The Urban Sustainability Challenge

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IIASA and Yale University

International Symposium
“Realizing Low Carbon Cities: Bridging Science and Policy”

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Global Energy Assessment

IIASA

International Institute for Applied Systems Analysis
and its international partners

GEA Knowledge Clusters

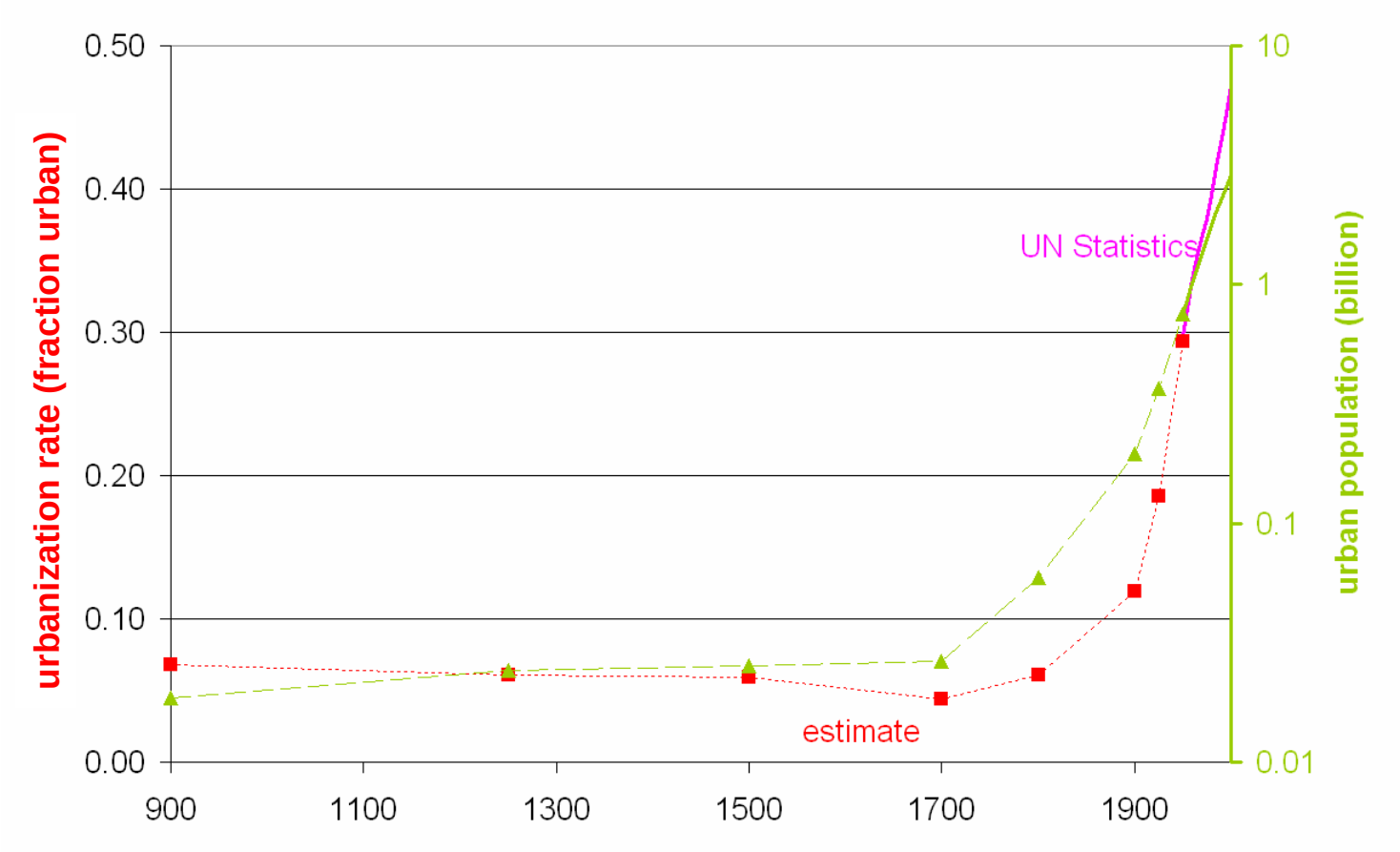
- **Cluster I: Major Global Issues and Energy**
  - assessment of the **Challenges**
- **Cluster II: Energy Resources and Technological Options**
  - assessment of the **Components** available to build future energy systems
- **Cluster III: Describing Possible Sustainable Futures**
  - assessment of how to combine the Components to create **Systems** that address the Challenges
- **Cluster IV: Realizing Energy for Sustainable Development**
  - assessment of the **Policies** needed to address the Challenges and realize the Systems

GEA KM18 Urbanization

- First Assessment with explicit discussion of urbanization and urban energy issues
- Increasing urban dominance in population, economic activity, energy use, CO_2 emissions
- Projected urban growth (scenarios)
- Unique urban energy and sustainability challenges identified
- Innovative solutions outlined

Urbanization: The last 1000 Years

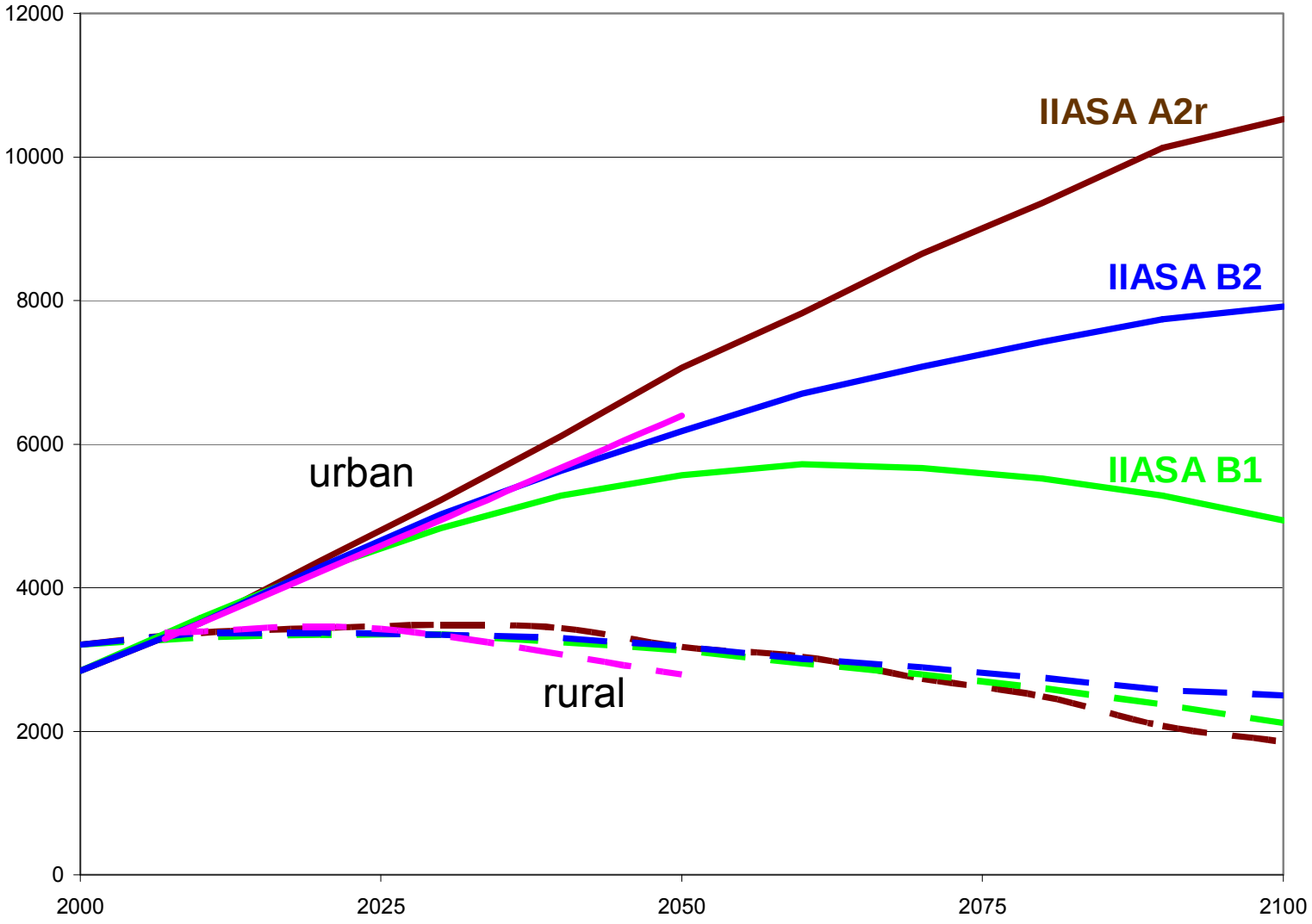
fraction urban, and total urban population in billion



