/Prijslijst%20eC1%202010%20resize.pdf
http://www.epa.gov/otaq/consumer/f00013.htm
http://www.worldometers.info/cars/
http://en.wikipedia.org/wiki/Motor_vehicle_emissions
http://rainforests.mongabay.com/09-carbon_emissions.htm
http://www.columbia.edu/~xzp1/About.html
2. Electric Cars

Induction Highway

Generic city
Technical information
Existing projects
Zoom in
2. Electric Cars

EC1 5-door Séduction
100% electric car
€35,995

Induction highway charging the battery

Induction battery charging while parked
2. Electric Cars

£5.000 subsidy
discount parking
2011: 50 charging points, 1.700 vehicles
2013: 1.300 charging points, 100.000 vehicles
£400/year (electric 10.000 miles) vs £1.300/year (petrol)
2. Catalogue

- Extreme zoning
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- Behavioural restrictions
- Car exhaust filters
- Tree filters
2. Street Ventilators

Category: Ventilate
Strategy/Product: Street ventilators

Price per capita: € 4.000
Program added: 1.600 m³
2. Street Ventilators
2. Street Ventilators

Ventilators in a street canyon
A no-slip enhanced wall treatment with zero roughness was assigned to the walls and ground keeping

\[ \text{y} \]

For all physical quantities, a Neumann boundary condition as a fully developed flow condition was also applied to the outflow boundary. Moreover, a ground-level pollution source of ethane with a constant mass fraction of 0.01 was placed in the studied street canyon.

Studied street canyon with pollution source

Logarithmic inflow
d=0.7H

3H 11H 4H

PVS

Wall

Ground

Neumann Boundary Condition

Symmetry Boundary Condition

Fig. 2. Simulation domain.

Contaminated/Fresh Air

Technique to Provide Pressure Gradient:
Natural Convection (Heating):
- Exhaust from AC's Condenser
- Solar Radiation
- Electricity Force Convection:
- Intake/Blowing Fan

Responsible Buildings to Pedestrian Level

Water Spray

Pedestrian Walking

Pedestrian

Pergola

Ventilation Ducts

Pedestrian Control Volume

Fig. 1. Pedestrian ventilation system (PVS) and configured strategies.

5. Conclusions

A two-dimensional numerical model was developed using the RSTM turbulence model of the FLUENTTM code to simulate the airflow, pollutant dispersion and particle deposition inside street canyons. Under different wind velocities, street width, and building heights the flow files is calculated and the results are validated with experimental data from wind tunnel tests obtained by Meroney et al.\[5\]. For the two-dimensional model studies, it was found that, in general, the computational model overestimates the concentrations of species in the canyon. Among the turbulence models used in this analysis, the RSTM showed somewhat better agreement with experimental data. The \( k/C_0 \) and the RNG \( k/C_0 \) turbulence models predicted similar results. This observation is consistent with the findings of Chang et al.\[30\], but in contrast with the results Chan et al.\[13\]. This latter work, suggested that the RNG \( k/C_0 \) turbulence model leads to concentrations that are in good agreement with the experimental data while those obtained by the standard \( k/C_0 \) model significantly overestimate the concentration profiles.

In agreement with the earlier works, the present simulations showed that the gaseous pollutants concentration and particle deposition on the leeward walls of the buildings is much higher that those on the windward walls. An increase in the wind speed also increases the differences observed. In addition, the effects of different configuration of buildings and streets were studied and it was shown that vertical motion might appear within the canyon cavity. Depending on wind velocity, width of streets, and heights of building, presence of up to four vortices were observed. Reverse flows near the building roofs were also observed. It was found that the building height and building arrangement are important factors for particulate pollutant deposition. For street level emission, as building height increases, particle deposition rate on leeward wall increases and that on windward wall decreases. As the wind speed increases more particle are deposited on the windward walls and on the street surface. A large fraction of particles are deposited on the street surface for all wind velocities.

Present simulation study suggests that the three-dimensional and transient effects are important in modeling the airflow pollutant transport in street canyons. In addition in parts of the street canyons, the flow may be in transitional regime, where the RANS
2. Catalogue

- Extreme zoning
- Fresh air tubes
- New mountains
- Funneling towers
- $1 billion vacuum cleaner
- Falling water
- Gasmasks
- Exodus of industry
- Special street profiles
- Road roof
- Crowdsourcing
- Electric cars
- Industry emission cuts
- Street ventilators
- Façade filter
- Algae lakes
- Behavioural restrictions
- Car exhaust filters
- Tree filters
2. Tree Filters

Category: Filter
Strategy/Product: Tree filter

Price per capita: € 9.180 (1 tree = € 20)

Program added: 38.407.504.320.000 m³
2. Tree Filters
2. Tree Filters

918 layers of trees solves everything 2.754m high
2. Tree Filters

- Trees in streets:
  - Slows down wind in streets.
  - Filters larger particles.
  - Higher concentration of PMx.

