Urban Energy Use and Urban Sustainability from the Climate Change Perspectives

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Global Carbon Project

Goal
• To develop comprehensive, policy-relevant understanding of the global carbon cycle, encompassing its natural and human dimensions and their interactions and management

Theme 3. Carbon Management
• Urban and regional carbon management
• Bio-energy and the earth systems
• Deforestation avoidance
Urban and Regional Carbon Management (URCM) Initiative

A. Large (Global) spatial scales

1. Understanding global urbanization trends and their implications for the carbon cycle

Drivers and mechanisms - population, energy and others

B. Smaller (urban and regional) spatial scales

1. Understanding urban/regional development pathways and carbon consequences

Historical carbon accounting, configuration of drivers, future scenarios

2. Clarifying avenues of interventions, instruments and tradeoffs for carbon management inside cities

Local trade-offs, multi-scale governance and co-benefits

International Scientific Programs on Global Environmental Change Science

International offices
- NIES, Tsukuba
- CSIRO, Canberra

ESSP 2006 Beijing Conference
IHDP’s vision

• To provide international leadership in framing, developing, and integrating social science research on global change and to promote the application of the key findings of the research to help address environmental challenges

IHDP’s Programmatic Structure

- Earth System Governance Project (ESG)
- Integrated Risk Governance Project (IRG)
- Vulnerability, Resilience, and Adaptation Initiative (VRA)
IHDP’s projects, cross-cutting themes, and methodologies

IHDP Open Meeting 2008

• New Delhi: 15-19 October, New Delhi
• Title: Social Challenges of Global Environmental Change
• Major Themes: Demographic change, social equity, social cohesion, resource depletion
• Over 1000 people, largest conference of its kind
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Reality of city and climate change

• ICLEI, C40, mayor’s summits, and intercity cooperation networks are leading the debate
• In reality, city governments have limited ability to influence carbon emission even in developed countries
• In developing countries, city governments are not in position even to influence air pollution significantly
• Developing countries’ share in world’s urban population is a key factor already and future growth comes primarily from them
Reality of city and climate change

• Current city climate debate lacks three basic points
  – the definition
  – Global/national estimate of urban contributions and their drivers, and
  – Discussions on the capability and the relevance of city authorities in global carbon management debate
  – How to meaningful action
• Research Need:
  – Knowledge generation on cities and carbon
  – Option exploration towards low carbon pathways and
  – Clarifying tapping climate co-benefits of local actions

Contents

• Urban population and the scale of urban change worldwide in 1950-2005
• Determinants of global urban energy use and carbon emissions
• Urban energy use in China and East Asian mega-cities
• Observations/conclusions
The Scale of Urban Change Worldwide 1950-2005

Urbanization trends

Slide courtesy: Arnulf Grubler, Yale/IIASA; Mostly from T. Chandler and UN data
World urbanization at nutshell

- Historically urbanization speed has been accelerated

<table>
<thead>
<tr>
<th>World urban population</th>
<th>Time taken</th>
<th>Years</th>
</tr>
</thead>
<tbody>
<tr>
<td>0 – 1 billion</td>
<td>10,000 years?</td>
<td>8000 BC - 1960</td>
</tr>
<tr>
<td>1-2 billion</td>
<td>25 years</td>
<td>1960 – 1985</td>
</tr>
<tr>
<td>2-3 billion</td>
<td>17 years</td>
<td>1985 – 2002</td>
</tr>
<tr>
<td>3-4 billion</td>
<td>15 years</td>
<td>2002 -2017</td>
</tr>
</tbody>
</table>

- Size of urban population has been unprecedented

<table>
<thead>
<tr>
<th>Year</th>
<th>Urban Population</th>
</tr>
</thead>
<tbody>
<tr>
<td>1950</td>
<td>0.7 billion</td>
</tr>
<tr>
<td>2005</td>
<td>3.1 billion</td>
</tr>
</tbody>
</table>

- Urban and rural population to be equal in 2007

<table>
<thead>
<tr>
<th>Year</th>
<th>Urban Population</th>
</tr>
</thead>
<tbody>
<tr>
<td>1900</td>
<td>15% (urban pop)</td>
</tr>
<tr>
<td>2007</td>
<td>50%</td>
</tr>
</tbody>
</table>


World urbanization at nutshell

- World urban population: 3.2 billion (49% of world population of 6.5 billion in 2005, will be 50% by 2008)
- Asia hosts largest world urban population! (Asia 1.6 billion, Europe 0.5, Africa 0.3, North America 0.3, Latin America, Caribbean and Oceania 0.4 - in 2005)
- China, India, USA have largest urban population in 2005 as countries
- Cities and Asia:
  - 11 out of 20 mega-cities (over 10 million), 17 out of 30 cities of 5-10 million, 184 out of 364 cities of 1-5 million, 225 out of 455 cities of 0.5-1 million

Regional distribution of world’s urban population

Percentage of population residing in urban areas within regions, 1950, 1975, 2005 and 2030


Number of “Million-cities” by region over time

1800- London and Peking

Cities by size

- Mega-cities are few and collectively makes small share
- Urban settlements with less than half-million make over half of urban population

Aggregated statistics suggest rapid urbanization but..

- Large proportions of world’s urban centers are not growing rapidly
- A significant proportion are actually losing population
- Statistics hide people living in poor condition in mega-cities
- However, despite appearing chaotic, provision for basic services are well-above their national averages in large cities
World’s ten fastest growing cities

• By annual average population increment (1950-2000)
  – Tokyo (464,000), Mexico City (304,000), Sao Paulo (296,000), Mumbai (262,000), Delhi (221,000), Dhaka (195,000), Jakarta (191,000), Karachi (180,000), Seoul (178,000), Kolkata (172,000)

• By annual average growth rate (1950-2000)
  – Karaj/Iran (10.5%), Brasilia (9.1%), Abidjan (8.2%), Lusaka/Zambia (8.1%), Faridabad (8%), Dubai (7.9%), Kaduna/Nigeria (7.8%), Riyadh (7.7%), Las Vegas (7.6%), Dammam/Saudi Arabia (7.4%)

World’s ten slowest growing cities (1950-2000)

• By annual average growth rate
  – Liverpool, Leeds, Copenhagen, London, Manchester, Genoa (reducing population)
  – Berlin, Birmingham, Xiaoshan, Xintai, Buffalo, Newcastle, Budapest

• Slowest glowing cities are mostly in Europe, many in China and some in USA
We overestimated in the past!!

• Less urbanized and less dominant by large cities than predicted
  – Mexico City: 18 million in 2000 as opposed to 31 million predicted by UN in 1975
  – Calcutta: 13 million in 2000 as opposed to 40-50 million predicted by Lester Brown in 1974
  – Mega-cities: 18 in 2000 as opposed to 27 predicted by UN in 1975
  – Several million fewer than predicted for Sao Paulo, Rio, Seoul, Chennei and Cairo

Often cross-city comparisons are confusing and misleading

• What is city population?
  – City boundaries are not set by universal criteria
  – Can go + – few millions depending on boundaries
  – Most large cities has at least three definitions (core city, metropolitan city, development planning zone)

• What is level of urbanization?
  – Definition of “urban” is locally determined which varies widely from country to country

• Is it census data?

• Bottom-line: Urbanization data is not a precise figure
What is city population?

<table>
<thead>
<tr>
<th>Population</th>
<th>Area(km²)</th>
<th>Explanation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Beijing (1990)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2,336,544</td>
<td>87</td>
<td>Four inner-city district including old city</td>
</tr>
<tr>
<td>5,400,000</td>
<td>158</td>
<td>Core city</td>
</tr>
<tr>
<td>6,325,722</td>
<td>1,369</td>
<td>Inner city + inner suburban districts</td>
</tr>
<tr>
<td>10,819,407</td>
<td>16,808</td>
<td>Including outer districts + 8 counties</td>
</tr>
<tr>
<td>Tokyo (1990)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>8,164,000</td>
<td>598</td>
<td>Tokyo 23-wards</td>
</tr>
<tr>
<td>11,856,000</td>
<td>2,162</td>
<td>Tokyo prefecture (Tokyo-to)</td>
</tr>
<tr>
<td>31,559,000</td>
<td>13,508</td>
<td>Greater Tokyo Metropolitan Area</td>
</tr>
<tr>
<td>39,158,000</td>
<td>36,834</td>
<td>National Capital Region</td>
</tr>
<tr>
<td>Los Angeles (1990)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>3,000,000</td>
<td>752</td>
<td>LA City</td>
</tr>
<tr>
<td>8,700,000</td>
<td>10,635</td>
<td>LA counties</td>
</tr>
<tr>
<td>8,863,000</td>
<td>6,526</td>
<td>LA-Long Beach Primary metropolitan statistical area</td>
</tr>
<tr>
<td>14,532,000</td>
<td>88,000</td>
<td>LA consolidated metropolitan statistical area</td>
</tr>
</tbody>
</table>

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- What is city population?
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National definitions of “urban” in UN Urban population statistics

<table>
<thead>
<tr>
<th>Criterion</th>
<th>Countries</th>
</tr>
</thead>
<tbody>
<tr>
<td>Administrative</td>
<td>83</td>
</tr>
<tr>
<td>Economic</td>
<td>1</td>
</tr>
<tr>
<td>Population size</td>
<td>57</td>
</tr>
<tr>
<td>Urban characteristic</td>
<td>4</td>
</tr>
<tr>
<td>Any combination</td>
<td>48</td>
</tr>
<tr>
<td>Entire population</td>
<td>6</td>
</tr>
<tr>
<td>No urban population</td>
<td>3</td>
</tr>
<tr>
<td>Unclear definition</td>
<td>1</td>
</tr>
<tr>
<td>No definition</td>
<td>25</td>
</tr>
<tr>
<td>Total</td>
<td>228</td>
</tr>
</tbody>
</table>

Source: Thomas Buettner, UN Population Division

Incomparable definitions of “urban” determines global urbanization numbers

- Who/how “urban” defined?
- Mexico can be 74.4% urban (in 2000) or 67.3% urban depending on definition of urban center as settlements with 2,500 or 15,000 people
- India classifies 500-5,000 inhabitant settlements as rural villages – if India changes definition, it will be predominantly urban population
- 17.5% of Egypt's population lived in settlements with 10,000 to 20,000 inhabitants which were not classified as urban (1996)
- In Sweden, urban (tätort) refers to settlements of more than 200 inhabitants with continuous built-up area that houses are not more than 200 meters apart when discounting rivers, parks, roads, etc
- What would be world’s urban population data if we apply Swedish definition to India and China?
- Lower ends of “urban” definition swings urbanization levels drastically
Often cross-city comparisons are confusing and misleading

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Beyond boundary issue- accurate accounting

- Census data - best case:10 years, worst case: 15-20 years (Sub-Saharan Africa)
- Projected data from 1970 for 1990 and 2000 are not reliable
- Often it is said that sub-Saharan Africa surprisingly urbanized without economic growth (World Bank in 1990) but those were projected data from 1970
Often cross-city comparisons are confusing and misleading

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Future of urbanization

- Urban population will grow twice as faster as compared to total population growth (1.78% vs. 0.95% annual rate for 2005-2030 projected) resulting 4.9 billion (about 60% of total population) by 2030 (out of 8.2 billion)

- 1.8 billion urban population will be added in 2005-2030 out of which 1.1 billion will be added in Asia
Cities by size, now and future

<table>
<thead>
<tr>
<th>Year</th>
<th>Urban &gt; 10M</th>
<th>Urban 5M to 10M</th>
<th>Urban 1M to 5M</th>
<th>Urban 0.5M to 1M</th>
<th>Urban &lt; 0.5M</th>
<th>Rural</th>
</tr>
</thead>
<tbody>
<tr>
<td>2000</td>
<td>20</td>
<td>30</td>
<td>364</td>
<td>455</td>
<td>9.3%</td>
<td>51.5%</td>
</tr>
<tr>
<td>2015</td>
<td>22</td>
<td>39</td>
<td>460</td>
<td>494</td>
<td>9.4%</td>
<td>50.5%</td>
</tr>
</tbody>
</table>

% of urban population in 2005 and 2015:
- Urban > 10M: 9.3% to 9.4%
- Urban 5M to 10M: 6.5% to 7.1%
- Urban 1M to 5M: 22.6% to 23.8%
- Urban < 0.5M: 10.1% to 9.1%
- Rural: 51.5% to 50.5%


What this means to urban energy and carbon emissions?

- **Rapid urbanization has its toll on energy**
- **Enormous fossil energy use in urban areas will rise greatly further—especially in Asia**
  - Rising fossil energy per capita due to income in cities
  - Rapid speed and size of urbanization
  - Energy efficiency gains unlikely to impress upon greatly rising scale of energy use
- **Greater role of urban activities in pumping up global CO2 emissions**
- **Urban areas providing greater opportunities to manage carbon emissions by influencing at greater degree globally**
Urban areas are expected to contribute a large share to global carbon emissions- how much?

How much cities/urban areas contribute to the global CO2 emissions?