Source: Grubler, 2006

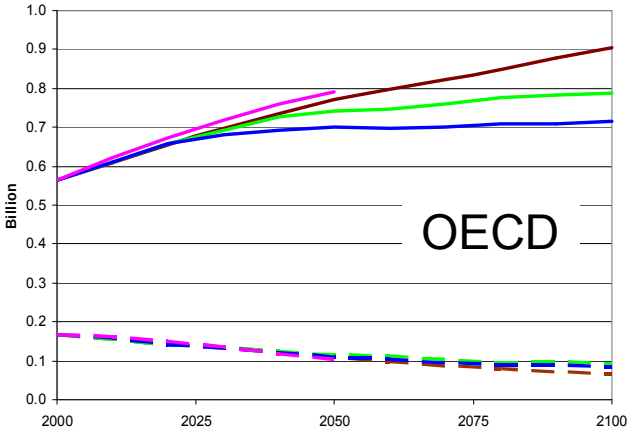
Urban and Rural Population Projections (Millions)

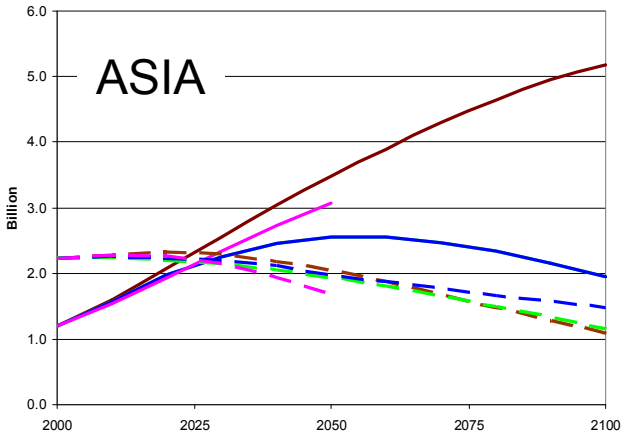
(IIASA GGI, 2007, and UN WUP, 2007)

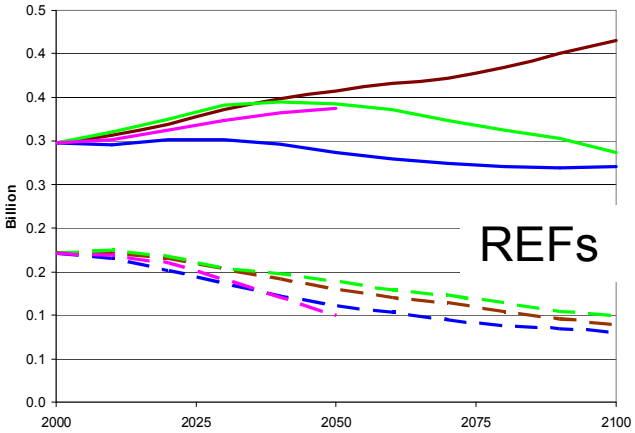


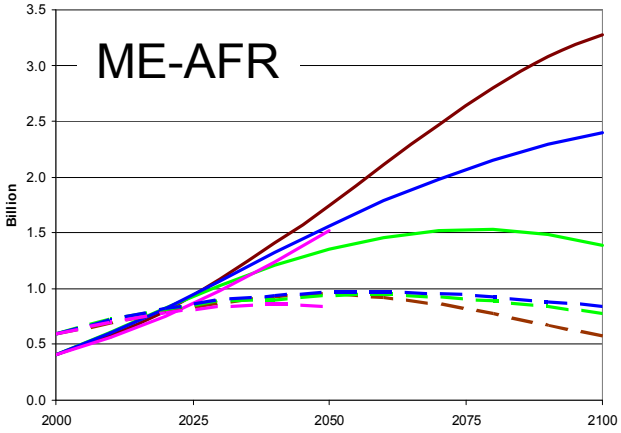
Data source: Riahi et al., 2007; UN, 2007

Urban vs. Rural Population Scenarios in 4 Macro-Regions (IIASA GGI, 2007, and UN WUP, 2007, in Billion)