- Trees on roofs:
  - No speed reduction.
  - Filters larger particles.

- Trees in start/en of street:
  - No speed reduction.
  - Filters larger particles.

- Trees in 'pockets':
  - No speed reduction.
  - Filters larger particles.

---

Generic city
Technical information
Existing projects
2. Tree Filters

Schematische opstelling van strook met vegetatie(boven) en zonder vegetatie(onder). (codering: S=3d-sonic, 2D=2d-windsonic, M=mierij, NOx=NO + NO2, FS=fijn stof met TEOM en Osiris, LASx en CPC=fijn stof met betreffende apparatuur)

From 3µm (=PM₃) 50% of particles is sunk
2. Catalogue

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New mountains
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Road roof
Crowdsourcing
Electric cars
Industry emission cuts
Street ventilators
Façade filter
Algae lakes
Behavioural restrictions
Car exhaust filters
Tree filters
2. Comparison

SO\textsuperscript{2} reduction

- 0% reduction
- Car exhaust filters
- Electric cars
- Road roof funnelling towers
- Falling water facade filters
- $1 billion vacuum cleaner
- Industry emission cuts
- Exodus of industry special street profiles
- Street ventilators
- Behavioural restrictions
- Fresh air tubes

- 100% reduction
- Algae lakes
- Tree filters
- Gasmasks
- New mountains
2. Comparison

City air layer height

Ground level

>457m

Crowdsourcing
Car exhaust filters
Electric cars
Road roof
Behavioural restrictions
Facade filters
Street ventilators
Falling water
Extreme zoning
Fresh air tubes
$1 billion vacuum cleaner
Algae lakes
Tree filters
Gasmasks
Exodus of industry
Funneling towers
New mountains
2. Comparison

- € investment per capita
- € 0
- € 1,000,000,000

- Gasmasks
- Extreme zoning
- Behavioural restrictions
- Industry emission cuts
- Crowdsourcing
- Car exhaust filters
- Tree filters
- Electric cars
- Funneling towers
- Falling water towers
- Road roof
- Facade filters
- Algae lakes
- Exodus of industry
- Special street profiles
- Street ventilators
- Fresh air tubes
- New mountains
- $1 billion vacuum cleaner

- $1 billion vacuum cleaner
- Sjoerd Hoogewerf
- 06.04.2011
2. Comparison

- New mountains
- Algae lakes
- Extreme zoning
- Road roof
- $1 billion vacuum cleaner
- Funneling towers
- Falling water
- Special street profiles
- Electric cars
- Exodus of industry
- Tree filters
- Fresh air tubes
- Industry emission cuts
- Street ventilators
- Facade filters
- Behavioural restrictions
- Car exhaust filters
- Crowdsourcing
- Gasmasks

€ investment per capita

€ 0

€ 1.000.000.000
2. Comparison

Gasmasks

Electric cars

Industry emission cuts

Behavioural restrictions
  Facade filters
  Special street profiles

Exodus of industry

Crowdsourcing

Car exhaust filters

Funneling towers

Road roof

Street ventilators

$1 billion vacuum cleaner

Tree filters

Algae lakes

Falling water

Fresh air tubes

New mountains

Extreme zoning

0 m³

38.407.504.320.000 m³
2. Comparison

- Gasmasks
- Tree filters
- Algae lakes
- Falling water
- Funneling towers
- $1 billion vacuum cleaner
- Electric cars
- Road roof
- Fresh air tubes
- Industry emission cuts
- Street ventilators
- New mountains
- Behavioural restrictions
- Facade filters
- Special street profiles
- Exodus of industry
- Crowdsourcing
- Extreme zoning
- Car exhaust filters