We do not know!!! Nobody has seriously estimated yet (perhaps between 70 to 80%)

IEA’s Cities Energy International Modeling Group- are estimating it and will reveal it soon in World Energy Outlook 2008

Such number should correspond to a finer definition

1. What is urban or city (discussed already)?
2. How energy use or carbon emission is accounted?
Existing energy/carbon accounting frameworks

- Accounting city government’ own activities only (corporate accounting)
- Accounting total direct emissions within certain boundary (administrative, agglomeration etc.)
- Accounting direct emissions plus other energy services such as imported electricity and heat
- Accounting responsibility in the form of emissions footprints

Case of China

- China now contributes
  - 16.8% of global urban population (UN 2007)
  - 15% of global primary energy demand, and
  - 19% of global energy-related CO2 (WEO 2007)
- China’s primary energy demand will increase
  - By 2.2 times in 2005-2030 to 3,819 Mtoe
- Urbanization in China will reach
  - 60% (880 million) by 2030 from 41% in 2005. MGI (2008) projects is to one billion for 2030
- 90% of GDP by 2025 from urban economy (MGI, 2008)
- Cities contribute to GDP from 75% to 95% in 2008-2025
- Caution: Cities and urban areas are different
  - Cities population is 90% of national population in 2004 (from CCSY 2005); Urban population is 41.7% in 2004
  - Urban population is 94% in Beijing, 95 % in Shangai, 82 % in Tianjin and 32 % in Chongquing in 2006
Urban energy use in China
Our preliminary estimates for 2006

<table>
<thead>
<tr>
<th>Items</th>
<th>Mtoe</th>
</tr>
</thead>
<tbody>
<tr>
<td>Estimated urban TFC</td>
<td>831</td>
</tr>
<tr>
<td>Estimated rural TFC</td>
<td>385</td>
</tr>
<tr>
<td>Estimated urban energy share (in national TFC)</td>
<td>68.4%</td>
</tr>
<tr>
<td>Estimated urban energy share (in commercial TFC)</td>
<td>84.07%</td>
</tr>
<tr>
<td>Per capita urban TFC, toe/person</td>
<td>1.52</td>
</tr>
<tr>
<td>Per capita rural TFC, toe/person</td>
<td>0.50</td>
</tr>
<tr>
<td>Per capita national TFC, toe/person</td>
<td>0.92</td>
</tr>
<tr>
<td>Ratio of urban to national per capita TFC</td>
<td>1.65</td>
</tr>
</tbody>
</table>

TFC = Total final energy consumption

Major observations
1. Urban share is 68%
2. Higher role of urban in commercial energy
3. Urban PC > National
4. High urban to national ratio is remainder that urban will play more powerful role in the country’s energy future

Based on 2006 population as 1.319 billion and urban population as 545 million
Source: Dhakal (2008), work in progress, please do not quote

Sector and fuel breakdown of China’s urban energy consumption, 2006

Industry: major driver
Coal: mainstay, rising share of natural gas and oil

Source: Dhakal (2008), work in progress, please do not quote
Influence of China’s largest and most important 35 cities

List of 35 most important cities that are mentioned in national plan: Beijing, Tianjin, Shijiazhuang, Taiyuan, Hohhot, Shenyang, Dalian, Changchun, Harbin, Shanghai, Nanjing, Hangzhou, Ningbo, Hefei, Fuzhou, Xiamen, Nanchang, Jinan, Qingdao, Zhengzhou, Wuhan, Changsha, Guangzhou, Shenzhen, Nanning, Haikou, Chongqing, Chengdu, Guiyang, Kunming, Xining, Lhasa, Lanzhou, and Urumqi.

Source: Dhakal (2008)

Note: Energy consumption could have been slightly overestimated because it was derived from provincial average energy intensity.

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Note: Energy consumption could have been slightly overestimated because it was derived from provincial average energy intensity.

Source: Dhakal (2008)
Varying energy-economy pathways in China’s cities

Per capita Income Vs. Per capita Energy Use in 34 Largest Chinese Cities in 2006

High energy pathway: Largely on middle and western China with energy intensive industries and climatically cooler

Low energy pathway: Cities in eastern part of the country with strong presence of service industries, close to coast and warmer climate

Note: Energy consumption could have been slightly overestimated because it was derived from provincial average energy intensity.

Common patterns in cities

• Rapid economic structure change
• Declining use of coal, rising use of electricity, natural gas and oil

Per capita final energy consumption, 2006

Per capita CO2 emissions, 2006

Based on permanent resident population

Dhakal (2008), do not quote
Energy consumption, sectoral share 1985

<table>
<thead>
<tr>
<th>Sector</th>
<th>Share (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Agriculture</td>
<td>2%</td>
</tr>
<tr>
<td>Industry</td>
<td>62%</td>
</tr>
<tr>
<td>Transport</td>
<td>6%</td>
</tr>
<tr>
<td>Commercial</td>
<td>14%</td>
</tr>
<tr>
<td>Residential</td>
<td>16%</td>
</tr>
</tbody>
</table>

Energy consumption, sectoral share 2006

<table>
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<tr>
<th>Sector</th>
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</tr>
</thead>
<tbody>
<tr>
<td>Agriculture</td>
<td>2%</td>
</tr>
<tr>
<td>Industry</td>
<td>41%</td>
</tr>
<tr>
<td>Transport</td>
<td>15%</td>
</tr>
<tr>
<td>Commercial</td>
<td>25%</td>
</tr>
<tr>
<td>Residential</td>
<td>17%</td>
</tr>
</tbody>
</table>

CO2 emissions, fuel share 1985

<table>
<thead>
<tr>
<th>Fuel</th>
<th>Share (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Coal</td>
<td>58.1%</td>
</tr>
<tr>
<td>Oil</td>
<td>13.4%</td>
</tr>
<tr>
<td>Natural gas</td>
<td>0.0%</td>
</tr>
<tr>
<td>Other gas</td>
<td>2.1%</td>
</tr>
<tr>
<td>LPG</td>
<td>1.2%</td>
</tr>
<tr>
<td>Refinery gas</td>
<td>0.5%</td>
</tr>
<tr>
<td>Heat</td>
<td>4.8%</td>
</tr>
<tr>
<td>Electricity</td>
<td>20.0%</td>
</tr>
</tbody>
</table>

CO2 emissions, fuel share 2006

<table>
<thead>
<tr>
<th>Fuel</th>
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</tr>
<tr>
<td>LPG</td>
<td>0.9%</td>
</tr>
<tr>
<td>Refinery gas</td>
<td>1.0%</td>
</tr>
<tr>
<td>Heat</td>
<td>8.6%</td>
</tr>
<tr>
<td>Electricity</td>
<td>40.7%</td>
</tr>
</tbody>
</table>

Beijing

Per capita energy and emissions

Trend of per capita energy consumption

Trend of per capita CO2 emissions

Dhakal (2008) don’t quote
City performance - log scale

Tokyo: Outstanding compared to other cities yet worsening per capita emission
Seoul: Rapidly worsening per capita emissions
Beijing: Improving per unit GRP greatly but worsening per capita emission
Shanghai: Improving per unit GRP moderately but worsening per capita rapidly

Tokyo is efficient

- Mass rail-based transportation; early rail based development and no competition with motorization
- Gradual transformation to commercial city
- High population density
- Huge commuting population - Tokyo is more efficient because calculation used residents in earlier slide (25% more daytime population)
- Energy efficient technologies
- Clean energy
- Sound urban management
- Climate factors

Source: Dhakal and Kaneko, 2002
Factor Analyses by Decomposition

\[ \Delta C = \Delta \text{Carbon intensity effect} + \Delta \text{energy intensity effect} + \Delta \text{income effect} + \Delta \text{population effect} \]

- Income was the major factor for CO₂
- Effect of fuel quality is very small
- Energy intensity played major role in dampening CO₂ in 70s and 80s but no more after 1990

Source: Dhakal and Kaneko, 2002 and 2003

Factor Analyses by Decomposition

- Income effect: major driver
- Energy intensity: dampening force
- Fuel quality: not much effect

Source: Dhakal and Kaneko, 2003

Factor Analyses by Decomposition

- Dominant income and energy intensity effect
Energy Footprint of Cities

Source: Kaneko, Nakayama, Dhakal, 2003

CO₂ Balance, million t-CO₂ (2)

Carbon footprint: 4.44 for 1995

Source: Shinji Kaneko, Hiroshima University, 2007
Conclusion

• The speed and size of urbanization has been unprecedented for last 100 years and more specifically in 1950-2005 period
• However, the world is less urbanized and less dominated by large cities than predicted few decades back
• Asia will continue to play center-stage in this saga
• Urban data are a good reference but one should be aware of its limitations, especially in cross-comparisons
• Economic, social, political and demographic changes underpin urban change - particular local and national factors influences

Conclusion

• The varying definition of “urban” and choice of “energy accounting framework” can swing urban energy and carbon estimates drastically
• Cities and urban are clearly different and caution is needed in using terms
• Asia, and in particular China and India will play bigger role in determining urban energy and emissions in the future
Conclusion

In case of China

- Already about 68% of total energy are used in cities and such share will further increase when urban population reaches 880 million or 1 billion (UN, 2007 or MGI, 2008) by 2030
- The varying energy-economy pathways adopted by Chinese cities influence China’s energy and carbon profile
- China 35 largest cities have enormous and disproportionate influence in shaping nation’s energy and carbon future
- As evidenced from Beijing, Shanghai, Tianjin, Chongqing, Seoul and Tokyo analyses, rapid energy transition taking place in cities characterized by rapid economic structure change and fuel shift

The fact that city’s footprint in high needs new considerations for allocating responsibility

Thank you !!
What these aggregated statistics don't tell?

Behind the story of urban change

- **Immediate cause** - movement of people from rural to urban area
- **Underlying case** – concentration of new investment and economic opportunities in urban centers

Key factors

- Economic, social, political and demographic changes underpinning urbanization
- Particular local and national influencing factors

Middle and low-income nations

- The scale and direction of people’s movement consistent with spatial location of economic opportunity (defined by concentration of profit-seeking enterprises) and people working outside agriculture for living - Large importance of industry and service sector
- Expanding economy attract more migrants
- In many nations rural-rural migration is on larger scale than rural-urban migration
- Urban centers concentrate public service provision (education, hospitals, government offices and functionaries)
Drivers for urban change

• State of national economy
  – Scale of economy
• Local factors
  – Decisions of national governments
  – Structure of government (division of power and resources between different levels of government)
  – Extent and spatial distribution of transport and communication investments
  – Local investors
  – Location, natural resources endowment, demographic structure
  – State of infrastructure
  – Quality and capacity of public institutions
• External factors
  – Connectedness of nation’s economy with neighboring nations and global economy
  – 30,000 or so global corporations who control significant share of world economy

Local factors are key to size and spatial distribution of urban population

• Case of Pakistan: Political factors
  – Partition from India (1.8 million added mostly to Sindh and Punjab, especially Hyderabad and Karachi; drop in NWFP by 1951), Bangladesh partition, Afgan civil war (3.7 million moved to Pakistan, Peshawar, Quetta), political structure
• Case of Mexico: economic changes
  – Up to 1940: Agro-exporting period (Cities grew as place for market and service centers for agriculture)
  – 1940-70: Import substitution period (Mexico City expanded)
  – 1970-90: Slowing economic growth led to export-oriented industry (deceleration of Mexico and growth of US-border cities as export processing zones and port cities)
  – In 2000, Mexico grew half of what was expected 20 years back
  – Strong impact of migration – slowed economy
Local factors are key to size and spatial distribution of urban population

- Case of South Africa: Racial discrimination
  - Strict control over rights of black majority to live and move to urban centers limited scale of urban growth (displaced within 60 km of large cities)
  - Urban center are also shaped by development of gold and diamond mines
  - Influence of immigration flows and decline in white population since 1991

Urbanization level and economic change

- In general, nations with higher income are also nations with higher level of urbanization… however
- Amongst the nations of same income there is a great diversity in urbanization level
  - Thailand 20% and Columbia 75% in 2001 (about 6,000 US$, PPP)
- Amongst the nations of same urbanization rates, there are a great diversity in income levels
  - Such as Columbia and USA in 2001 (close to 77%) where per capita income (PPP) of USA was about 7 times more

World Bank data and UN Pop statistics
Environmental efficiency in transport

Akimasa Fujiwara, Hiroshima University
Daisaku Yoshino, Fukken Co., Ltd.
Contents

1. Introduction
   - Background
   - EE Applications to Transport Sector
   - Objectives

2. Environmental efficiency model
   - DEA Cost Efficiency Model
   - DEA under Environmental Condition
   - Heterogeneity of energy consumption system

3. Empirical analysis
   - Data
   - City heterogeneity
   - Evaluation result of EE model
   - Characteristics of cities on the frontier

4. Policies to improve EE
   - Scenarios
   - Effects of emissions trading

5. Conclusion
Background, Motivation

- Dilemma of sustainable urban development
  - Control of energy consumption in transport sector
  - Improving the levels of urban mobility and activities

A solution coping with both needs?