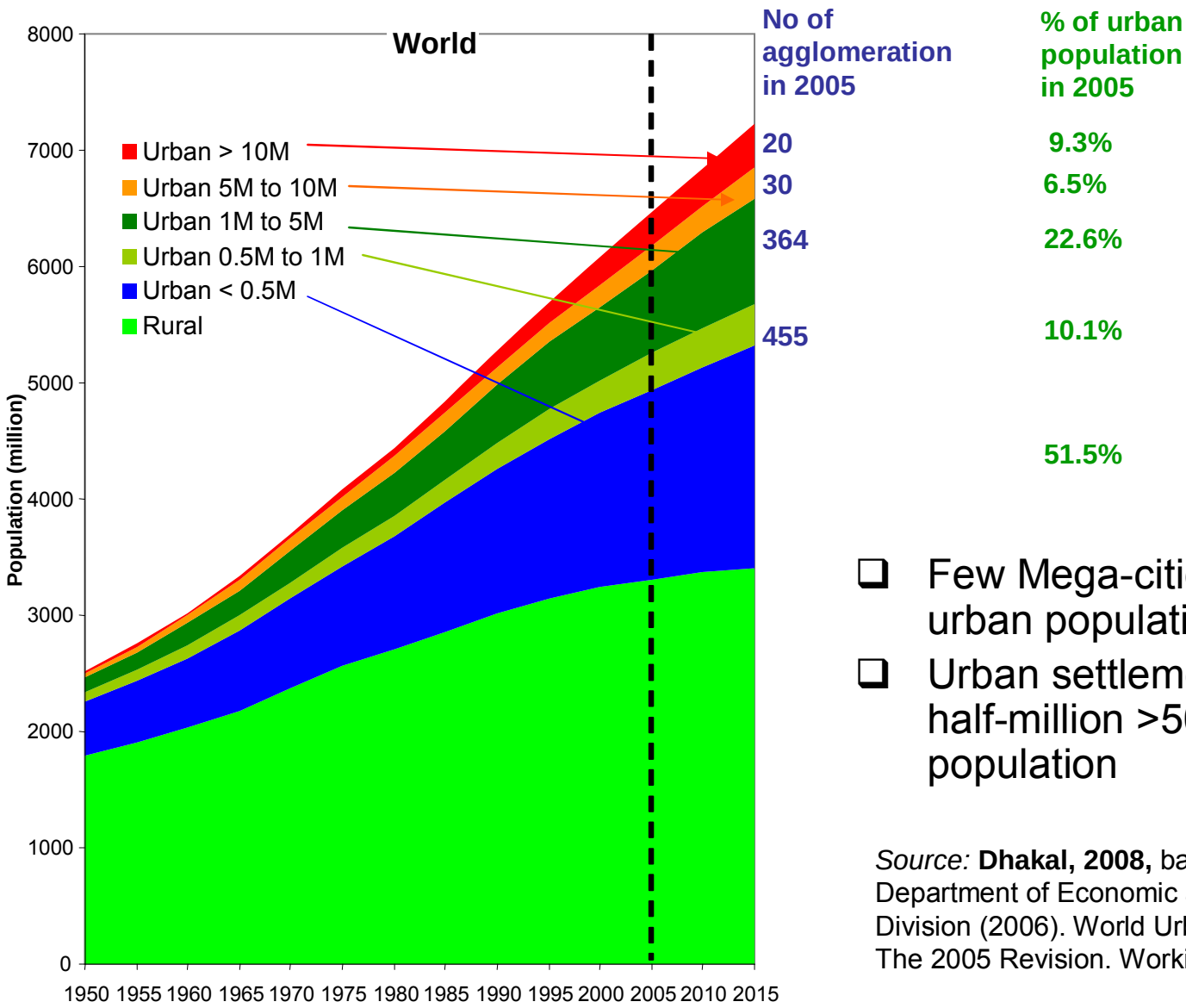






Data source: Riahi et al., 2007; UN, 2007

Population by Residence and Settlement Size

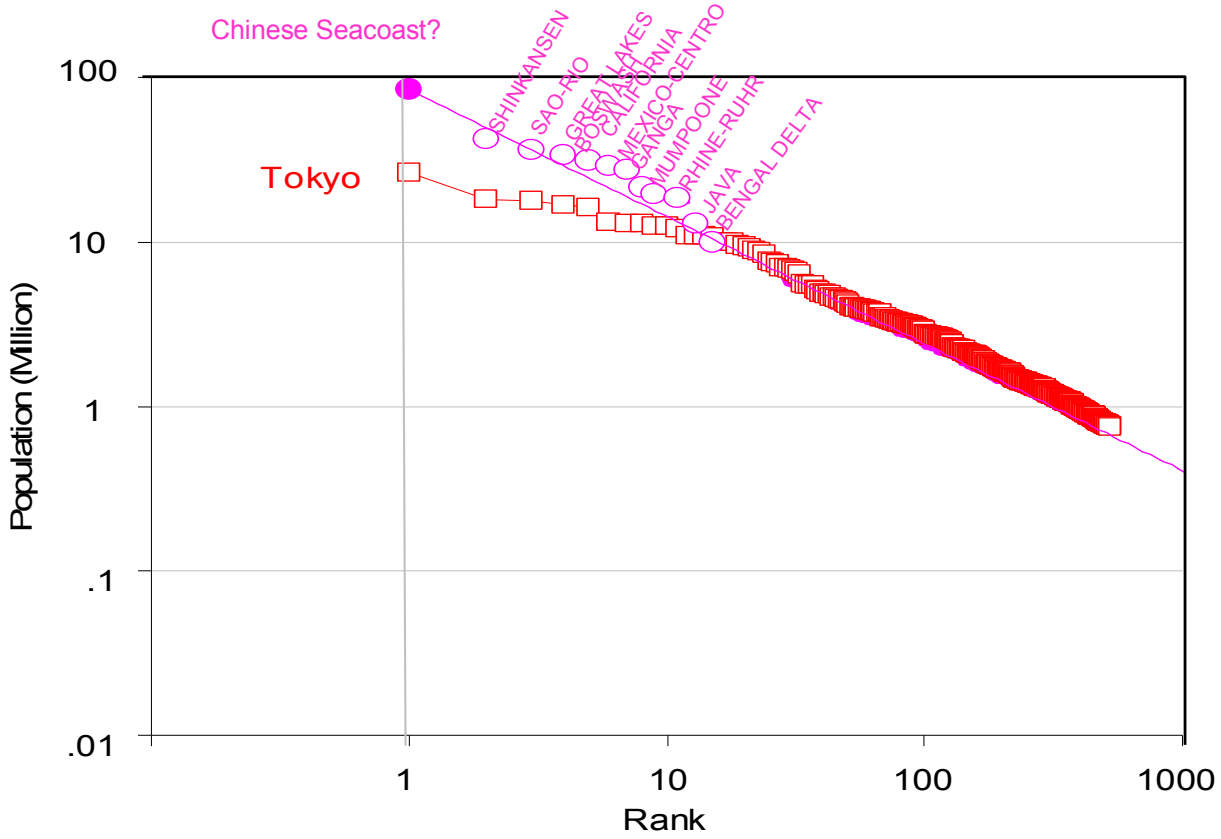


	No of agglomeration in 2005	% of urban population in 2005
Urban > 10M	20	9.3%
Urban 5M to 10M	30	6.5%
Urban 1M to 5M	364	22.6%
Urban 0.5M to 1M	455	10.1%
Urban < 0.5M		51.5%

- Few Mega-cities with <10% of urban population
- Urban settlements with less than half-million >50% of urban population

Source: **Dhakal, 2008,** based on: United Nations, Department of Economic and Social Affairs, Population Division (2006). World Urbanization Prospects: The 2005 Revision. Working Paper No. ESA/P/WP/200.

World City Hierarchies (Rank Size): Cities vs. Agglomerations/Corridors



Megacities increasingly fuse into agglomeration corridors!

Source: Grubler, 2006

City Population by Size Class and Urban Growth Trends

(Million Inhabitants, AD 2000, only largest cities included)

Note strong North-South heterogeneity in growth patterns and importance of declining cities

		city size class				
	growth	small	intermediate	big	large	**Total**
	regime	0.1-0.5 M	0.5-1 M	1-5 M	>5 M	
	declining	131	36	84	10	**261**
IND	0-2%/yr	184	32	96	20	**332**
	>2%/yr	23	3	3	10	**39**
	declining	26	25	60	30	**141**
DEV	0-2%/yr	95	88	243	80	**506**
	>2%/yr	153	101	276	80	**609**
	declining	157	61	144	40	**402**
WORLD	0-2%/yr	279	120	339	100	**838**
	>2%/yr	176	104	279	90	**648**
	ALL	612	284	762	230	**1888**