0% pollution reduction

€ investment per capita

€ 0

€ 1,000,000,000

06.04.2011 06/04/2011 1153250 Sjoerd Hoogewerf
2. SubConclusion

Different heights

Different pollution reduction

A single strategy cannot solve everything
3. Application

1. Inventarisation
   Why?
   What?

2. Solutions
   Model description
   Catalogue
   Subconclusion

3. Application
   Beijing

4. Conclusion
   Investment vs death toll
   Other cities
   Recommendations for the future city
3. Beijing case study

Top 10 worst air quality

1. Beijing
2. New Delhi
3. Santiago
4. Mexico City
5. Ulaan Baatar
6. Cairo
7. Chongqing
8. Guanzhou
9. Hongkong
10. Kabul
3. Beijing case study

Deaths from urban air pollution

UAP deaths/million

Estimates by WHO sub-region for 2000 (WHO World Health Report, 2002). The boundaries shown on this map do not imply the expression of any opinion whatsoever on the part of the World Health Organization concerning the legal status of any country, territory, city or area or of its authorities, or concerning the delimitation of its frontiers or boundaries. Dotted lines on maps represent approximate border lines for which there may not yet be full agreement. © WHO 2005. All rights reserved.
3. Global NO$_2$
3. Global $\text{O}_3$

Beijing $\text{O}_3$
3. Aim for Beijing

To bring the air quality of the city (within the fifth ringroad) to within the WHO guidelines.
### BEIJING

Population (City): 13,14 million
Area: 87 km²
Density: 782 people/km²
Population (Metropolitan): 16,95 million
Elevation: 43 m
Roadlength: 4,460 km
of which main + expressways: 236 km

Population (Metr): 16.95 million
Area: 16807.8 km²
urban population: 77.54%
Density: 805 inh/km²
Average Household Size: 3.21
GDP: US$ 34.07 billion
Per capita GDP: US$ 3060
3. Beijing topography
3. Outside of the city

- Sparsely populated north
- 30%
- Mountains
- Ocean
- Industrialized south
- 45%
- Winter
- Summer

- Summer Monsoon
- May - September

- Winter Monsoon
- November - March

Sources:
3. Inside of the city

Mobility within Beijing

SO$_x$ 60%  
CO$_x$ 90%  
NO$_x$ 70%  
PM$_x$ 60%  
O$_3$ 80%  

remaining = powerplants  
household heating/cooking  
waste processing  
small factories
3. Beijing pollution

Pollution from outside of the city

Pollution from within the city

Urban climate (UHI, wind, pollution layers, rain, topography)
3. UHI & pollution layers

Sun heats buildings => UHI

City pollutes the air

A polluted warm air layer forms over the city creating a buffer between ventilating winds and the city
### Beijing now

<table>
<thead>
<tr>
<th></th>
<th>PM10</th>
<th>SO2</th>
<th>NO2</th>
<th>O3</th>
<th>CO</th>
</tr>
</thead>
<tbody>
<tr>
<td>tons</td>
<td>3.368,5</td>
<td>191.000</td>
<td>139.369</td>
<td>1.593</td>
<td>45.520</td>
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<tr>
<td>concentration (µg/m3)</td>
<td>148</td>
<td>50</td>
<td>66</td>
<td>70</td>
<td>2.000</td>
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<tr>
<td>WHO (µg/m3)</td>
<td>20</td>
<td>20</td>
<td>40</td>
<td>40</td>
<td>40</td>
</tr>
<tr>
<td>China I</td>
<td>40</td>
<td>50</td>
<td>40</td>
<td>120</td>
<td>-</td>
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</table>

<table>
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<tr>
<th>WHO</th>
<th>PM10 24hours</th>
<th>annual</th>
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<tbody>
<tr>
<td>China I</td>
<td>50</td>
<td>40</td>
</tr>
<tr>
<td>China II</td>
<td>100</td>
<td>60</td>
</tr>
<tr>
<td>China III</td>
<td>150</td>
<td>120</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>WHO</th>
<th>SO2 10min</th>
<th>1hour</th>
<th>24hours</th>
</tr>
</thead>
<tbody>
<tr>
<td>WHO</td>
<td>500</td>
<td>20</td>
<td></td>
</tr>
<tr>
<td>China I</td>
<td>150</td>
<td>50</td>
<td>20</td>
</tr>
<tr>
<td>China II</td>
<td>250</td>
<td>150</td>
<td>50</td>
</tr>
<tr>
<td>China III</td>
<td>700</td>
<td>500</td>
<td>150</td>
</tr>
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</table>