- Evaluation based on “Environmental Efficiency” (WBCSD, 1992)
  - EE=level of services/environmental loads
    - “Higher transport service by lower consumption”
  - An useful tool to solve the above problem?
Background, Motivation

- City heterogeneity

- Motorization rate

- Population density vs Energy consumption

- Energy consumption for transport
EE application in transportation


EE = Transport LOS Index / Environmental Index

\[ TI = u_1x_1 + u_2x_2 + \ldots + u_mx_m \]
\[ EI = v_1y_1 + v_2y_2 + \ldots + v_sy_s \]

Problems

- Poor description of city heterogeneity
  - Even weight coefficients ignoring individual city’s characteristics
    - not deal with heterogeneous energy consumption across cities
    - a uniform goal for energy reduction will be set up across cities
- Index function (i.e. I/O ratio)
  - Cannot identify causal factors of inefficient energy consumption
    (Energy intensity? Transport capacity? Modal share?)
    - Infeasible and unpractical policies might be miss-leded
Objectives

1. Redefinition of EE in Transport
   - Evaluation of urban transportation systems in developed/developing cities based on EE index
   - Development of EE model
     - To solve a dilemma between LOS and environmental load
     - To describe city heterogeneity of energy consumption in transport sector
     - To confirm the effectiveness and applicability of EE model

2. Effects of EE improvement
   - Evaluation of urban policies affecting on EE index
Environmental efficiency model

EE model proposed in this study is
① based on DEA(Data Envelopment Analysis) cost efficiency model
② to incorporate environmental conditions into DEA

● DEA Cost efficiency model
  ● A member of DEA with flexible (not-fixed, not-even) weights
    ● To relax an even weight constraint
  ● Not based on I/O ratio
    ● To evaluate inefficiency remained latent in energy consumption

● DEA incorporating environmental conditions
  ● To realize the evaluation results by considering policy feasibility
    eg. Withdraw policy in developed city by referring developing city?
Environmental efficiency model

- Concept:
  Minimizing input cost by keeping a given level of output

\[
\text{EE} = \frac{\text{Minimum energy consumption}}{\text{Observed energy consumption}}
\]

Input (smaller is better):
- Cost data 1
- Input data 1
- Energy intensity (public)
- Passenger-km (public)
- Input data 2
- Passenger-km (private)
- Cost data 2
- Energy intensity (private)

Output (higher is better):
- Minimum energy consumption
- Average travel speed

<trade-off between inputs>

2 inputs 1 output cost efficiency model
Environmental conditions

1. Policy variable with threshold (passenger-km by public transport)
   - Input variable: passenger-km of public transport should not be reduced
   - Public transport use should be a current level and more (non-negative constraint)

2. Anti-frontier cities
   - Uncultivated (no motorized) city cannot be referred even less energy consumption
   - Developing city with lower level of service cannot be in a reference set (cannot reflect a fine goal)

3. Describe city heterogeneity of energy consumption in urban transport sector
City heterogeneity of energy consumption

Frontier cube dealing with all cities homogenously

- Efficiency frontier (private-public mixed)
- Unrealized solution
- Frontier consist of two cities with different characteristics
- More efficient, closer to the origin (low input high output)

Energy contour of City A

- PT-oriented developed city
- PC-oriented developed city
City heterogeneity of energy consumption

Independent frontier

Energy contour of City A

Frontier based on PT-oriented cities

Frontier based on PC-oriented cities

Not shift from PC-oriented to PT-oriented

O pas.-km of PC average speed

O pas.-km of PT average speed

PT-oriented developed city

PC-oriented developed city
City heterogeneity of energy consumption

Integrated frontier

- Frontier based on PT-oriented cities
- Frontier based on PC-oriented cities
- PT-oriented frontier by shifting urban system
- PC-oriented frontier by remaining urban system

Feasible solution by considering characteristics

Energy contour of City A
Energy contour of City B

O pas.-km of PT average speed

PT-oriented developed city
PC-oriented developed city
Environmental efficiency models

\[
\min \ c_k = \sum_{i=1}^{m} p_{ik} x_i
\]

Minimize energy consumption

\[
s.t.
\]

\[
\sum_{j=1}^{n'} x_{ij} \lambda_{1j} + \sum_{j=n'+1}^{n''} x_{ij} \lambda_{2j} \leq x_i \quad (i = 1, 2, \cdots, m'),
\]

\[
x_{ik} \leq x_i \quad (i = m'+1, m'+2, \cdots, m),
\]

\[
\sum_{j=1}^{n'} y_{rj} \lambda_{1j} + \sum_{j=n'+1}^{n''} x_{rj} \lambda_{2j} \quad \text{PT use keeps a current level and more}
\]

\[
\sum_{j=1}^{n'} \lambda_{1j} = z_1, \sum_{j=n'+1}^{n''} \lambda_{2j} = z_2,
\]

\[
z_1 + z_2 = 1,
\]

\[
\lambda_{1j} \geq 1, \lambda_{2j} \geq 1,
\]

\[
z_1, z_2 = 0 \text{ or } 1,
\]

\[
x_i \geq 1 \quad (i = 1, 2, \cdots, m).
\]

where

- \(x_{ij}, y_{rij}\): I/O data
- \(i\): input variable
- \(r\): output variable
- \(j\): city
- \(1\sim n': \) PT-oriented
- \(n'+1\sim n'': \) PC-oriented
- \(n''+1\sim n: \) Developing city
- \(z_1, z_2\): binary dummy

A priori
Empirical analysis: Data

- 46 cities at 4 time points
- collected by Kenworthy, J., Laube, F. (UITP)
- World-wide database including both developed/developing cities
- Items
  - Indices of city characteristics
  - Transport demand and supply indices
  - Mobility index
  - Environmental indices
City heterogeneity of energy consumption in transportation sector

Heterogeneity of energy consumption

- Categorize cities due to energy consumption by transport mode
- Cluster analysis
- Distinction variables
  - Road length per capita [km/person]
  - PT operation length per capita [km/person]
  - Categorized by the level of infrastructure investment

Analysis result

- **cluster 1**: PT oriented city
  - London, Hong Kong, Copenhagen etc.
  - Highly depend on PT

- **cluster 2**: PC/PT balanced city
  - N.Y., Tokyo, Paris etc.

- **cluster 3**: PC oriented city
  - Houston, L.A., Portland etc.
  - Highly depend on PC
Evaluation result of EE model

Target of energy consumption

Reduced

EE index

0.667

1.000

0.803

Optimum energy consumption
Potentially reduced energy

Statistics in 1990

Energy consumption [MJ/person]

16/22
Characteristics of cities on the frontier

- Cities in reference set
  - PC-oriented city
    - Denver
    - Sacramento
    - Winnipeg
      - Detroit, Houston, San Diego, etc: 8 cities refer
  - PC-PT balanced city
    - Canberra
    - Montreal
      - Boston: 1 city refers
  - PT-oriented city
    - Copenhagen
    - Hong Kong
      - London, Tokyo, Los Angeles etc: 37 cities refer

Car dependent cities refer PC-oriented cities
Shift from PC to PT-oriented city
PT-oriented cities are more efficient

Feasible reference set appropriate to each city can be found
Reference cities

Copenhagen, Denmark
EE=1.0, 20430MJ/person
PT-oriented
Higher density
Radial public transport network

Denver, Colorado
EE=1.0, 68275MJ/person
PC-oriented
Lower density
Grid road network
Policies to improve EE: scenarios

- **Modal shift**

- **Improving energy intensity of private car**

- **Emissions trading among cities**

  - City A
  - City B
  - Emission
  - Goal
Effects of emissions trading

- Policy scenarios

Energy consumption should be reduced

- City A buys emission surplus from cities B-D

Energy consumption after emissions trading

- EE=0.2

Energy consumption after emissions trading

- 0.8

Energy consumption after emissions trading

- 0.6

More energy consumption concentrates to higher EE city

Because cities B-D have already achieved the goal, they will sell the right to city A

Total amount of energy reduced must be sum up across cities. Once total energy rights are evenly distributed to all cities.
Effects of emissions trading

- Improving EE in a whole system all over the world
- Reducing variance of EE among cities
  → an useful tool toward system optimum
Conclusion

Findings

- Development of EE model
- Apply the model to evaluate EE in transport system
  - Public transport-oriented cities are more efficient
  - A realistic evaluation considering urban characteristics
- Policy evaluation of EE improvement
  - Feasible scenarios
  - Effectiveness of emissions trading scheme in a whole system

Future works

- Removing arbitrariness
  - Heterogeneity of energy consumption system in cities
  - Distinction between developed and developing countries
Promoting Environmentally Sustainable Transport (EST) in Korea

Jun. 12, 2008

Sungwon Lee, Ph.D.
Director, Center for Sustainable Transportation
The Korea Transport Institute

Outline

- Background and introduction
- EST in general
- Trends in transport demand
- Policy measures for reducing energy and GHG in transport
- Effectiveness of policy measures
- Special legislation for EST in Korea
Background and Introduction

- Recently, greenhouse gas emission and the possibility of global warming have become the main environmental concern in the transport sector.
- Transport sector is the dominant source of urban air pollution and noise disturbance in most cities in the world.
  - 20 – 30% of total energy consumption
  - More than 90% of air pollutant emission in urban areas
- Controlling transport activity and thus energy consumption in the transport sector has been regarded as very difficult

EST in General

- Transportation demand is a Derived Demand
- Reduction is extremely difficult
- Rapid Motorization Everywhere
- Definition of EST: EST is: Transportation that does not endanger public health or ecosystem and meets needs for access consistent with (a) use of renewable resources at below their rate of regeneration, and (b) use of non-renewable resources at below their rate of development of renewable substitute (OECD)
Trends in Transportation Demand

- Transport Sector: 20% of total energy consumption
  - Rapid increase in developing countries
- Second largest source of GHG and most rapidly increasing sector
- Road transport is responsible for more than 80% of social cost, more than 90% of urban air pollution
- Air transport: Rapidly increasing air transport demand
- Air transport sector is responsible for more than proportional impact on global warming
- Maritime sector is the major emitter of NOx and SOx

Policy Measures for Reducing Energy and GHG in Transport

- Technological innovations
  - Engine efficiency
  - Aerodynamics
  - Transmission efficiency
- Vehicle mileage standards and emission standards
  - Fuel efficiency standards
  - Emissions standards
- Fuels policy
  - Lowering sulfur contents in diesel
  - Improving gasoline, additives, benzene or toluene levels
- Alternative fuels
  - Electric and hybrid vehicles
  - Fuel cells
  - Hydrogen and CNG
- Infrastructure for environmental sustainability
- Infrastructure for environmental sustainability
  - Rail and water transport related infrastructure
  - Bicycle roads
  - Infrastructure for intermodal transport
- Inspections and maintenance
  - In-use vehicle management
- Travel demand management (TDM)
  - Fuel and road pricing
  - Parking policy
  - Public transport promotion
- Traffic flow management
  - Signal synchronization
  - ITS
- Educational campaigns and information
- Controlling travel demand
  - Land use planning
  - Telecommuting and teleconferencing

Effectiveness of Policy Measures
# Table 1  Macro-economy and energy consumption, reference case

<table>
<thead>
<tr>
<th></th>
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<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Real GDP (1000 billion won)</td>
<td>377.4</td>
<td>442.4</td>
<td>729.6</td>
<td>1,067.6</td>
<td>3.23</td>
<td>5.13</td>
<td>3.88</td>
</tr>
<tr>
<td>Population (million)</td>
<td>45.0</td>
<td>47.2</td>
<td>50.8</td>
<td>52.4</td>
<td>0.96</td>
<td>0.74</td>
<td>0.30</td>
</tr>
<tr>
<td>GHG emissions (million TC)</td>
<td>120.0</td>
<td>138.1</td>
<td>215.1</td>
<td>313.5</td>
<td>2.85</td>
<td>4.53</td>
<td>3.84</td>
</tr>
<tr>
<td>Final energy consumption (million TOE)</td>
<td>120.9</td>
<td>149.6</td>
<td>253.1</td>
<td>380.9</td>
<td>4.35</td>
<td>5.40</td>
<td>4.17</td>
</tr>
<tr>
<td>Energy intensity (mil. TOE/1000 billion won)</td>
<td>0.320</td>
<td>0.338</td>
<td>0.347</td>
<td>0.357</td>
<td>1.08</td>
<td>0.26</td>
<td>0.28</td>
</tr>
<tr>
<td>Emission intensity (TC/million won)</td>
<td>0.318</td>
<td>0.312</td>
<td>0.295</td>
<td>0.294</td>
<td>-0.37</td>
<td>-0.57</td>
<td>-0.04</td>
</tr>
</tbody>
</table>

* Annual average growth rate

# Table 2  Public transport policy scenario

<table>
<thead>
<tr>
<th>Scenario</th>
<th>Assumptions</th>
</tr>
</thead>
<tbody>
<tr>
<td>BAU Scenario</td>
<td>Current trends scenario: Declining public transport modal share</td>
</tr>
<tr>
<td>Public transport scenario</td>
<td>Bus: Maintaining current modal share (9.96%) up to 2020. Subway: Maintaining current modal share (9.49%) up to year 2020.</td>
</tr>
</tbody>
</table>
### Table 3 Passenger transport demand forecast by public transport policy scenario

<table>
<thead>
<tr>
<th></th>
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</tr>
</thead>
<tbody>
<tr>
<td><strong>BAU</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Passenger car</td>
<td>168,126</td>
<td>217,043</td>
<td>280,194</td>
<td>361,718</td>
<td>466,963</td>
</tr>
<tr>
<td>Bus</td>
<td>27,695</td>
<td>25,917</td>
<td>24,253</td>
<td>22,695</td>
<td>21,238</td>
</tr>
<tr>
<td>Subway</td>
<td>28,365</td>
<td>34,445</td>
<td>38,899</td>
<td>51,541</td>
<td>61,170</td>
</tr>
<tr>
<td>Total</td>
<td>224,186</td>
<td>277,405</td>
<td>343,345</td>
<td>435,954</td>
<td>549,371</td>
</tr>
<tr>
<td><strong>Maintaining public transport modal share</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Passenger car</td>
<td>168,126</td>
<td>207,477</td>
<td>258,367</td>
<td>330,241</td>
<td>418,397</td>
</tr>
<tr>
<td>Bus</td>
<td>27,695</td>
<td>35,254</td>
<td>42,842</td>
<td>53,297</td>
<td>66,032</td>
</tr>
<tr>
<td>Subway</td>
<td>28,365</td>
<td>34,673</td>
<td>42,136</td>
<td>52,417</td>
<td>64,942</td>
</tr>
<tr>
<td>Total</td>
<td>224,186</td>
<td>277,405</td>
<td>343,345</td>
<td>435,954</td>
<td>549,371</td>
</tr>
</tbody>
</table>

### Table 4 Estimation of CO₂ emission under public transport policy

<table>
<thead>
<tr>
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</tr>
</thead>
<tbody>
<tr>
<td><strong>BAU</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Passenger car</td>
<td>6,853</td>
<td>8,847</td>
<td>11,421</td>
<td>14,745</td>
<td>19,035</td>
</tr>
<tr>
<td>Bus</td>
<td>417</td>
<td>390</td>
<td>365</td>
<td>342</td>
<td>320</td>
</tr>
<tr>
<td>Subway</td>
<td>85</td>
<td>103</td>
<td>117</td>
<td>155</td>
<td>184</td>
</tr>
<tr>
<td>Sub-total</td>
<td>7,355</td>
<td>9,341</td>
<td>11,903</td>
<td>15,241</td>
<td>19,538</td>
</tr>
<tr>
<td>Total Emission¹</td>
<td>18,681</td>
<td>22,176</td>
<td>26,565</td>
<td>31,044</td>
<td>34,748</td>
</tr>
<tr>
<td><strong>Maintaining public transport modal share</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Passenger car</td>
<td>6,853</td>
<td>8,457</td>
<td>10,532</td>
<td>13,461</td>
<td>17,055</td>
</tr>
<tr>
<td>Bus</td>
<td>417</td>
<td>531</td>
<td>645</td>
<td>803</td>
<td>994</td>
</tr>
<tr>
<td>Subway</td>
<td>85</td>
<td>104</td>
<td>126</td>
<td>157</td>
<td>195</td>
</tr>
<tr>
<td>Sub-total</td>
<td>7,355</td>
<td>9,092</td>
<td>11,383</td>
<td>14,421</td>
<td>18,244</td>
</tr>
</tbody>
</table>