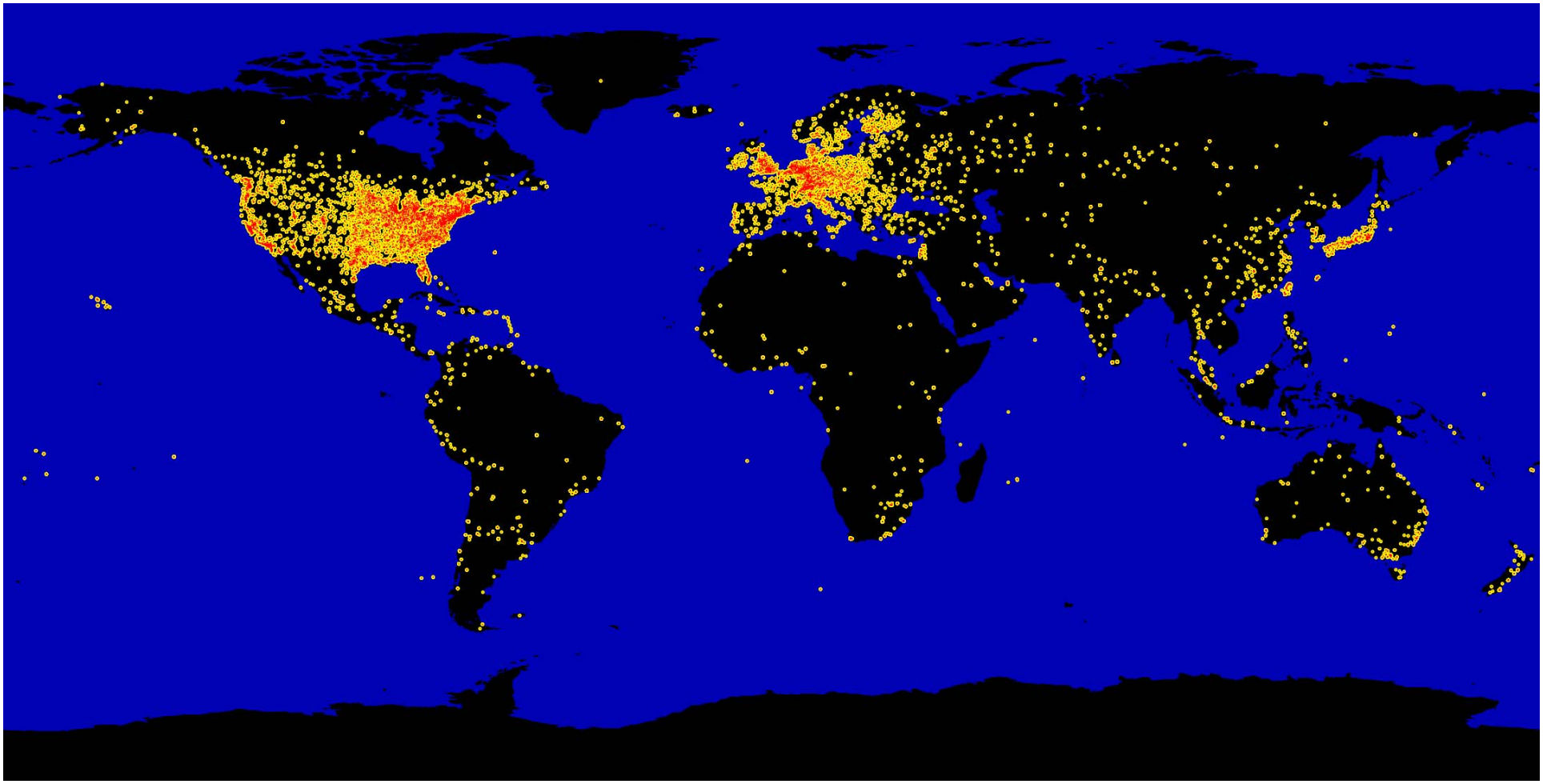
Memo item: total urban population: 2850

Source: UN HABITAT, 2008, based on UN Dem. Yearbks *var. vols.*
Growth trends of population size calculated over 1990-2000 period.

Internet Router Density

(sample of 564,521 routers)

Data: Mark Crovella, Boston University, 2007



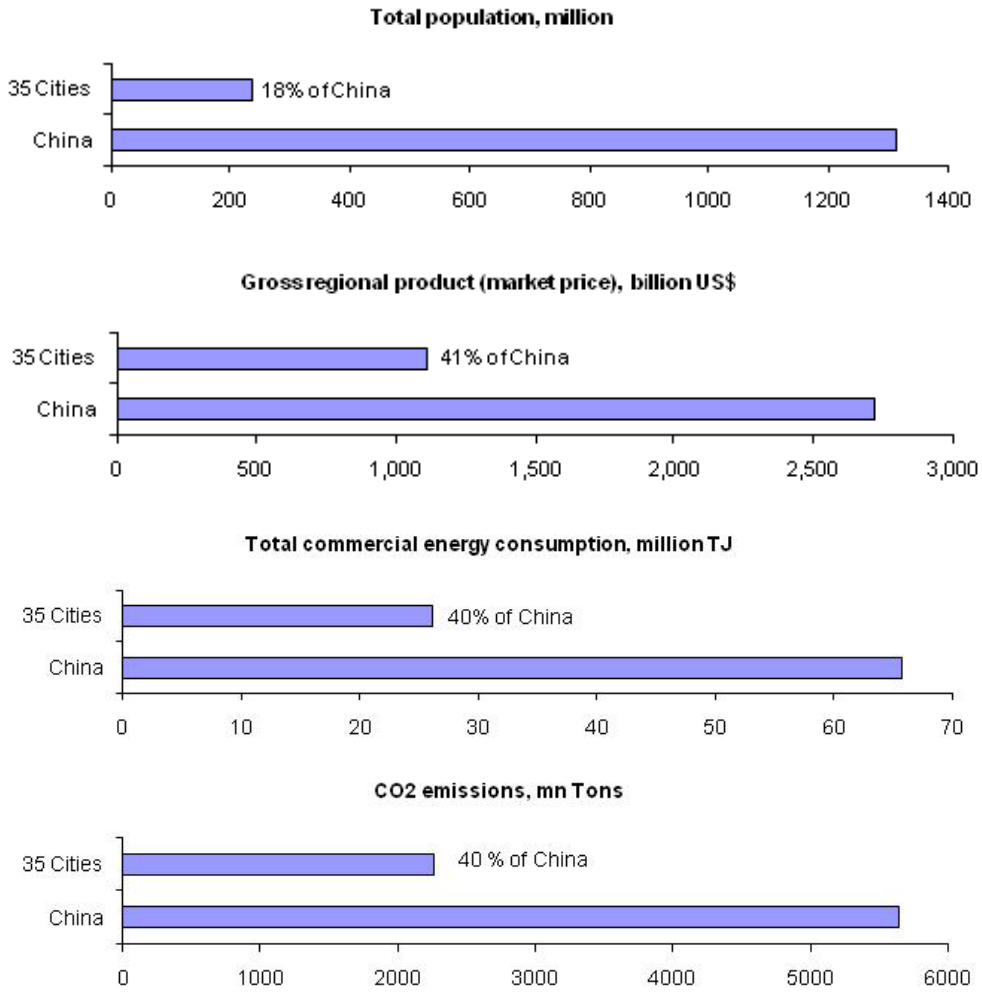
Urbanization Indicators AD 2000

URBAN		OECD90	REFs	ALM	ASIA	WORLD
Area	**(1000 km2)**	618	227	658	1426	2929
	% of total	***1.9***	***1.0***	***1.2***	***6.5***	***2.2***
Population	**(million)**	714	260	791	1089	2855
	% of total	***77.7***	***63.0***	***53.8***	***33.5***	***47.2***
GDP (MER 1990$)	**(billion)**	17522	587	2154	1729	21991
	% of total	***83.8***	***72.0***	***83.1***	***62.1***	***81.1***
Final energy use	**(EJ)**	107	23	29	32	192
	% of total	***76.4***	***72.5***	***64.5***	***45.7***	***66.6***
Light luminosity	**(million NLIS)**	23	3	5	3	33
	% of total	***56.1***	***53.2***	***53.9***	***71.9***	***56.7***
Internet routers	**(number in 1000)**	524	20	13	35	592
	% of total	***96.5***	***97.5***	***94.3***	***96.8***	***96.5***

GDP (MER) = Gross Domestic Product at market exchange rates 1990 US$.
EJ = 10^{18} Joules. NLIS: (sum of) Night Luminosity Index of Stable lights.
Definition of regions:
OECD90: OECD countries as of 1990; REFs: reforming economies of Eastern Europe and ex-USSR;
ALM: Africa, Middle East, and Latin America; ASIA: (developing economies in) Asia.