<table>
<thead>
<tr>
<th>WHO</th>
<th>NO2 1hour</th>
<th>24hours annual</th>
</tr>
</thead>
<tbody>
<tr>
<td>WHO</td>
<td>200</td>
<td>40</td>
</tr>
<tr>
<td>China I</td>
<td>120</td>
<td>80</td>
</tr>
<tr>
<td>China II</td>
<td>120</td>
<td>80</td>
</tr>
<tr>
<td>China III</td>
<td>240</td>
<td>120</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>WHO</th>
<th>O3 1hour 8hours 24hours annual</th>
</tr>
</thead>
<tbody>
<tr>
<td>WHO</td>
<td>100</td>
</tr>
<tr>
<td>China I</td>
<td>120</td>
</tr>
<tr>
<td>China II</td>
<td>120</td>
</tr>
<tr>
<td>China III</td>
<td>240</td>
</tr>
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<table>
<thead>
<tr>
<th>WHO</th>
<th>CO 1hour annual</th>
</tr>
</thead>
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<tr>
<td>WHO</td>
<td>200</td>
</tr>
<tr>
<td>China I</td>
<td>120</td>
</tr>
<tr>
<td>China II</td>
<td>160</td>
</tr>
<tr>
<td>China III</td>
<td>200</td>
</tr>
</tbody>
</table>

Class I: tourist, historical and conservation areas;
Class II: residential urban and rural areas;
Class III: industrial and heavy traffic areas.
3. Beijing in tons

air pollutants

tons of pollution in the air

SO\textsubscript{x}, CO\textsubscript{x}, NO\textsubscript{x}, PM\textsubscript{x}, O\textsubscript{3}
3. Cleaning Beijing’s air in 5 steps

1. Prevent polluted air from outside of the city
   Algae filters
   Cost?
   How much will it clean?

2. Prevent UHI (lower urban wind layer) and filter air
   Tree filters; 2 layers of trees on every building in Beijing
   Cost?
   How much will it clean?

3. Suck away air from mobile sources and penetrate UHI air layer
   Solar towers (Jonathan) grid over the city
   Cost?
   How much will it clean?

4. Clean last bits of pollution from the air
   Falling water filter
   Cost?
   How much will it clean?

5. Beijing air = CLEAN! => What is the reduction in death toll?
3. Beijing in tons

3. Beijing in tons

air pollutants

tons of pollution in the air

SO<sub>x</sub> CO<sub>x</sub> NO<sub>x</sub> PM<sub>x</sub> O<sub>3</sub>
3.1 Algae Filters

- Factory smoke
- Algae reactor
- Fuel production
- Fuel combustion

Industrialized south
3.1 Algae Filters
3.1 Algae Filters

14,500 m³ algae pond
€5,800,000 (or €0,44/capita)
3.2 Tree Filters

Category: Filter
Strategy/Product: Tree Filter

Specs:
- Filters PM$_x$, aerosols and CO$_2$ (1 tree=20kg/year) from air flowing through the canopies

Trees on roofs:
++
No speed reduction.
+ Filters larger particles.
### 3.2 Tree Filters

<table>
<thead>
<tr>
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<th>PM10</th>
<th>CO</th>
</tr>
</thead>
<tbody>
<tr>
<td>tons filtered by trees</td>
<td>132,3000</td>
<td>256,4000</td>
<td>100,7000</td>
<td>772,0000</td>
<td>275,9496</td>
</tr>
<tr>
<td>total tons in city</td>
<td>139396</td>
<td>1593</td>
<td>191000</td>
<td>3368,5</td>
<td>45520</td>
</tr>
<tr>
<td>percentage of tons filtered</td>
<td>0,09%</td>
<td>16,10%</td>
<td>0,05%</td>
<td>22,92%</td>
<td>0,61%</td>
</tr>
<tr>
<td>times more trees needed</td>
<td>1054</td>
<td>6</td>
<td>1897</td>
<td>4</td>
<td>165</td>
</tr>
<tr>
<td>area1 trees now (m²)</td>
<td>44.508</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>area1 extra trees (m²)</td>
<td>46.895.217</td>
<td>84.419.345</td>
<td>194.204</td>
<td>7.341.935</td>
<td></td>
</tr>
<tr>
<td>area1 extra layers on top of built</td>
<td>823</td>
<td>1.481</td>
<td>3</td>
<td>129</td>
<td></td>
</tr>
<tr>
<td>area2 extra trees (m²)</td>
<td>38.461.917</td>
<td>69.237.974</td>
<td>159.279</td>
<td>6.021.614</td>
<td></td>
</tr>
<tr>
<td>area2 extra layers on top of built</td>
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*68/99*
3.2 Tree Filters
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<td>918</td>
<td>1.653</td>
<td>4</td>
<td>144</td>
<td></td>
</tr>
<tr>
<td>tons reduction with 2 layers trees</td>
<td>264.6</td>
<td>512.8</td>
<td>201.4</td>
<td>1544.0</td>
<td>551.9</td>
</tr>
</tbody>
</table>
3.2 Tree Filters
3.2 Tree Filters