Estimated reduction compared with the total²

|                       | 249 (1.12%) | 600 (2.26%) | 820 (2.64%) | 1,294 (3.72%) |

1) Total emission in the transport sector
2) The estimated reduction is in comparison with the total transport emission.
### Table 5 CO₂ emission units by freight transport modes

<table>
<thead>
<tr>
<th></th>
<th>Private freight vehicle</th>
<th>Commercial freight vehicle</th>
<th>Rail</th>
<th>Water</th>
<th>Air</th>
</tr>
</thead>
<tbody>
<tr>
<td>Freight ton km</td>
<td>33,376</td>
<td>9,227</td>
<td>10,072</td>
<td>33,699</td>
<td>151</td>
</tr>
<tr>
<td>(million ton-km)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Share (%)</td>
<td>38.6</td>
<td>14.6</td>
<td>11.6</td>
<td>38.9</td>
<td>0.2</td>
</tr>
<tr>
<td>CO₂ emission (thousand TC)</td>
<td>5,251.3</td>
<td>1,167.7</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>CO₂ emission unit</td>
<td>157.3</td>
<td>126.6</td>
<td>7.1</td>
<td>10.0</td>
<td>402.0</td>
</tr>
<tr>
<td>(g-C/ton km)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

### Table 6 Proposed freight modal share change

<table>
<thead>
<tr>
<th></th>
<th>1997</th>
<th>2010</th>
<th>2020</th>
</tr>
</thead>
<tbody>
<tr>
<td>Road</td>
<td>56.6</td>
<td>48.2</td>
<td>41.2</td>
</tr>
<tr>
<td>Rail</td>
<td>14.2</td>
<td>15.5</td>
<td>20.3</td>
</tr>
<tr>
<td>Water</td>
<td>35.8</td>
<td>36.0</td>
<td>38.1</td>
</tr>
<tr>
<td>Air</td>
<td>0.1</td>
<td>0.3</td>
<td>0.4</td>
</tr>
</tbody>
</table>

Unit: %
### Table 7 Freight modal shift policy scenario

<table>
<thead>
<tr>
<th>BAU Scenario</th>
<th>Current trend and no infrastructure investment</th>
<th>Modal shift scenario</th>
<th>Government infrastructure investment and modal shift plan</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
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<td></td>
</tr>
</tbody>
</table>

### Table 8 Freight modal demand forecasting by scenario

<table>
<thead>
<tr>
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<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Road Private</td>
<td>34,379</td>
<td>40,066</td>
<td>46,841</td>
<td>55,201</td>
<td>65,491</td>
</tr>
<tr>
<td></td>
<td>Road Commercial</td>
<td>9,504</td>
<td>11,060</td>
<td>12,950</td>
<td>15,261</td>
<td>18,106</td>
</tr>
<tr>
<td></td>
<td>Rail</td>
<td>10,375</td>
<td>12,073</td>
<td>14,136</td>
<td>16,659</td>
<td>19,764</td>
</tr>
<tr>
<td></td>
<td>Water</td>
<td>34,712</td>
<td>40,394</td>
<td>47,295</td>
<td>55,736</td>
<td>66,125</td>
</tr>
<tr>
<td></td>
<td>Air</td>
<td>156</td>
<td>182</td>
<td>213</td>
<td>251</td>
<td>298</td>
</tr>
<tr>
<td>Total</td>
<td>89,126</td>
<td>103,715</td>
<td>121,435</td>
<td>143,108</td>
<td>169,784</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Road Private</td>
<td>34,379</td>
<td>38,448</td>
<td>49,972</td>
<td>41,468</td>
<td>41,971</td>
</tr>
<tr>
<td>Road Commercial</td>
<td>9,504</td>
<td>10,375</td>
<td>14,592</td>
<td>18,822</td>
<td>25,477</td>
</tr>
<tr>
<td>Rail</td>
<td>10,375</td>
<td>14,592</td>
<td>18,822</td>
<td>25,477</td>
<td>34,483</td>
</tr>
<tr>
<td>Water</td>
<td>34,712</td>
<td>46,007</td>
<td>43,717</td>
<td>53,178</td>
<td>64,688</td>
</tr>
<tr>
<td>Air</td>
<td>156</td>
<td>252</td>
<td>364</td>
<td>491</td>
<td>662</td>
</tr>
<tr>
<td>Total</td>
<td>89,126</td>
<td>105,715</td>
<td>121,435</td>
<td>143,108</td>
<td>169,784</td>
</tr>
</tbody>
</table>
Table 9 CO\textsubscript{2} emission forecasting and reduction potential under the infrastructure and modal shift policy

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
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</tr>
</thead>
<tbody>
<tr>
<td><strong>BAU Scenario</strong></td>
<td></td>
<td></td>
<td></td>
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</tr>
<tr>
<td>Road Private</td>
<td>5,409</td>
<td>6,294</td>
<td>7,370</td>
<td>8,685</td>
<td>10,304</td>
</tr>
<tr>
<td>Road Commercial</td>
<td>1,203</td>
<td>1,400</td>
<td>1,639</td>
<td>1,931</td>
<td>2,291</td>
</tr>
<tr>
<td>Rail</td>
<td>74</td>
<td>86</td>
<td>101</td>
<td>119</td>
<td>141</td>
</tr>
<tr>
<td>Water</td>
<td>347</td>
<td>404</td>
<td>473</td>
<td>557</td>
<td>661</td>
</tr>
<tr>
<td>Air</td>
<td>63</td>
<td>73</td>
<td>86</td>
<td>101</td>
<td>120</td>
</tr>
<tr>
<td>Sub total</td>
<td>7,096</td>
<td>8,257</td>
<td>9,668</td>
<td>11,394</td>
<td>13,518</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td>18,681</td>
<td>22,056</td>
<td>26,565</td>
<td>30,855</td>
<td>33,869</td>
</tr>
</tbody>
</table>

|                      |       |       |       |       |       |
| **Infrastructure & modal shift policy Scenario** |       |       |       |       |       |
| Road Private         | 5,409 | 6,049 | 6,446 | 6,525 | 6,604 |
| Road Commercial      | 1,203 | 1,318 | 2,222 | 2,847 | 3,541 |
| Rail                 | 74    | 104   | 134   | 182   | 246   |
| Water                | 347   | 400   | 437   | 532   | 647   |
| Air                  | 63    | 101   | 146   | 197   | 266   |
| Sub total            | 7,096 | 7,973 | 9,387 | 10,282| 11,304|
| **Reduction potential** | 284  | 282   | 1,111 | 2,214 |
|                      | (1.29%)| (1.06%)| (3.60%)| (6.54%)|

Public transit related policies would bring GHG related improvements. They are more easily implementable politically.

Freight modal shift could bring greater GHG emission. However this could imply substantial investments in related infrastructure.
Special Legislation for EST in Korea

EST Law in Korea

- EST Law in Korea is now in legislation process
- “Environmentally Sustainable Transport and Logistics Law”
- Motivated by UNFCCC and Kyoto protocol
- Empowers MLTM to exercise diverse regulatory measures
Important Provisions in the EST Law

- EST planning by MLTM and Provinces
  - Long term planning by MLTM
  - Regional planning by Provinces
- Regional planning requires long term land use and transportation planning consistent with EST

- EST zoning and EST indicator based management
  - Arterial transportation zone
  - Urban transportation zone
  - Regional transportation zone
- EST related indicators
  - Environmental indicators
  - Economic indicators
  - Social indicators
- **Special EST planning**
  - Modal shift policies
  - TDM management
  - Environmentally friendly infrastructure
- **Regulatory measures**
  - Heavy duty freight regulation
- **Public transport promotion**
  - Economic incentives

- **Transport related price control**
  - Economic incentives, taxation and subsidy
- **Infrastructure development**
  - Environmental benefits must be included in the evaluation
- **Economic incentives for low polluting vehicles**
- Integrated urban planning
  - Urban planning must consider EST
- Green transport promotion
  - Walking and bicycles
  - Walking related infrastructure and survey
  - Bicycle related infrastructure and safety plan

- Funding for EST
  - Special fund for EST development
- Capacity building for EST
  - Special higher education institute for EST
- International collaboration
  - Exchange of information and expertise
  - Collaborative researches
Transport Policies for EST

- Diverse measures required for reduction in GHG in transport sector
- Technological innovation and economic incentives
- Limitations in policy options and secondary impacts
- No Panacea
- A comprehensive approach is required

Thank you!
Sustainable Urban Form
in case of Korea

Kwangik Wang
KRIHS

Research Structure

Introduction, Research Problem, Aim & Questions

Review Previous Studies

Measuring CO₂ emissions & Urban Form

Empirical Analysis
- Bivariate / Classification / Multivariate

Conclusion
UN Conference on Environment and Development (1992) and the Johannesburg World Summit on Sustainable Development (2002) → Promote Sustainable Development by Connection between Development Patterns and Human Activity

“Compact City” as Sustainable Urban Form/Structure
→ Enhancing the Aggravated Urban Environment by Green Paper on the Urban Environment (1990, European Commission)
→ For the Energy Efficiency and Quality of Life
→ Academic Debates on the Connection between Land Use and Road Transport in Western Society from 90s'
Problem Statements

- **S. Koreans Global Warming Attribution**
  - 9th in Total Greenhouse Gases (GHGs)
  - 25th in Per Capita GHGs in 2000
  - Highest Increase Rate in Per Capita CO₂ Emissions
  → Rise of 1.5 degrees Celsius over two times larger than the global average

- **Serious Urban Environmental Problems**
  - Past Growing Urban Land Expansion
  - Explosive Growth in Automobile Dependency
  → Metropolitanization, Conurbation, Satellite New Town

- **Most of GHGs emitted from Urban Area**

Problem Statement

- **No Regional & Urban Planning Policies for GHGs**
  → S. Korea : Not in the First Group Currently
  → Still for Nat’l Level Policy and International Negotiation

- **MLTM (Ministry of Land, Transport and Maritime Affairs)**
  → New Town Guideline based on “Compact City” theory

- **Potential Urban Structure Change in 10 Years**
  → Multi-functional Administrative City, Innovations Cities, Enterprise Cities, New Town, Redevelopment, Regeneration Policy, etc.
Research Aims & Questions

- **Research Aims**
  - To Establish Base Knowledge for Connection between Urban Planning and Global Warming
    - Identifying the association of Urban Structure and CO₂ emissions in Road Transport Sector
    - Empirical Research by Aggregate Data at City Level

- **Research Questions**
  - Can “Compact City” theory apply to Korean cities?
  - How do the urban form variables influence road transport CO₂ emissions per capita?
  - Which form, Compact City vs. Decentralized Concentration, is more efficient for transport CO₂ emissions in the case of Korean cities?
Review Previous Studies
- CO2 emission per-capita from transport (Onishi, 1998) → Assist for Integrated Land-use and Transport policies
- Strong Influences of Spatial Features on Travel Pattern (Newman & Kenworthy, 1989; Banister, 1992; Bourne, 1992; Cervero, 1996; Song, 1998)
- Highly Mixed Land Use Areas (Cervero, 1991) → More Popular for Walking and Cycling

→ Densities and Gasoline Use (Kenworthy and Newman, 1989; Kenworthy and Laube, 1999)

Private motor vehicle fuel use vs. urban density for 46 international cities

Spatial advantages and disadvantages of infrastructure cost in low and high density cities
Transport Problem → Solved by Market Itself
(Gordon et al., 1989a, 1989b, 1991; Giuliano & Small, 1993; Levinson & Kumar, 1994)

Densification → Not Feasible or Not Acceptable
(Breheny, 1995a, 1995b; Thomas & Cousins, 1996)

Very Difficult to Compare between Cities:
Huge differences of Asia, Africa, Europe and US
(Williams, http://www.urbancity.org)

Compact City for Asian cities? (Marcotullio, 2001):
Already the densest or most ‘compact’ in the world
Suffer from extreme environmental conditions

---

Measuring CO₂ & Urban Form

Components of the spatial structure:
- Streets
- Basic services
- Residences

- Rail roads
- Employment areas

- Highway and transit systems
- Major transport terminals (ports and airports)

(Source from http://people.hofstra.edu/geotrans/eng/ch6env/conc6env/ch6c1en.html)
**Measure CO₂ emissions**

### CO₂ Emissions per capita from Road Transport

- **IPCC Tier 1 Method**

  \[ CO₂ \text{ emissions} = FC \times FOC \times EF \times (CO₂/C) \]

  where, \( CO₂ \text{ emissions} \) (unit: tons of Carbon Dioxide)
  
  \( FC = \) Fuel Consumption (1000toe)
  
  \( EF = \) Emission Factor by Fuel Type (tonC/1000toe)
  
  \( FOC = \) Fraction of Carbon Stored
  
  \( CO₂/C = 44/12 \)

  *** C to CO₂ conversion factor = 44/12:
  
  The weight of 1 unit of C (elemental Carbon) is equivalent to the weight of 44/12 units of CO₂ because one CO₂ molecule is heavier than just one Carbon atom

- **IPCC Tier 3 Method**

  \[ CO₂ \text{ emissions} = \sum (EF_{abc} \times Activity_{abc}) \]

  where:  
  
  \( EF = \) emission factor
  
  Activity = amount of energy consumed or distance traveled for a given mobile source activity
  
  \( a = \) fuel type (diesel, gasoline, LPG, etc.)
  