Source: Draft IIASA estimates

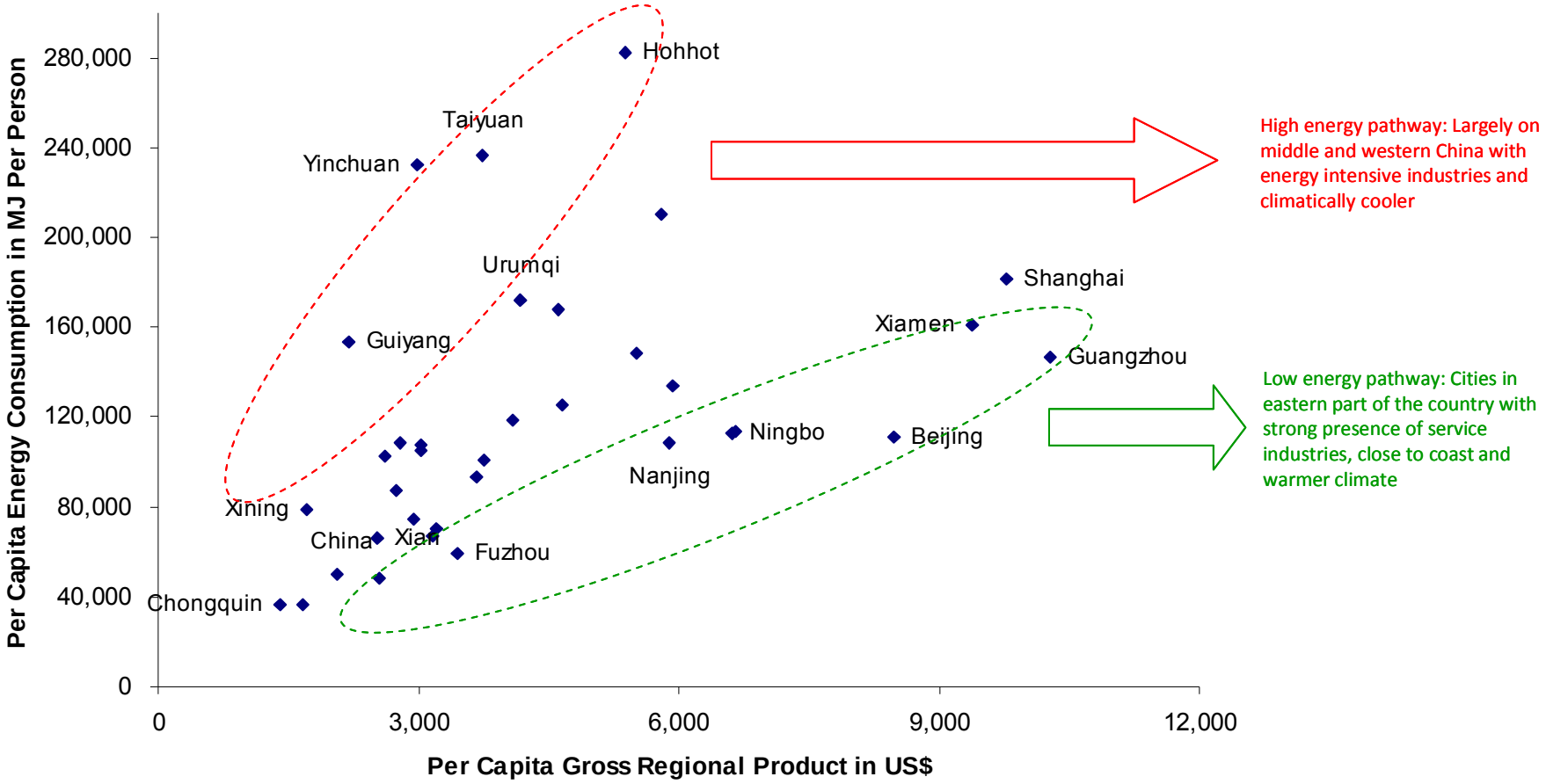
China's Top 35 Cities



List of 35 most important cities 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, Xi'an, Lanzhou, Xining, Yinchuan, and Urumqi.

Source: Dhakal, 2008

Path Dependent Development Trajectories of Chinese Cities



Source: Dhakal, 2008

Urban Sustainability Challenges

- Vast and rapid urban growth
- Access to modern & clean services (health, jobs, water, energy)
- Security, reliability, and resilience of systems
- Pollution reduction
- Efficiency improvements -- individual plus systemic measures
- Clean supply: Need for integrative view to assess sustainability of imports

Population Living in Slums (Million)

	1990	2005	2020 **BAU Projection**
Developing Asia	420	582	807
Africa	123	220	414
Latin America	111	134	163
Others	61	62	8
World	715	998	1392

Energy Infrastructure investments for halving slum population: 700 billion $

Source: UN HABITAT, 2008

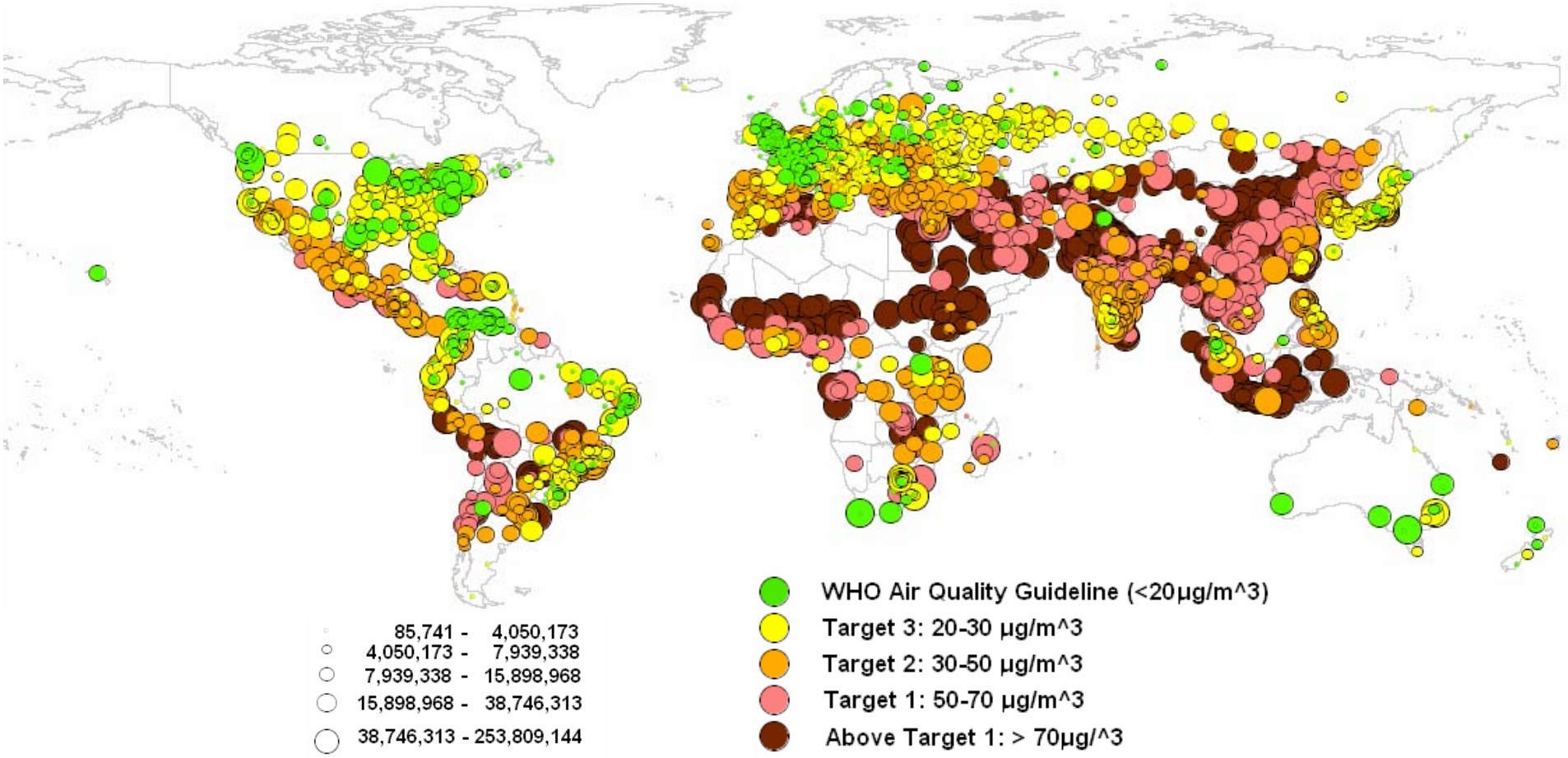
Urban Electricity Access and Poverty

	urban population (Million), 2002			
	with electricity access	without access	TOTAL	*% electrification*
North Africa	**73**	**1**	**74**	*98.8*
Sub-Saharan Africa	**125**	**117**	**242**	*51.5*
China & East Asia	**696**	**29**	**725**	*96.0*
South Asia	**271**	**119**	**390**	*69.4*
other dev. Countries	**433**	**9**	**441**	*98.1*
Developing total	**1597**	**275**	**1872**	*85.3*
Ind. Countries	**1085**	**0**	**1085**	*100.0*
Total Urban	**2682**	**275**	**2957**	*90.7*
Total Rural	**1876**	**1347**	**3223**	*58.2*

Minimum access investments: 1.5 trillion $

Source: IEA, WEO, 2004 estimates

PM10 Exposures in 3200 Cities



Exposure: PM_{10} concentration*City population (capita.µg/m^3)
Size of circle indicates exposure (Quintiles)
Color of circle indicates underlying PM_{10} Concentration (µg/m^3) range: 7-358 µg/m^3

Source: C. Doll, 2009, based on World Bank data

Air Pollution in 3200 Cities with 2 Billion People

and WHO PM-10 non-/attainment Status

GLOBAL	# Cities	Population (millions)
ACQ	446	164
Target 3	809	385
Target 2	777	409
Target 1	362	260
Above Target 1	803	739

Annex-I	# Cities	Population (millions)
ACQ	325	121
Target 3	610	314
Target 2	371	183
Target 1	51	41
Above Target 1	26	12

ALM	# Cities	Population (millions)
ACQ	115	41
Target 3	160	60
Target 2	228	126
Target 1	132	103
Above Target 1	205	160

ASIA	# Cities	Population (millions)
ACQ	6	2
Target 3	39	11
Target 2	178	101
Target 1	179	116
Above Target 1	572	567

Only 160 Million breathing clean air.