15.170.625 extra trees

€1.896.328.125 (or €144/capita)
3.2 Tree Filters

summer:

1460kg of water

860MJ = 5 air conditioners
3.3 Solar Towers
3.3 Solar Towers

1 tower = 33,5 MW

use in Beijing = 4.735 MW

- All energy by Solar Towers: **141 towers** (=13km² towers/87km² Beijing)

- All cars electric and powered by Solar Towers: **4 towers** (=0,36km² towers/87km² Beijing)

- All energy formerly from coal produced by Solar Towers: **81 towers** (=7,5km² towers/87km² Beijing)

- All energy in THE WHOLE OF CHINA by Solar Towers: 25.216 towers
3.3 Solar Towers

1 tower = 33.5 MW

use in Beijing = 4.735 MW

-All energy by Solar Towers: **141 towers** (=13km² towers/87km² Beijing)

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3.3 Solar Towers
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81 towers or 7.5 km²

€404,311,500 (or €30/capita)
3.4 Falling Water Filters
3.4 Falling Water Filters

Water falls down in drops like rain

Particles get dragged down by the drops

Water is filtered in a biofilter

Water recycles through the system
3.4 Falling Water Filters

Making rain through artificial means

Cloud seeding is a weather modification system that aims to boost precipitation or rain by introducing condensation nuclei such as salt or dry ice.

1. Aircraft drop flares or artillery/rockets are shot from the ground to introduce artificial nuclei into cloud systems that have the right conditions.

   The artificial nuclei then attract water vapour within the cloud system to become larger droplets. Once it becomes heavy, the droplets fall as rain. Hygroscopic seeding, which involves using salts such as sodium chloride or potassium chloride, are larger nuclei resulting in very big cloud droplets.

2. Once seeded, it could take less than an hour to rain. In case of warm cloud systems, wherein the temperature is not colder than OC, salt is preferred for seeding. Silver iodide or dry ice is generally used for clouds colder than OC.
3.4 Falling Water Filters
3.4 Falling Water Filters
3.4 Falling Water Filters
3.4 Falling Water Filters

600 waterfalls

€600.000.000 (or €45,66/capita)
3. Result
4. Conclusion

1. Inventarisation
   Why?
   What?

2. Solutions
   Model description
   Catalogue
   Subconclusion

3. Application
   Beijing

4. Conclusion
   Investment vs death toll
   Other Cities
   Recommendations for the future city
To calculate the expected number of deaths due to air pollution (E), we take the product of:

\[ E = \beta \times B \times P \times C \]

where:
E = expected number of premature deaths due to short-term exposure
\( \beta \) = percentage change in mortality per 10-μg/m³ change in PM10
B = incidence of the given health effect (deaths per 1000 people)
P = relevant exposed population for the health effect
C = change in PM10 concentration (μg/m³ × 0.1).

\[ E = 0.15 \times \left( \frac{?}{13.140.000} \right) \times 13.140.000 \times 1.28 = ??? \]
4. Reduced death toll

Research indicates that when the air pollution index (AQI) in Beijing rose by 10%, the daily number of deaths caused by respiratory disease increased by 3.52% (Zhang et al., 2003).

6.631 deaths/year    AQI 500

2.707 deaths/year    AQI 34

€2,892,141,600
or
€220,10/capita
4. Being realistic?

€1.838.960.200.000

- €2.664/capita globally/year

+ €220/capita globally/year

+ €2.444/capita globally/year
4. Other cities
4. Mexico City perfect mix

- Façade filter
- Funneling towers
- Electric cars
- Tree filters

Standards:
- WHO

Pollutants:
- SO\textsubscript{x}
- CO\textsubscript{x}
- NO\textsubscript{x}
- PM\textsubscript{x}
- O\textsubscript{3}
4. Recommendations

Choose a mix of different strategies to address different types of pollutants at different heights.

Mix strategies that complement each other.

New designs should consider UC, street profiles and surrounding sources of pollution.

Take three steps:
1. prevent pollution from outside
2. prevent pollution from staying in or above the city (e.g. UHI)
3. remove pollution