  \( b = \) vehicle type (e.g., passenger, bus and truck for road vehicles)
  
  \( c = \) emission control

**Potential Errors for Calculating Per Capita CO₂ in Road Transport of Each City**

- **IPCC Tier 1 Method:**

  Based on the energy use data which collected from the Retail Gas Station and Wholesale

- **IPCC Tier 3 Method:**

  Only estimated from the Provincial Level
  
  Then, data were break down by city capacity

**Estimation Method for this Research**

- **Average of Tier 1 and Tier 3 Method CO₂ emissions**
Definition of Urban Form (Anderson et al, 1996)

→ The spatial configuration of fixed elements within city boundary, which includes the spatial pattern of land uses and their densities as well as the spatial design of transport and communication infrastructure

→ The pattern of land use refers to the arrangement of the built environment for residential and employment activities

Measure Urban Form

Panorama picture of Suwon City

3D image of Suwon City

Residential Density

Workers Density

Source: (Residential Density)
Urban Form Indicators

a. Density

b. Inequality of Density by Gini Coefficient

c. Spatial Dispersion by Mean Distance Deviation

d. Spatial Association by Spatial Autocorrelation

e. Patterns of CBD: Monocentric vs. Multicentric

f. Mixed Land Use

b. Inequality of Density by Gini Coefficients

\[ G = 1 - \sum_{i=1}^{k} X_i \left( \sum_{j=1}^{i-1} Y_j + \sum_{j=i+1}^{k} Y_j \right) \]

where, \( G \) = Gini coefficient
\( X_i \) = Percentage for total amount of variable X (number of sub-area)
\( Y_i \) = Percentage for total amount of variable Y (density of sub-area)

(Kim, 1987)
c. Spatial Dispersion by Mean Distance Deviation

Illustrating the relative positioning of parcel center-points, the weighting of parcels by units of development, unweighted tile centers, and weighted tile centers for a hypothetical city.

Diagram illustrating two cases of spatial dispersion (recited from Paul M. Torrens and Marina Alberiti 2000, adapted from Suen 1998)

\[ M_d = \frac{\sum_{i} P_i (X_i - \bar{X})^2 + (Y_i - \bar{Y})^2}{\sum_{i} P_i} \]

Where, \( M_d \) = mean of deviation distance
\( P_i \) = observed population zone \( i \)
\( X_i, Y_i \) = center point coordinates of observed population zone \( i \)
\( \bar{X}, \bar{Y} \) = mean center point coordinates of observed population

Measure Urban Form

d. Spatial Autocorrelation by Global Moran’s I

\[ I = \frac{\sum_{i} \sum_{j} W_{ij} (X_i - \bar{X})(X_j - \bar{X})}{\sum_{i} \sum_{j} W_{ij} (X_i - \bar{X})^2} \]

Where, \( N \) is the number of cases
\( X_i \) is the variable value at a particular location
\( X_j \) is the variable value at another location
\( \bar{X} \) is the mean of the variable
\( W_{ij} \) is a weight applied to the comparison between location \( i \) and location \( j \)

- Oldest Indicators and Still Standard (Moran, 1950)
- Positive Autocorrelation
  → Nearby or Neighboring Areas are More Alike
- Negative autocorrelation
  → Neighboring Areas are Unlikely
- No Autocorrelation
  → Random Patterns exhibit
e. Monocentric vs. Multicentric (CBD)

Mono-centric form by sub-areas with percentage of commercial workers

<table>
<thead>
<tr>
<th>Area</th>
<th>Percentage of Commercial Workers</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gimcheon-si</td>
<td>19.2% 17.4% 12.9% 10.3% 10.1% 0.2% - 6.1%</td>
</tr>
<tr>
<td>Changwon-si</td>
<td>19.6% 14.0% 13.1% 9.9% and below</td>
</tr>
<tr>
<td>Bucheon-si</td>
<td>3.2% and below</td>
</tr>
</tbody>
</table>
| Goyang-si   | 5.6% 5.3% 5.6% 5.6%             

Multi-centric form by sub-areas with percentage of commercial workers

<table>
<thead>
<tr>
<th>Area</th>
<th>Percentage of Commercial Workers</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bucheon-si</td>
<td>3.2% and below</td>
</tr>
<tr>
<td>Goyang-si</td>
<td>5.6% 5.3% 4.7-4.9% 0.4-4.4%</td>
</tr>
</tbody>
</table>

**Variables and Data**

- **CO₂ per capita**
- **City Size**
- **Urban Form density**
- **polarization clustered**
- **Nuclearity**
- **Land Use Mix**
- **Open Space**
- **Road**
- **Socio-economic**
- **Demographic**

**Measure CO₂ & Urban Form**

<table>
<thead>
<tr>
<th>Variables</th>
<th>Data Sources</th>
</tr>
</thead>
<tbody>
<tr>
<td>CO₂ per capita for road transport (tons of CO₂)</td>
<td>Calculated from KNOC and MOE/NIES data</td>
</tr>
<tr>
<td>Size</td>
<td>Korea National Statistical Office Homepage</td>
</tr>
<tr>
<td>City Size</td>
<td>Computed from Land Classification Data</td>
</tr>
<tr>
<td>Urban Form density</td>
<td>Population and Housing Census</td>
</tr>
<tr>
<td>polarization clustered</td>
<td>Census on basic characteristics of establishments</td>
</tr>
<tr>
<td>Nuclearity</td>
<td>Korea National Statistical Office Homepage</td>
</tr>
<tr>
<td>Land Use Mix</td>
<td>Computed from variable 2 and 3</td>
</tr>
<tr>
<td>Open Space</td>
<td>Computed from variable 4 and 5</td>
</tr>
<tr>
<td>Road</td>
<td>Computed from variable 6 and 7</td>
</tr>
<tr>
<td>Socio-economic</td>
<td>Computed from Urban Planning Book</td>
</tr>
<tr>
<td>Demographic</td>
<td>Computed from Land Classification Data</td>
</tr>
</tbody>
</table>

**Variables and Data**

- **KNOC**: Korea National Oil Corporation
- **MOE/NIES**: Ministry of Environment / National Institute of Environmental Study

*KNOC: Korea National Oil Corporation*  
*MOE/NIES: Ministry of Environment / National Institute of Environmental Study*
**Measure CO₂ & Urban Form**

**Variables and Data**
- Commuting Modal Split
- Commuting Time
- Commuting Patterns
- Commuters Characteristics

**Commuting Modal Split**
- Mode split
  - Proportion of foot and bicycle use
  - Proportion of mass and public transit use
  - Proportion of private car use

**Average Time**
- Average commuting time by foot and bicycle use
- Average commuting time by mass and public transit use
- Average commuting time by private car use

**Commuters Housing**
- Percentage of commuters living in collaborative housing

**Commuters Parking**
- Percentage of parking space in house or apartment

**Commuters Job Characters**
- Job position and type

**Commuters Education**
- Percentage of university education

**Commuters Marriage Status**
- Percentage of married commuters

* Sources for Commuting Data: Recoded from the 2% Sample Data of Population and Housing Census

---

**Empirical Analysis**

(Source from http://people.hofstra.edu/geotrans/eng/ch8en/conc8en/ch8c4en.html)
70 cities (out of total 79 cities)
### Variations of Key Variables

#### Higher CO₂ emitted Cities

<table>
<thead>
<tr>
<th>REGION</th>
<th>CITY</th>
<th>CO₂ per capita (tons of CO₂)</th>
<th>Density (persons/ha)</th>
<th>Grid significant deviation</th>
<th>Mean deviation distance (populations)</th>
<th>Pattern of central commercial sub-area</th>
<th>Motor vehicles per km²</th>
<th>Blue-collar job commuters ratio</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Local</td>
<td>1.66</td>
<td>115,981</td>
<td>0.375</td>
<td>0.739</td>
<td>Monocentric Form</td>
<td>0.44</td>
<td>0.25</td>
</tr>
<tr>
<td>2</td>
<td>Local</td>
<td>1.71</td>
<td>254,272</td>
<td>0.379</td>
<td>0.660</td>
<td>Monocentric Form</td>
<td>0.33</td>
<td>0.29</td>
</tr>
<tr>
<td>3</td>
<td>Local</td>
<td>1.76</td>
<td>128,921</td>
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<td>0.702</td>
<td>Monocentric Form</td>
<td>0.53</td>
<td>0.27</td>
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<tr>
<td>4</td>
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<td>98,722</td>
<td>0.480</td>
<td>0.596</td>
<td>Monocentric Form</td>
<td>0.36</td>
<td>0.26</td>
</tr>
<tr>
<td>5</td>
<td>SMA</td>
<td>1.66</td>
<td>120,977</td>
<td>0.345</td>
<td>2.372</td>
<td>Monocentric Form</td>
<td>0.49</td>
<td>0.18</td>
</tr>
<tr>
<td>6</td>
<td>Local</td>
<td>1.80</td>
<td>328,160</td>
<td>0.481</td>
<td>0.812</td>
<td>Monocentric Form</td>
<td>0.36</td>
<td>0.35</td>
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<tr>
<td>7</td>
<td>Local</td>
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<td>195,560</td>
<td>0.654</td>
<td>0.573</td>
<td>Monocentric Form</td>
<td>0.44</td>
<td>0.29</td>
</tr>
<tr>
<td>8</td>
<td>SMA</td>
<td>1.80</td>
<td>314,372</td>
<td>0.515</td>
<td>0.715</td>
<td>Monocentric Form</td>
<td>0.26</td>
<td>0.32</td>
</tr>
<tr>
<td>9</td>
<td>Local</td>
<td>1.80</td>
<td>211,461</td>
<td>0.586</td>
<td>0.762</td>
<td>Monocentric Form</td>
<td>0.51</td>
<td>0.29</td>
</tr>
<tr>
<td>10</td>
<td>Local</td>
<td>1.80</td>
<td>188,200</td>
<td>0.499</td>
<td>0.595</td>
<td>Monocentric Form</td>
<td>0.48</td>
<td>0.28</td>
</tr>
<tr>
<td>11</td>
<td>Local</td>
<td>1.80</td>
<td>118,900</td>
<td>0.368</td>
<td>1.742</td>
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<td>0.38</td>
<td>0.29</td>
</tr>
<tr>
<td>12</td>
<td>Local</td>
<td>1.80</td>
<td>92,300</td>
<td>0.390</td>
<td>0.600</td>
<td>Monocentric Form</td>
<td>0.49</td>
<td>0.34</td>
</tr>
<tr>
<td>13</td>
<td>SMA</td>
<td>1.80</td>
<td>179,720</td>
<td>0.373</td>
<td>0.743</td>
<td>Monocentric Form</td>
<td>0.48</td>
<td>0.28</td>
</tr>
<tr>
<td>14</td>
<td>Local</td>
<td>1.80</td>
<td>128,200</td>
<td>0.386</td>
<td>0.803</td>
<td>Monocentric Form</td>
<td>0.36</td>
<td>0.30</td>
</tr>
<tr>
<td>15</td>
<td>Local</td>
<td>1.80</td>
<td>75,399</td>
<td>0.780</td>
<td>12.161</td>
<td>Monocentric Form</td>
<td>0.54</td>
<td>0.27</td>
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<td>16</td>
<td>Local</td>
<td>1.80</td>
<td>151,281</td>
<td>0.725</td>
<td>0.702</td>
<td>Monocentric Form</td>
<td>0.42</td>
<td>0.33</td>
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<tr>
<td>17</td>
<td>Local</td>
<td>1.80</td>
<td>136,969</td>
<td>0.794</td>
<td>0.702</td>
<td>Monocentric Form</td>
<td>0.41</td>
<td>0.23</td>
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<tr>
<td>18</td>
<td>Local</td>
<td>1.80</td>
<td>273,833</td>
<td>0.794</td>
<td>0.699</td>
<td>Monocentric Form</td>
<td>0.42</td>
<td>0.25</td>
</tr>
<tr>
<td>19</td>
<td>Local</td>
<td>1.80</td>
<td>147,939</td>
<td>0.729</td>
<td>0.869</td>
<td>Monocentric Form</td>
<td>0.43</td>
<td>0.23</td>
</tr>
<tr>
<td>20</td>
<td>Local</td>
<td>1.80</td>
<td>94,922</td>
<td>0.811</td>
<td>0.732</td>
<td>Monocentric Form</td>
<td>0.51</td>
<td>0.25</td>
</tr>
<tr>
<td>21</td>
<td>Local</td>
<td>1.80</td>
<td>111,204</td>
<td>0.750</td>
<td>0.705</td>
<td>Monocentric Form</td>
<td>0.44</td>
<td>0.25</td>
</tr>
</tbody>
</table>

#### Bivariate Analysis (Correlation Analysis)

The economical, cultural, social and political context of our investigation is much homogenous than in Newman and Kenworthy’s study, because all the cities included in one country, S. Korea.