More than 1 billion need improved urban air quality.

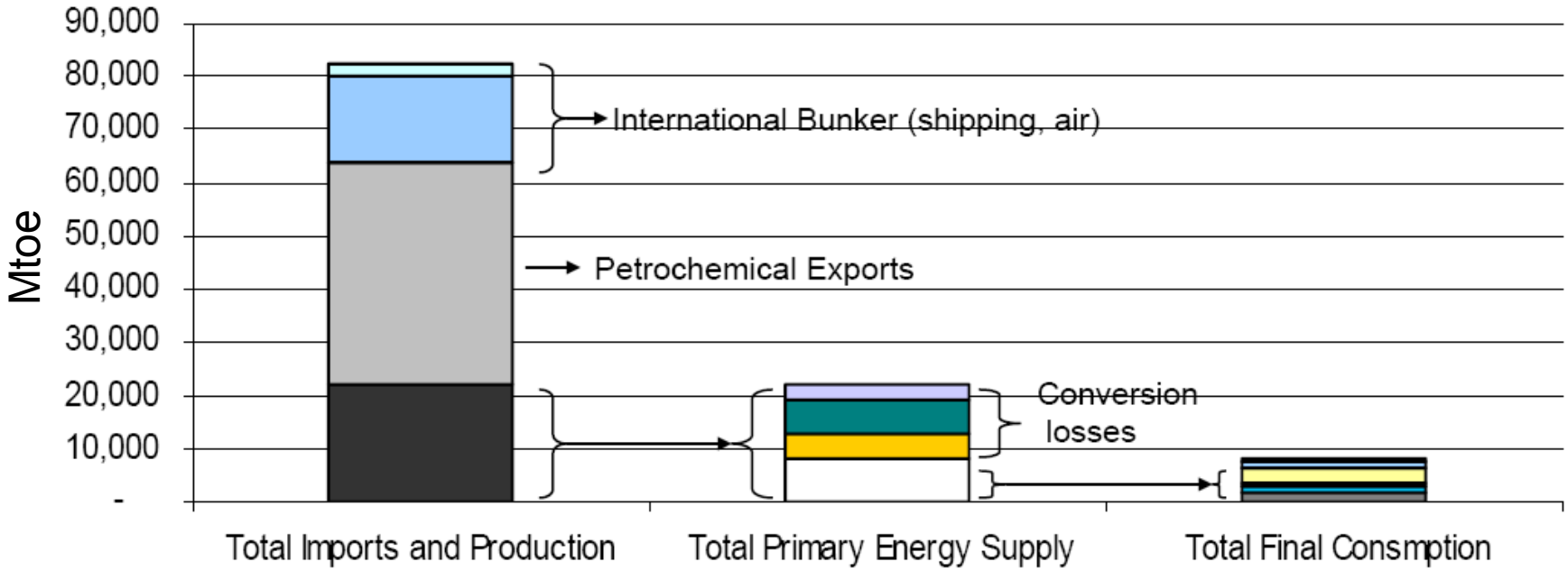
740 Million above minimum WHO air quality standard.

Source: C. Doll, 2009, based on World Bank data

Hierarchy in Urban Energy and CO_2 Reductions

1. Spatial division of labor
   (trade, industry structure)
2. Urban form
   (functional mix, public transport,
   car ownership,…)
3. Efficiency of energy end-use
   (buildings, appliances, processes)
4. Energy systems integration
   (co-generation, heat-cascading)
5. Fuel substitution (renewables, nuclear)