### Population vs. CO2 emissions per capita

<table>
<thead>
<tr>
<th>N = 70</th>
<th>Urban size</th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Residential Population</td>
<td>Daytime Workers</td>
<td></td>
</tr>
<tr>
<td>CO₂ per capita</td>
<td>-0.276(*)</td>
<td>-0.240(*)</td>
<td></td>
</tr>
<tr>
<td>Sig. (2-tailed)</td>
<td>0.021</td>
<td>0.045</td>
<td></td>
</tr>
</tbody>
</table>

*Correlation is significant at the 0.05 level (2-tailed).*

### Density vs. CO₂ emissions per capita

<table>
<thead>
<tr>
<th>N = 70</th>
<th>Density</th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Residential persons per ha</td>
<td>Daytime workers per ha</td>
<td></td>
</tr>
<tr>
<td>CO₂ per capita</td>
<td>-0.759(**)</td>
<td>-0.713(**)</td>
<td></td>
</tr>
<tr>
<td>Sig. (2-tailed)</td>
<td>0.000</td>
<td>0.000</td>
<td></td>
</tr>
</tbody>
</table>

**Correlation is significant at the 0.01 level (2-tailed).**

Correlation (Pearson’s r) = -0.759 R²=0.576 Sig. 0.000
Regrssion equation Y=2.114 – 0.004 X
where Y represents annual CO₂ emissions per capita (Tons of CO₂)
X is persons per hectare of built-up land

**Correlation (Pearson’s r) = -0.713 R²=0.508 Sig. 0.000**
Regression equation Y= 2.095 – 0.015 X
where Y represents annual CO₂ emissions per capita (Tons of CO₂)
X is workers per hectare of built-up land
**Urban Form and CO₂ emissions per capita**

<table>
<thead>
<tr>
<th>Variable</th>
<th>Mean deviation distance</th>
<th>Global Moran coefficient N:38</th>
<th>Mixed land-use zone ratio</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gini coefficient</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>CO₂ per capita</td>
<td>.658(<strong>), .674(</strong>), .673(<strong>), .609(</strong>), 0.288</td>
<td>0.080, 0.719</td>
<td>0.000</td>
</tr>
<tr>
<td>Sig. (2-tailed)</td>
<td>0.000, 0.000, 0.000, 0.000, 0.000</td>
<td>0.080, 0.719</td>
<td>0.000</td>
</tr>
<tr>
<td>Population density</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Job density</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Population weight</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Job weight</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

*Correlation is significant at the 0.05 level (2-tailed). **Correlation is significant at the 0.01 level (2-tailed).*

---

**Pattern of CBD and CO₂ emissions per capita**

**Compared the mean of variables by Monocentric and Multicentric Forms**

<table>
<thead>
<tr>
<th>Variable</th>
<th>Mean</th>
<th>F</th>
<th>Sig.</th>
</tr>
</thead>
<tbody>
<tr>
<td>CO₂ per capita</td>
<td>1.77</td>
<td>1.30</td>
<td>15.681</td>
</tr>
<tr>
<td>Population*</td>
<td>304035</td>
<td>1267276</td>
<td>8.689</td>
</tr>
<tr>
<td>Population density</td>
<td>86</td>
<td>171</td>
<td>16.880</td>
</tr>
<tr>
<td>Square meters per capita*</td>
<td>177</td>
<td>78</td>
<td>16.994</td>
</tr>
<tr>
<td>Job density*</td>
<td>23</td>
<td>49</td>
<td>21.810</td>
</tr>
<tr>
<td>Mixed land-use ratio</td>
<td>7.4%</td>
<td>9.7%</td>
<td>2.634</td>
</tr>
<tr>
<td>Green area ratio</td>
<td>16.1%</td>
<td>19.1%</td>
<td>0.362</td>
</tr>
<tr>
<td>Road area density*</td>
<td>38.6%</td>
<td>31.1%</td>
<td>11.064</td>
</tr>
<tr>
<td>Road number per square kilometer</td>
<td>41</td>
<td>54</td>
<td>1.996</td>
</tr>
<tr>
<td>Detached house ratio*</td>
<td>44.1%</td>
<td>24.4%</td>
<td>17.417</td>
</tr>
<tr>
<td>Collaborative house ratio*</td>
<td>43.8%</td>
<td>58.5%</td>
<td>13.169</td>
</tr>
<tr>
<td>Cars per capita</td>
<td>0.29</td>
<td>0.28</td>
<td>1.037</td>
</tr>
<tr>
<td>Foot and bicycle</td>
<td>61.9%</td>
<td>59.6%</td>
<td>1.167</td>
</tr>
<tr>
<td>Public transit*</td>
<td>17.8%</td>
<td>29.1%</td>
<td>28.794</td>
</tr>
<tr>
<td>Private car*</td>
<td>50.2%</td>
<td>45.4%</td>
<td>5.168</td>
</tr>
</tbody>
</table>

*It is significant at the 0.05 level*
Classification Analysis

Classification by Gini and MDD

Inequality by Gini Coefficient & Spatial Dispersion by Mean Distance Deviation

<table>
<thead>
<tr>
<th></th>
<th>Population density</th>
<th>Workers density</th>
<th>Gini coefficient for population</th>
<th>Gini coefficient for workers</th>
</tr>
</thead>
<tbody>
<tr>
<td>Population density</td>
<td>0.931**</td>
<td>0.736**</td>
<td>-0.724**</td>
<td>-0.724**</td>
</tr>
<tr>
<td>Workers density</td>
<td>0.931**</td>
<td>0.736**</td>
<td>-0.724**</td>
<td>-0.724**</td>
</tr>
<tr>
<td>Gini coefficient for population</td>
<td>-0.736**</td>
<td>0.736**</td>
<td>-0.864**</td>
<td>-0.864**</td>
</tr>
<tr>
<td>Gini coefficient for workers</td>
<td>-0.724**</td>
<td>-0.724**</td>
<td>-0.864**</td>
<td>-0.864**</td>
</tr>
<tr>
<td>Mean deviation distance by population</td>
<td>-0.566**</td>
<td>-0.459**</td>
<td>0.509**</td>
<td>0.581**</td>
</tr>
<tr>
<td>Mean deviation distance by workers</td>
<td>-0.508**</td>
<td>-0.398**</td>
<td>0.448**</td>
<td>0.496**</td>
</tr>
</tbody>
</table>

*Correlation is significant at the 0.01 level (2-tailed).

Deduction:
“Decentralized Concentration”
More Efficient for Reducing CO₂ emissions per capita from Road Transport in case of Korean cities.

Road Transport CO₂ emissions per capita
## Multivariate Analysis

### Selecting Variables

<table>
<thead>
<tr>
<th>Variable</th>
<th>70</th>
<th>Self</th>
<th>SMA</th>
<th>Local</th>
<th>Medium</th>
<th>Small</th>
</tr>
</thead>
<tbody>
<tr>
<td>1  CO₂ emission per capita for road transport</td>
<td>N=70</td>
<td>N=17</td>
<td>N=20</td>
<td>N=44</td>
<td>N=22</td>
<td>N=41</td>
</tr>
<tr>
<td>2  Residential population</td>
<td>-0.241</td>
<td>0.247</td>
<td>0.365</td>
<td>-0.762</td>
<td>-0.574</td>
<td>-0.294</td>
</tr>
<tr>
<td>3  Population density (persons per hectare)</td>
<td>-0.756(*)</td>
<td>-0.680(***)</td>
<td>-0.876(***)</td>
<td>-0.742(***)</td>
<td>-0.751(***)</td>
<td>-0.676(***)</td>
</tr>
<tr>
<td>4  Population polarization: Gini coefficient by population density</td>
<td>0.658(***)</td>
<td>0.675(***)</td>
<td>0.583(***)</td>
<td>0.886(***)</td>
<td>0.531(*)</td>
<td>0.590(***)</td>
</tr>
<tr>
<td>5  Job polarization: Gini coefficient by job density</td>
<td>-0.276(*)</td>
<td>-0.247</td>
<td>-0.280</td>
<td>-0.575(***)</td>
<td>-0.289</td>
<td>-0.578(***)</td>
</tr>
<tr>
<td>6  Population spatial dispersion: Mean distance by population</td>
<td>-0.759(***)</td>
<td>-0.680(***)</td>
<td>-0.876(***)</td>
<td>-0.742(***)</td>
<td>-0.751(***)</td>
<td>-0.676(***)</td>
</tr>
<tr>
<td>7  Population spatial dispersion: Mean distance by jobs</td>
<td>0.609(***)</td>
<td>0.599(*)</td>
<td>0.644(***)</td>
<td>0.832(***)</td>
<td>0.729(*)</td>
<td>0.669(***)</td>
</tr>
<tr>
<td>8  Percentage of mixed land-use zone area in built-up area</td>
<td>0.584(***)</td>
<td>0.492(***)</td>
<td>-0.656(***)</td>
<td>-0.841(***)</td>
<td>-0.695(***)</td>
<td>-0.596(***)</td>
</tr>
<tr>
<td>9  Pattern of central commercial sub-areas</td>
<td>-0.433(***)</td>
<td>-0.311</td>
<td>-0.407</td>
<td>-0.329(*)</td>
<td>-0.05</td>
<td>-0.445(**)</td>
</tr>
<tr>
<td>10 Road area density in built-up area</td>
<td>-0.681(***)</td>
<td>-0.491(***)</td>
<td>-0.741(***)</td>
<td>-0.619(***)</td>
<td>-0.619(***)</td>
<td>-0.619(***)</td>
</tr>
<tr>
<td>11 Motor Vehicles per person</td>
<td>-0.350(***)</td>
<td>-0.674(***)</td>
<td>-0.623(***)</td>
<td>-0.371(***)</td>
<td>-0.620(***)</td>
<td>-0.516(***)</td>
</tr>
<tr>
<td>12 Local tax burden per household (WON)</td>
<td>-0.212</td>
<td>0.131</td>
<td>0.588(***)</td>
<td>-0.329(*)</td>
<td>-0.455(***)</td>
<td>-0.214(*)</td>
</tr>
<tr>
<td>13 Job Numbers / Employed Population</td>
<td>0.748</td>
<td>0.280</td>
<td>0.574</td>
<td>0.430</td>
<td>-0.483</td>
<td>-0.019(*)</td>
</tr>
<tr>
<td>14 Proportion of mass and public transit mode (intra-urban commuters)</td>
<td>0.658(***)</td>
<td>-0.468</td>
<td>-0.611(***)</td>
<td>-0.636(***)</td>
<td>-0.575(***)</td>
<td>-0.584(***)</td>
</tr>
<tr>
<td>15 Percentage of female commuters</td>
<td>0.490(***)</td>
<td>0.203</td>
<td>0.372</td>
<td>0.372</td>
<td>0.167</td>
<td>0.510(***)</td>
</tr>
<tr>
<td>16 Percentage of parking space owned in commutes house or apartment</td>
<td>0.269(***)</td>
<td>0.252</td>
<td>0.377</td>
<td>0.297(*)</td>
<td>0.522(*)</td>
<td>0.218(*)</td>
</tr>
<tr>
<td>17 Percentage of blue-collar occupation</td>
<td>0.659(***)</td>
<td>0.599(***)</td>
<td>0.642(***)</td>
<td>0.856(***)</td>
<td>0.462(*)</td>
<td>0.650(***)</td>
</tr>
</tbody>
</table>

** Correlation is significant at the 0.01 level (2-tailed). * Correlation is significant at the 0.05 level (2-tailed).
Based on this regression model, road transport CO₂ emissions per capita may be estimated by means of the following regression equation:

\[
Y = -0.512 - 0.001 X_1 + 0.055 X_2 + 1.177 X_3 + 4.130 X_4 + 0.008 X_5
\]

where,
- \( Y \) = CO₂ emissions per capita for road transport
- Constant = -0.512
- \( X_1 \) = Population density
- \( X_2 \) = Population Spatial Dispersion (Scatter) from Population Mean Center
- \( X_3 \) = Road Area Density per square kilometers of built-up area
- \( X_4 \) = Mover Vehicles per capita
- \( X_5 \) = Percentage of blue-collar occupation among commuters

Power of explanation \( R^2 = 0.732 \), Adjusted \( R^2 = 0.711 \)

### Six Different Regression Models

<table>
<thead>
<tr>
<th>City classification</th>
<th>All cities (N:70)</th>
<th>Self cities (N:17)</th>
<th>SMR cities (N:20)</th>
<th>Local cities (N:44)</th>
<th>Medium cities (N:22)</th>
<th>Small cities (N:41)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Adjusted ( R^2 )</td>
<td>0.711</td>
<td>0.648</td>
<td>0.932</td>
<td>0.688</td>
<td>0.796</td>
<td>0.722</td>
</tr>
<tr>
<td>B</td>
<td>Beta t</td>
<td>Beta t</td>
<td>Beta t</td>
<td>Beta t</td>
<td>Beta t</td>
<td>Beta t</td>
</tr>
<tr>
<td>Population spatial dispersion</td>
<td>0.259*** 3.090 0.488*** 3.230</td>
<td>0.459*** 4.338 0.348* 1.921 0.372*** 2.913</td>
<td>0.254*** 3.283</td>
<td>0.269** 2.590 0.438** 2.528 0.360*** 4.230</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Motor vehicles per capita</td>
<td>0.259*** 3.283</td>
<td>0.269** 2.590 0.438** 2.528 0.360*** 4.230</td>
<td>0.269** 2.590</td>
<td>0.438** 2.528 0.360*** 4.230</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Population density -0.225* -1.813 -0.597*** -3.964 -0.540*** -6.964</td>
<td>0.246*** 3.404</td>
<td>0.246*** 3.404</td>
<td>0.246*** 3.404</td>
<td>0.246*** 3.404</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Population</td>
<td>-0.306*** -3.026 -0.315** -2.913 -0.233** -2.727</td>
<td>0.266** 2.320</td>
<td>0.266** 2.320</td>
<td>0.266** 2.320</td>
<td>0.266** 2.320</td>
<td></td>
</tr>
<tr>
<td>Road area density 0.219** 2.337 0.246*** 3.404</td>
<td>0.269** 2.359</td>
<td>0.269** 2.359</td>
<td>0.269** 2.359</td>
<td>0.269** 2.359</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Proportion of female commuters</td>
<td>-0.245*** 3.964</td>
<td>-0.245*** 3.964</td>
<td>-0.245*** 3.964</td>
<td>-0.245*** 3.964</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Spatial pattern of commercial sub-area 0.269** 2.359</td>
<td>0.269** 2.359</td>
<td>0.269** 2.359</td>
<td>0.269** 2.359</td>
<td>0.269** 2.359</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Inequality of workers density 0.229* 1.912</td>
<td>0.229* 1.912</td>
<td>0.229* 1.912</td>
<td>0.229* 1.912</td>
<td>0.229* 1.912</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Proportion of blue-collar commuters 0.222* 1.720</td>
<td>0.222* 1.720</td>
<td>0.222* 1.720</td>
<td>0.222* 1.720</td>
<td>0.222* 1.720</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Proportion of mixed land-use zone area -0.201** -0.964</td>
<td>-0.201** -0.964</td>
<td>-0.201** -0.964</td>
<td>-0.201** -0.964</td>
<td>-0.201** -0.964</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Residential parking space ownership 0.178* 1.817</td>
<td>0.178* 1.817</td>
<td>0.178* 1.817</td>
<td>0.178* 1.817</td>
<td>0.178* 1.817</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Local tax burden per household 0.152** 2.171</td>
<td>0.152** 2.171</td>
<td>0.152** 2.171</td>
<td>0.152** 2.171</td>
<td>0.152** 2.171</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

*** It is significant at 0.01 level ** significant at 0.05 level * significant at 0.1 level
Path Analysis

Direct and Indirect Effects by Path Analysis

- CO2 per capita for Road Transport
- Population density in built-up area (persons per ha)
- Spatial dispersed distance
- Road area density (road area per km²)
- Gini coefficient of population density
- Percentage of mixed land-use area
- Blue-collar job ratio in commuters
- Local tax burden per household
- Motor-vehicles per person
- Residential population

Coefficients:
- .303**
- -.481**
- -.610**
- -.512**
- .580**
- .327**
- -.14
- .29
- .25
- .30
- .26
- .024
- .553*
- .641**
- .107
- -.353**
- .15
- -.303**
- -.292
- -.292
- -.292
- -.292
- -.292
- -.292
- -.292
- -.292
- -.292
- -.292
- -.292
- -.292
In this research, we have tried to assess to what extent urban form characteristics affect CO2 emissions from energy use for transportation. The empirical evidence from the various investigations presented in the preceding chapters indicates that urban form variables exert important influences on transportation energy use. According to the empirical findings of these investigations, the following urban form characteristics contribute to a low CO2 emissions per capita for transport:

- A concentrated location of residential population to central sub-areas
- A high population density for cities as a whole
- A high population size
- A low road area in built-up area
- A decentralized pattern (or more equal distribution of density) within the urban area (i.e. employment density are not concentrated on one or two sub-areas)
- A high mixed land-use zone area
- A multicentric form of central commercial sub-areas

Of the above seven factors, the first four are considered to be strongest and most certain, as their influences have been confirmed by several of our investigations and are in line with theoretical considerations. The effects of the three latter variables are weaker or less certain.
Conclusion: General Finding

- Large populations of cities tend to reduce road transportation CO2 emissions per capita.
- Higher density of population and workers affect on decreased CO2 emissions per capita.
- The inequality of population density and the scattered population dispersion make to increase CO2 emissions per capita.
- More proportion of mixed land-use area and multicentric form of central commercial sub-areas also influence on decreased CO2 emissions per capita in road transport sector.

Results Summary

The following Urban Form characteristics contribute to low CO2 emissions per capita for Road Transport in case of Korean cities:

- Large Population Size
- High Population Density
- More Equal Distribution of Density
- High Mixed Land-Use
- Multi-centric Form of CBD
- Low Road area in built-up area
Research Limits and Working Research

- **Limitation of Research**
  - Data Availability: Energy, Travel, Transportation, etc.
  - Focus on CO₂, not Social & Economic Aspects
  - Limited Indicators to Define Accurate Urban Form

- **Working Research in KRIHS**
  - Establishing Regional GHGs Inventory
  - Relations between Regional Characters with GHGs
  - Establishing Territorial and Urban Planning Strategies against Climate Change Issues

Thanks a lot !!!!
Hypothetical Test of Urban Form Indicators

Low Density  Intermediate Density  High Density

- [Same Moran coefficient with Different Gini coefficient and Mean Deviation Distance]
  - Gini: 0.2036
  - MDD: 3.62km
  - Moran: 0.5908

- [Similar and Different Mean Deviation Distance (MDD) with Similar Urban Forms]
  - Extreme Multi-centric Form
  - More Uneven Multi-centric Form
  - Uneven Multi-centric Form
  - Extreme Multi-centric Form

- [Similar and Different Mean Deviation Distance (MDD) with Similar Urban Forms]
  - Low Density  Intermediate Density  High Density
  - Gini: 0.4112
  - MDD: 3.91km
  - Moran: 0.3930

- [Similar and Different Mean Deviation Distance (MDD) with Similar Urban Forms]
  - Low Gini Coefficient  Intermediate Gini Coefficient  High Gini Coefficient
  - Gini: 0.6321
  - MDD: 2.44km
  - Moran: 0.5908

- [Similar and Different Mean Deviation Distance (MDD) with Similar Urban Forms]
  - Intermediate Gini Coefficient  Low Gini Coefficient
  - Gini: 0.0000
  - MDD: 1.92km
  - Moran: 0.3758

- [Similar and Different Mean Deviation Distance (MDD) with Similar Urban Forms]
  - Low Gini Coefficient  Intermediate Gini Coefficient
  - Gini: 0.0000
  - MDD: 2.69km
  - Moran: 0.6311

- [Similar and Different Mean Deviation Distance (MDD) with Similar Urban Forms]
  - Low Gini Coefficient  High Gini Coefficient
  - Gini: 0.1828
  - MDD: 2.69km
  - Moran: 0.6311

- [Similar and Different Mean Deviation Distance (MDD) with Similar Urban Forms]
  - High Gini Coefficient  Intermediate Gini Coefficient
  - Gini: 0.4991
  - MDD: 0.3758
  - Moran: 0.4172

- [Similar and Different Mean Deviation Distance (MDD) with Similar Urban Forms]
  - High Gini Coefficient  Low Gini Coefficient
  - Gini: 0.0000
  - MDD: 2.69km
  - Moran: 0.6311

- [Similar and Different Mean Deviation Distance (MDD) with Similar Urban Forms]
  - Low Gini Coefficient  High Gini Coefficient
  - Gini: 0.0000
  - MDD: 2.69km
  - Moran: 0.6311

- [Similar and Different Mean Deviation Distance (MDD) with Similar Urban Forms]
  - Medium Density  Low Density
  - Gini: 0.3958
  - MDD: 2.69km
  - Moran: 0.4172

- [Similar and Different Mean Deviation Distance (MDD) with Similar Urban Forms]
  - Low Gini Coefficient  High Gini Coefficient
  - Gini: 0.0000
  - MDD: 2.69km
  - Moran: 0.6311

- [Similar and Different Mean Deviation Distance (MDD) with Similar Urban Forms]
  - High Gini Coefficient  Low Gini Coefficient
  - Gini: 0.0000
  - MDD: 2.69km
  - Moran: 0.6311
Hypothetical Test of Urban Form Indicators

<table>
<thead>
<tr>
<th>Urban Form</th>
<th>Gini</th>
<th>Moran</th>
<th>MDD</th>
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</thead>
<tbody>
<tr>
<td>Mono-centric Form</td>
<td>0.4577</td>
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<td>Multi-centric Form</td>
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<td>Decentralized Form</td>
<td>0.4957</td>
<td>-0.0506</td>
<td>3.95km</td>
</tr>
</tbody>
</table>

- High Density
- Medium Density
- Low Density

Compact Form
- Gini: 0.4915
- Moran: 0.4221
- MDD: 2.74km

Intermediate Decentralized Form
- Gini: 0.4532
- Moran: 0.7208
- MDD: 2.88km

More Decentralized Form
- Gini: 0.4627
- Moran: 0.6156
- MDD: 3.13km

[Same Gini Coefficients with Different Urban Forms]
Urban Subsurface Environments in Asian Mega Cities

Makoto Taniguchi
Research Institute for Humanity and Nature (RIHN), Japan
The RIHN campus is designed to facilitate discussions among researchers with different background.

**RIHN Guest House**

**Japanese style tea room**

**Project Room**

Established: 2001  
New building: 2006  
At Kyoto

---

**Traditional Groundwater Problems**

- Land subsidence due to excessive pumping
- Saltwater intrusion due to groundwater pumping

Land surface before subsidence in Osaka

Saltwater-fresh water interface
New Groundwater Problems

- Floating of subway stations due to regulation of pumping
- Subsurface thermal anomaly due to global warming and urbanization

<table>
<thead>
<tr>
<th>Population</th>
<th>Repeated groundwater problems in Asia</th>
</tr>
</thead>
<tbody>
<tr>
<td><img src="Population.png" alt="" /></td>
<td>![](Repeated groundwater problems in Asia.png)</td>
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</table>

Subsurface environmental problems such as land subsidence, groundwater pollution, and subsurface thermal anomalies, occurred one after another in Asian major cities with a time lag depending on the development stage of each city.
Subject 1: Development stages of cities and sub-surface environmental problems

Subject 2: Degradation of subsurface environments and change in reliable water resources

Subject 3: Subsurface contaminations and loads to the coast

Subject 4: Global warming & heat island effects on subsurface environment

RIHN project 2-4 (2006-2010)

Incubation Study (2003)
↓ (Internal evaluation)
Feasibility Study (2004)
↓ (External evaluation)
Pre-Research (2005)
↓ (1st Int Symp, Kyoto Oct, 2005)
Full-Research (2006-2010)
↓ (2nd Int Symp, Bali Dec, 2007)
Intermediate Evaluation (Feb, 2008)
RIHN project core members

- Makoto Taniguchi
  RIHN

- Shoji KANEKO
  Institute for International Development and Cooperation, Sophia University

Social economy

- Shung Ho-Wang
  Institute of Science, Technology, University of Tokyo

Urban geography

- Atsushi Tomogi
  University of Oxford

Makoto YAMANO
  Earthquake Research Institute, Tokyo University

Material

- William C. Burnett
  FSU, USA

- Gayl Ness
  U of Michigan , USA

- Shaopeng Huang
  U of Michigan , USA

- Makoto Taniguchi
  RIHN

- Shoji KANEKO
  Institute for International Development and Cooperation, Sophia University

- Gayl Ness
  U of Michigan , USA

- Shaopeng Huang
  U of Michigan , USA

- William C. Burnett
  FSU, USA

and more....

Urban Group (social economy + urban geography)

GIS (land use) in Osaka

1920's impermeable:permeable = 68:88
1960's impermeable:permeable = 158:30
2000's impermeable:permeable = 183:17
Groundwater flow modeling in Tokyo

Recharge area in Bangkok

GRACE + Re-Analyses, Gravity in situ

Material Group (groundwater contamination)

River water
Shallow groundwater

Ca(HCO₃) → Pollution
Hydrothermal water
Fossil water

Na(HCO₃) → Marine component
Hot spring water

CaSO₄, CaCl₂ → Human impact

Natural

Deep groundwater

Trilinear diagram
Groundwater contamination in Asian mega city

Anthropogenic

Sea water intrusion

Groundwater nitrate

Nitrate pollution

Figure 7: Distribution of nutrient compositions in shallow groundwater drawn on Prefecture maps. The data classifications in the 7 categories were compiled from the full classification provided by the Ministry of Natural Resources and Environment, Thailand and Research Center for Groundwater Resources (Ministry of Natural Resources and Environment, Thailand).
Groundwater pumping for subway
↓
Change of flow system
↓
Material transports
↓
Groundwater contamination

Heat Group

Borehole Thermometry

Surface warming

Depth departing from steady gradient shows: the timing and magnitude of surface warming (GW + HI)

\[ T(z) = T_0 + Gz \]
Effects of global warming & heat island on subsurface temperature

Increase in surface temperature

Tokyo: +2.8°C
Seoul: +2.5°C
Osaka: +2.2°C
Bangkok: +1.8°C
Jakarta: +1.2°C

Depth apart from steady gradient

Tokyo: 140m
Osaka: 80m
Seoul: 50m
Bangkok: 50m
Jakarta: 40m

Air temperature records

Time starting surface warming (air temp)
Tokyo (100y) > Osaka (70y) > Seoul (50y) > Bangkok (30y)
Decrease of “Max-Min” indicates “heat island effect”
Integration

- Population/land use
- GW storage
- GW flow model
- DPSIR model
- Integrated index

Determinants:
- Law/religion
- Material
- Heat

Compartments:
- Urban
- Law/religion
- Water
- Material
- Heat

Database:
- GIS/database

Cities:
- Tokyo
- Osaka
- Seoul
- Taipei
- Jakarta
- Manila
- Bangkok
- Manila

Time:
- Integration

GW flow/residence time
- Subsurface temp.
- GW pollutions
- Constructions
- Subsidence
Summary 1 (general)

- RIHN Project 2-4 “Human impacts on urban subsurface environment” (2006-2010) has started to evaluate the changes in subsurface environments in Asia under the pressures of human activities and climate changes.
- Target areas are Tokyo, Osaka, Bangkok, Jakarta, Manila, Seoul, and Taipei. Four subjects; (1) urban, (2) water, (3) material, and (4) heat, with cross cutting issues are chosen.
- We are evaluating the relationships between the development stage of the cities and subsurface environmental problems.
- We will assess the sustainable use of groundwater and subsurface environments to provide for better future development and human well-being.

Summary 2 (specific)

- Both effects of climate change and heat island on subsurface temperature have been evaluated in some Asian cities,
- The depth departing from constant gradient may be the integrated indicator of the magnitude of surface warming and elapsed time starting from SW due to GW and heat island due to urbanization,
- Contaminations of groundwater depend on the development stage of the city in Asia,
- RIHN would like to work with KRIHS for urban information in Seoul to achieve this project.

Research Institute for Humanity and Nature
ENDO, Takahiro

1. Why Land Subsidence?
2. Land subsidence as social dilemma
3. Countermeasures in Japan
4. Countermeasures in Thailand
5. A Comparative Analysis
6. Conclusion

KRIHS and RIHN Joint International Symposium on Urban Sustainability in Asia: Urban Planning, Environment and Transportation (KRIHS, Seoul, Korea, June 12, 2008)
Why Land Subsidence?

Volume of groundwater pumping for industrial and architectural use in Osaka, Japan: "Advanced country" on land subsidence

Previous works on land subsidence lacks a comparative viewpoint

Q. What are the key elements of effective countermeasures?
2, Land subsidence as social dilemma

A theory of social dilemma:

◆ sum of individual “rational” behavior $\neq$ a “rational” outcome

1) A number of individuals share a common interest

2) However, each individual does not have an incentive to contribute the benefit by themselves.

◆ Land subsidence problem

   = a typical example of social dilemma

- GW pumping brings about negative impacts to others.
  - negative impacts: lower groundwater table, higher flood risk
- Accumulation of the negative impacts: a public bad / nuisance
  $\Leftrightarrow$ prevention or solution of such nuisance: a common benefit
1. Everyone agrees that stopping/reducing GW pumping is desirable.
2. But cooperation does not always pay from individual viewpoint.
   - Group size effects
3. Each individual has incentive to be a free-rider who just expects the spill-over benefit made by others.
4. “Everybody’s business is nobody’s business”
   - Social Dilemma, Collective Action Problem (Olson 1965, Dawes 1975)
   → The case for government

“Hard” Solution and “Soft” Solution

1. “Hard” Solution: artificial recharge of groundwater
   → Supply side

Kern Water Bank, CA, USA  Rokugo Water Bank, Akita, Japan

2. “Soft” Solution: law, regulation
   → demand side
**Legal response to land subsidence**

Volume of groundwater pumping for industrial and architectural uses, Osaka city

1. 1951 1st Industrial waterworks construction project → 4th construction project by 1967
2. 1956 Industrial water law
3. 1959 Osaka city land subsidence control ordinance
4. 1962 Revised industrial water law + Laws concerning regulation on pumping up groundwater for use in buildings (Building water law)

**Countermeasures against land subsidence in Osaka City**

1. 1956: Industrial water law
   - Aim: Regulation on groundwater pumping for industrial use by furnishing alternative water supply to subsiding areas
   - Setting up critical areas + Introduction of permitted system on groundwater use in critical areas
   - Setting up a standard on wells + new wells beyond the standard are prohibited in critical area.

2. 1959: Osaka city land subsidence control ordinance
   - Regulation on groundwater pumping for uses in buildings in downtown of Osaka

3. 1962: Revised industrial water law
   - More strict standard enforced → All new wells are practically prohibited
   - Critical areas enlarged
   - Regulations enforced on existing wells → Existing well beyond standard was supposed be shut after moratorium

4. 1962: Laws concerning regulation on pumping up groundwater for use in buildings (Building water law)
   - Osaka city was appointed as designated area of this law
   - New standard for well construction → New wells for use in buildings are practically prohibited.
   - Regulations enforced on existing wells → Existing well beyond standard was supposed be shut after moratorium
4. Countermeasures in Thailand

① 1977 Groundwater Act
- Aim: Regulation on groundwater pumping in Bangkok and adjacent Provinces (Das Gupta and Babel 2005:459)
  - The only legal constraint against private pumping
  - Designation of target area: Permission system was introduced in the area
  - New wells was prohibited where public water supply had been available (Ramnarong 1999:55-56)
  - A system of groundwater charged was admitted (Das Gupta and Babel 2005:459, Babel et al. 2006:75)

② 1983 Mitigation of the GW Crisis and Land Subsidence in Bangkok
- Long term plan from 1983-2000
- Designation of “Critical Zone”—the target area for GW pumping reduction
- Groundwater fee was introduced in Bangkok and 5 adjacent provinces (Das Gupta and Babel 2005:459, Babel et al. 2006:75)

③ 1985 Groundwater Charge

④ 1995 Critical Zone enlarged
5. A Comparative analysis

1. Common features
   • Governmental intervention
   • Designation of target area (⇔ Monitoring)
   • Prohibition of new wells in designated areas
     (= Prevention further land subsidence)

2. Countermeasures peculiar to Bangkok
   • Groundwater Charge
     → A room for flexible rate in accordance
     with severity of land subsidence

3. Countermeasures peculiar to Osaka
   • Construction of waterworks (Alternative water supply)
     → Conversion of water supply from groundwater to
     surface water was failed (Ramnarong 1999:55, 57)
   • Strict regulation against existing wells

A Few Insights from Two Cases

1. Effectiveness of waterworks

Waterworks = Alternative source of water supply (Kataoka 2006:287)

• Thailand: GW charge has a limited effects without alternative choice
  (Das Guputa and Babel 2005:453)
• GW charge system → More effective where there is a room of choice
  (Groundwater or Surface water)
A Few Insights from Two Cases

2. Managing Groundwater as one Unit

<table>
<thead>
<tr>
<th>Regulations on groundwater pumping in designated areas</th>
<th>Water works</th>
</tr>
</thead>
<tbody>
<tr>
<td>Regulations on existing wells</td>
<td>Regulations on newly-built wells</td>
</tr>
<tr>
<td>Permit system</td>
<td>Observation system</td>
</tr>
<tr>
<td>Dimension of pipe</td>
<td>Depth of wells</td>
</tr>
<tr>
<td>GW fee</td>
<td>Depth of wells</td>
</tr>
<tr>
<td>GW fee</td>
<td></td>
</tr>
</tbody>
</table>

- Regulations confined to wells for industrial use
- Critical areas narrowed by conditions
- Weak regulations on existing wells

Industrial water law (1956)
- Practical permission
- Possibility of abeyance

Osaka City land subsidence prevention ordinance (1956)
- Practical permission
- Possibility of abeyance

Revised industrial water law (1962)
- Practical permission
- Possibility of abeyance

Building water law (1962)
- Practical permission
- Possibility of abeyance

- Regulations on wells for industrial uses
- Critical areas narrowed by conditions
- Weak regulations on existing wells

3. Managing groundwater with attention to geographical unit

(Babel et al., 2006引用)

(Buapeng 2006:5より引用)
6. Conclusion

Q: What are the key elements of effective countermeasures against land subsidence?

1. Land subsidence can be regarded as an example of “social dilemma”
   → The Case for government intervention

2. Various intervention methods:
   - Regulation of construction of new wells, Permission system of GW pumping, GW Charge system,
   - Conversion of water supply from GW to SW

3. Managing Groundwater as a natural unit
   → Fragmented management has a limited effects

4. Importance of waterworks (Alternative source of water supply)
Thank you very much for your attention!
(Contact: endo@chikyu.ac.jp)

3, Countermeasures in Japan

Legal system on groundwater in Japan

◆ 1896/3/27 Supreme Court Decision
  - Right of use groundwater belongs to the ownership of land.
  - A landowner can make free use of groundwater that lies below its land.

◆ Civil Code § 207: Subject to limitations by laws and ordinances, the ownership of land extends both above and below its surface

→ Groundwater use based on land ownership = The Theory of Private Water

(Ogawa 1998:313, Ogawa 2003:15-16)
### 法規制: 大阪の場合

<table>
<thead>
<tr>
<th>指定地域における地下水取水に対する規制</th>
<th>上水道</th>
<th>備考</th>
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</thead>
<tbody>
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<td>既存井戸への規制</td>
<td>新規井戸開設への規制</td>
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<td>許可制</td>
<td>吐口の断面積</td>
<td>取水場所の深さ</td>
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<td>大阪市地震改下防 止条例（1959）</td>
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<td>ビル用水法（1982）</td>
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</table>

Urban form and Greenhouse Gas Emission in Asian cities

Backjin LEE, Minho SEO and Yunsuk LEE

Korea Research Institute for Human Settlements (KRIHS)
Department of Architecture, Korea University

Outline

- Background & Aims
- Literature reviews
  - Urban form, transportation and environment
- Methodology
- Empirical Study
  - Tokyo, Seoul, Beijing
- Urban development and GHG emission
- Regression analysis
- Conclusions and future works
Background & Aims

- Characteristics of sustainable urban development

Multidimensional aspects:
- Various factors influencing sustainable urban development:
  - Urban growth factors: urban structure, urban density, etc.
  - Environmental factors: air pollution, energy consumption, etc.
  - Transportation factors: car ownership, car usage, etc.

Time dimensional aspects of urban development:
- Varying influences at different stages of urban development

Source: Fujiwara, 2004
Time dimensional aspects of urban form:
- Variation of urban forms

Characteristics of sustainable urban development (cont’d)

A gap of developed and developing countries
- Socio-economic conditions
- Need to achieve joint development and environmental goals

Tokyo
- System-making
- System-working
- Self management

Beijing
- Bench mark

*Sustainability indicators

<Source: Fujiwara, 2004>
Aims

- To explicitly investigate time dimensional aspects of urban development and urban form incorporating the gap of developed and developing countries,

- To analyze the relationship between urban form and Green gas emission using time series data of major Asian cities (Seoul, Tokyo and Beijing).

Literature Reviews

Relationships of Urban form, Transportation & Environment

- Urban density and car usage
- Urban form and transport energy consumption
Urban density and car usage

- Very strong correlations were found between the level of urban density and automobile use, such as gasoline consumption.
- Thus, achieving a more sustainable urban form inevitably involves the development of densities that can enable to reduce car usage or increase public transport.
- And it is necessary to build ‘node and corridors’ of high-density development rather than suburb.

Urban form and transport energy consumption

- Analyze the influences of urban form on vehicle energy consumption
- A multi-sub-center form in which both residential population and employment are suburbanized with shorter working trip lengths will curb energy consumption increases and bring about less congestion.
Methodology

- Quantifying urban form
- Moran index
- Classification of urban form

Quantifying urban form

- One fundamental issue in urban form debate is in quantitatively distinguishing different degrees of compactness and sprawl
- General Indices are - Gini, Relative entropy, Moran and Geary
- Some literatures showed that the Gini or Relative Entropy indices did not reveal the spatial relationship of high-density sub-area or the dimension of monocentric, polycentric, or decentralized sprawl (Y. Tasi, 2005)
- Moran index distinguishes compactness from sprawl explicitly
**Moran Index**

**Definition of the Moran Index**

- The Moran coefficient is defined as

\[
\text{Moran} = \frac{N \sum_{i=1}^{N} \sum_{j=1}^{N} W_{ij}(X_i - X)(X_j - X)}{\left( \sum_{i=1}^{N} \sum_{j=1}^{N} W_{ij} \right) (X_i - X)^2}
\]

where, \( N \) is the number of sub-areas; \( X_i \) is population or employment in sub-area \( i \); \( X_j \) is population or employment in sub-area \( j \); \( X \) is the mean of population or employment; and \( W_{ij} \) denotes the weighting between sub-areas \( i \) and \( j \).

- The Moran coefficient ranges from -1 to +1, with a high positive value indicating that high-density sub-areas are closely clustered, a value close to zero meaning random scattering and a -1 value representing a ‘chessboard’ pattern of development.

**Classification of Urban form**

- Urban form can be defined as the spatial pattern of human activities (Anderson et al., 1996) at a certain point in time. In a general sense, it can be classified into three categories: density, diversity and spatial-structure pattern.

- In the study, urban form is classified into the three categories:
  - monocentric, polycentric and decentralised sprawl

<table>
<thead>
<tr>
<th>A. Monocentric Form</th>
<th>B. Polycentric Form</th>
<th>C. Decentralised Sprawl</th>
</tr>
</thead>
<tbody>
<tr>
<td>![Monocentric Form]</td>
<td>![Polycentric Form]</td>
<td>![Decentralised Sprawl]</td>
</tr>
</tbody>
</table>
Empirical Study

- Status and change in socio-economic
- Status and change in spatial structure
- Status and change in GHG emission

Subject Asian cities

- Beijing
- Seoul
- Tokyo
Status and change in socio-economic

Population Trend of subject Asian cities

<table>
<thead>
<tr>
<th>Year</th>
<th>Tokyo</th>
<th>Seoul</th>
<th>Beijing</th>
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<tbody>
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GNI per Capita Trend of subject Asian cities

<table>
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<th>Beijing</th>
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<td>55,000</td>
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Status and change in socio-economic (cont’d)

GNI per capita

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<tr>
<td>2006</td>
<td>55,000</td>
<td>65,000</td>
<td>75,000</td>
</tr>
</tbody>
</table>
Status and change in spatial structure

- Population density status and change (Tokyo)

- Employment density status and change (Tokyo)

Status and change in spatial structure (cont’d)
Status and change in spatial structure (cont’d)

- Population density status and change (Seoul)

- Employment density status and change (Seoul)
Status and change in spatial structure (cont’d)

- Population density status and change (Beijing)

- Employment density status and change (Beijing)
Moran index of population

![Moran index of population graph](chart)

Moran index of employment

![Moran index of employment graph](chart)
Relation with Urban Form and Moran Indices

- Gasoline consumption trend of subject Asian cities

Status and change in GHG emission
Status and change in GHG emission (cont’d)

CO emission

- 29 -

Status and change in GHG emission (cont’d)

SO₂ emission

- 30 -
Urban development and GHG emission

- Relationships between socio-economic and GHG
- Relationships between spatial structure and GHG

Relationships between socio-economic and GHG: Passenger vehicle stocks and CO
Relationships between socio-economic and GHG: Gasoline Consumption and CO

Relationships between socio-economic and GHG: Gasoline Consumption and SO$_2$
Relationships between spatial structure and GHG: Moran index of population and CO

Moran indices of pop. CO (mg/m³)

Beijing

Seoul

Tokyo

Relationships between spatial structure and GHG: Moran index of employment and CO

Moran indices of employment CO (mg/m³)

Beijing

Seoul

Tokyo
Relationships between spatial structure and GHG: Difference of Moran index and CO

Relationships between spatial structure and GHG: Difference of Moran index and SO₂
Regression analysis

- Curve fitting: Moran index of population and CO
- Curve fitting: Moran index of employment and CO
- Curve fitting: Difference of Moran index and CO
Curve fitting: Moran index of employment and CO

Curve fitting: Difference of Moran index and CO
Conclusion

- The study tried to explicitly investigate the relationships between urban forma and gas emission.
  - In our study, socio-economic variables did not significantly explain the GHS conditions of urban area in time, especially in case of Beijing, rapidly developed city in recent.
  - On the other hand, the Moran indices of both population and employment could explain significantly. The difference of the two Moran indices also was the good index to explain the urban GHS emission.
  - The model employing the difference of Moran index of population and employment had the goodness of fit.

Reference

- Seoul Metropolitan Government (http://stat-app.seoul.go.kr/).
- SEPA (http://www.sepa.gov.cn/).
- Beijing Statistical Information Net (http://www.bjstats.gov.cn/).
- Tokyo Metropolitan Government (http://www.metro.tokyo.gov/).

<Abbreviation>
- SEPA : Ministry of Environmental Protection the People’s Republic of China
- CIA-Asia : the Clean Air Initiative for Asian Cities
- ADB : the Asian Development Bank
- APERC : Asia Pacific Energy Research Centre