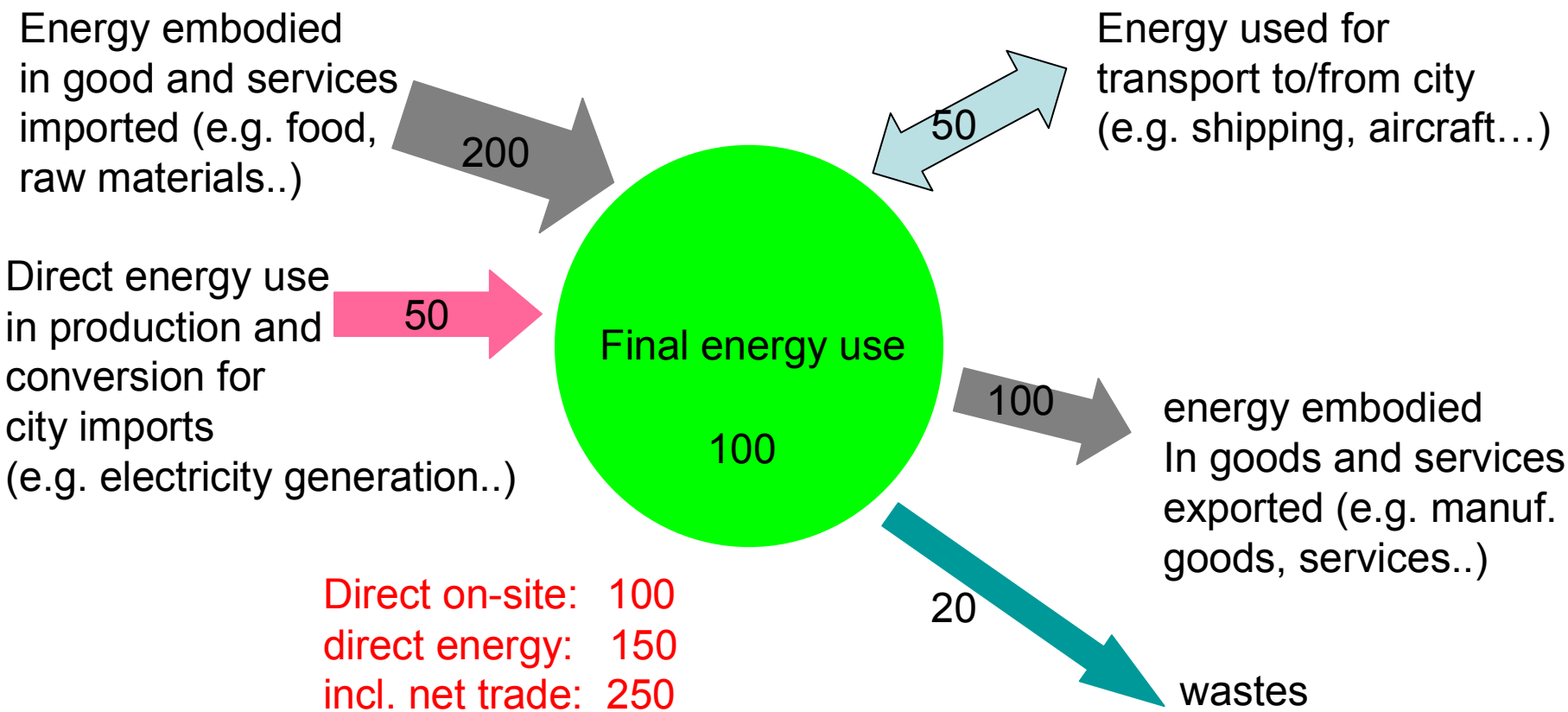
Singapore – Importance of Energy Trade



Source: Schulz, 2007 based on IEA/OECD

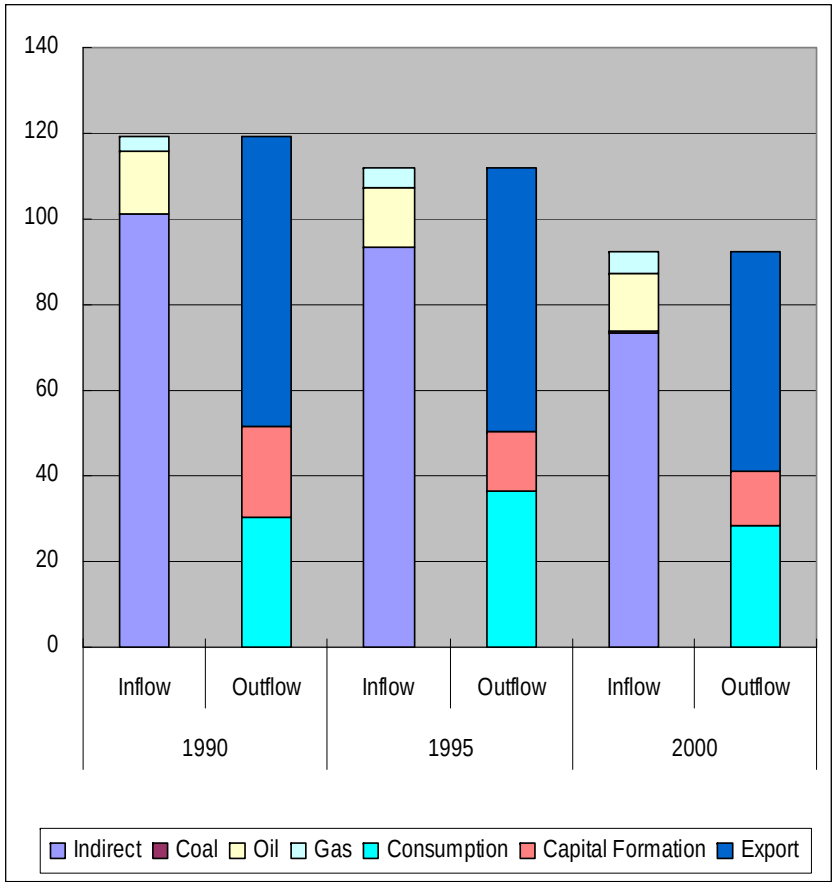
Complex Accounting for Urban Carbon

(energy only, hypothetical numbers)



Direct on-site (majority of "consumption"-based urban emission inventories) accounts only for fraction of all carbon flows!

Tokyo – Carbon Accounts (Million tons CO_2)
(based on regional I-O Analysis)



Carbon flows <u>across</u> systems boundaries dominate:
- inflows (embodied and upstream emissions)
-Outflows (embodied in exports)

Biggest unknowns:
- International trade and C-flows
- Other GHGs
- Source-sink allocation for large point sources

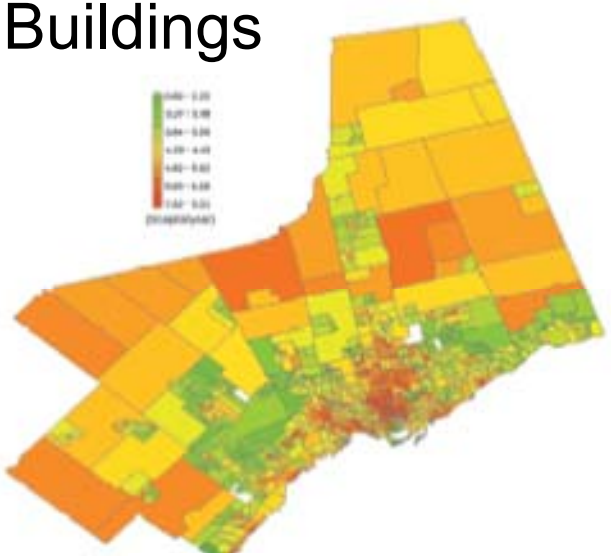
Current dominant inventories (apparent city consumption plus upstream pro-rated national emissions of energy conversion) offer poor policy guidance!

Source: Dhakal, based on Kaneko, 2007

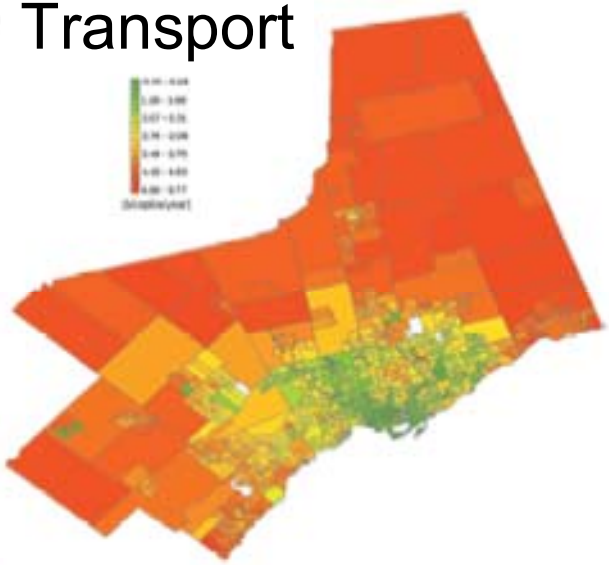
Toronto – Residential per Capita GHG Emissions

(tons CO_2-equiv)

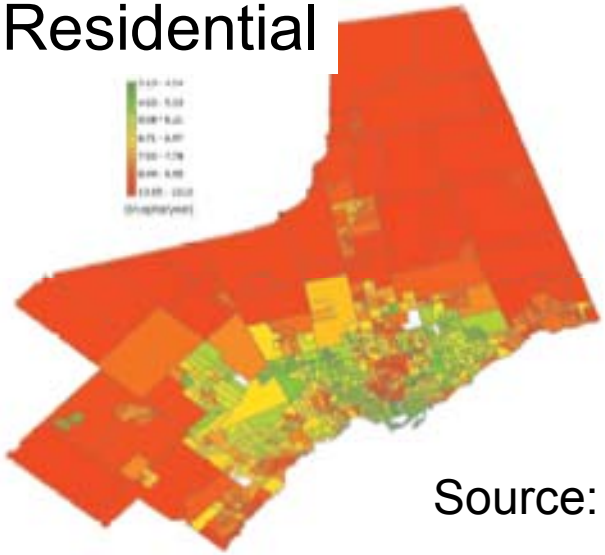
Buildings



Transport



Total Residential



Note dominance of transport-related emissions from suburbs

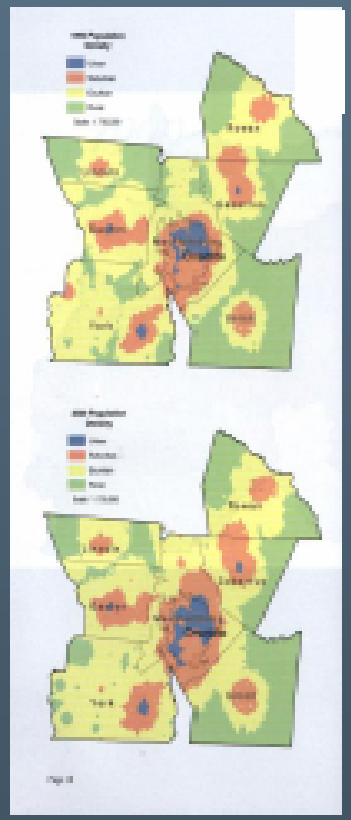
Source: WandeWeghe&Kennedy, 2007

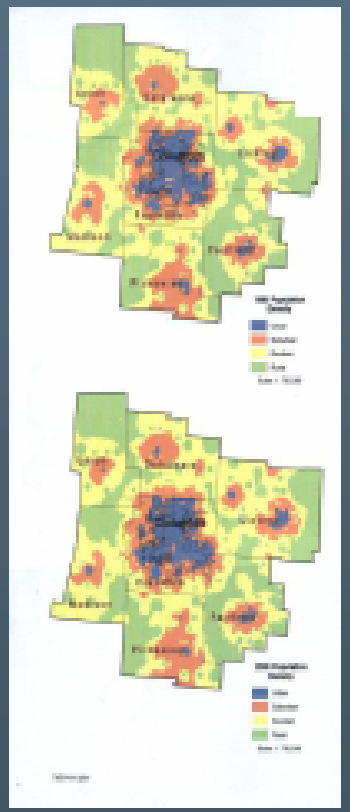
Urban Form and Sprawl:

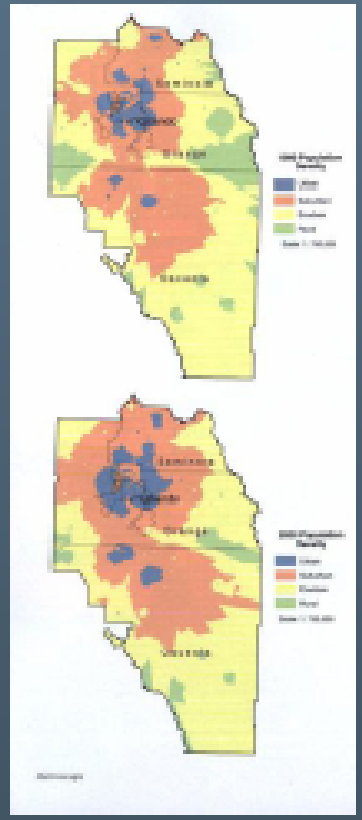
Critical Determinant for Transport and Total GHG Emissions

Source: Burkholder, 2007

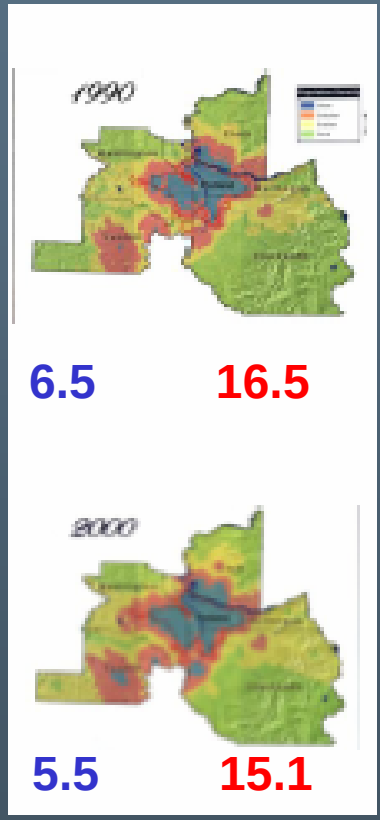
Per capita emissions, tons CO_2-equiv, transport and total







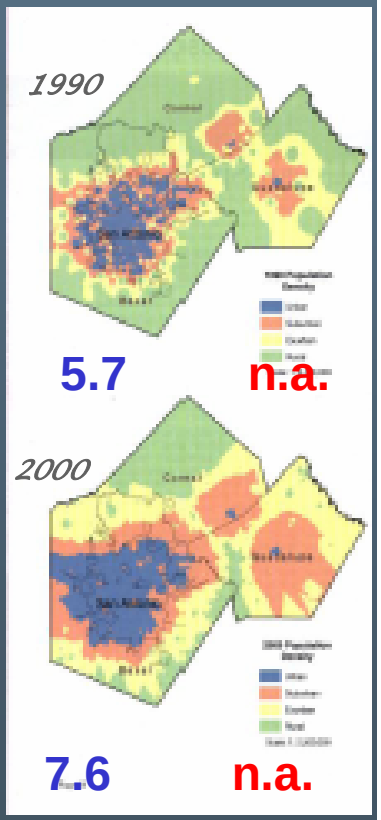
Portland



6.5 16.5

5.5 15.1

San Antonio

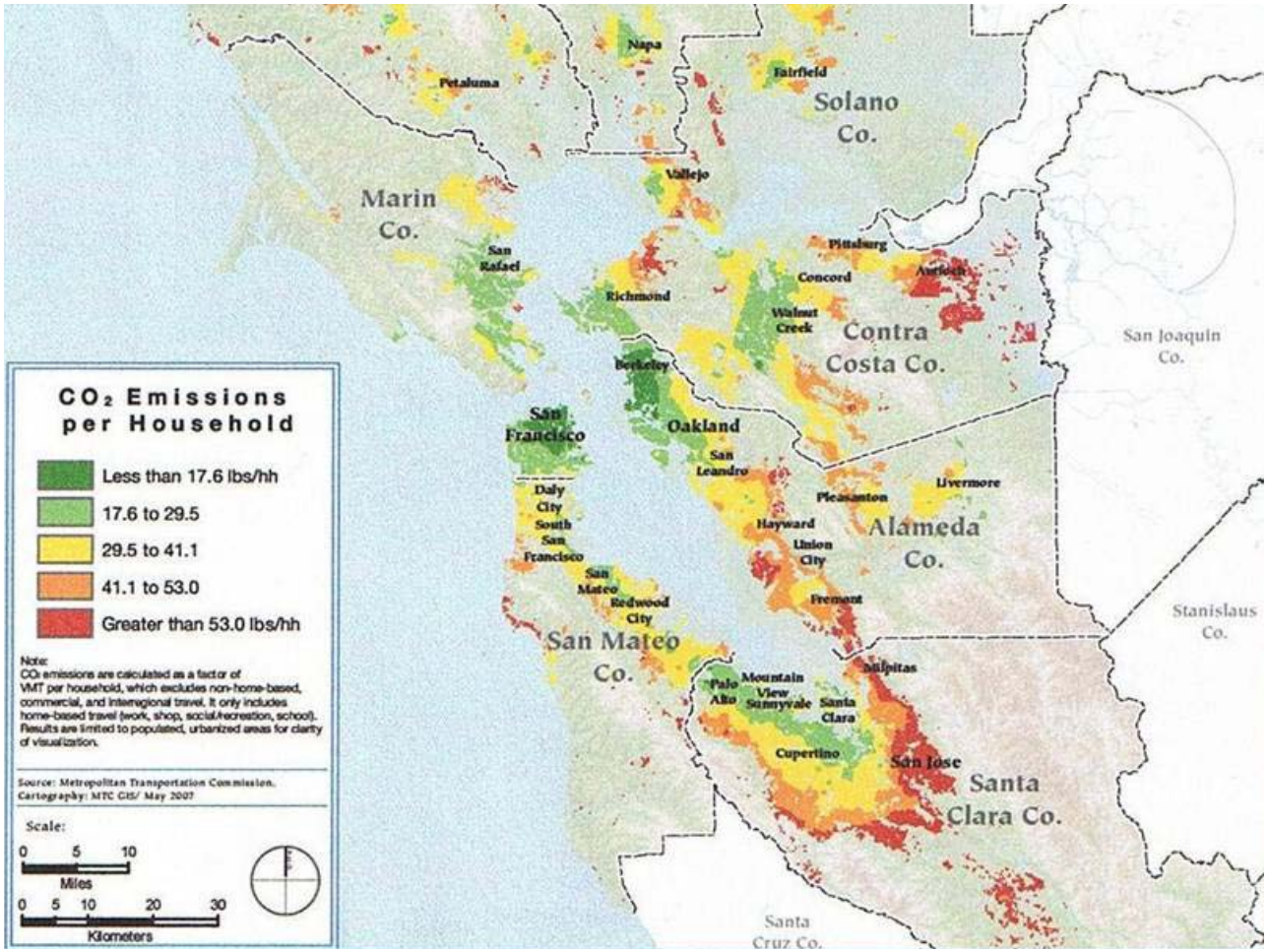


5.7 n.a.

7.6 n.a.

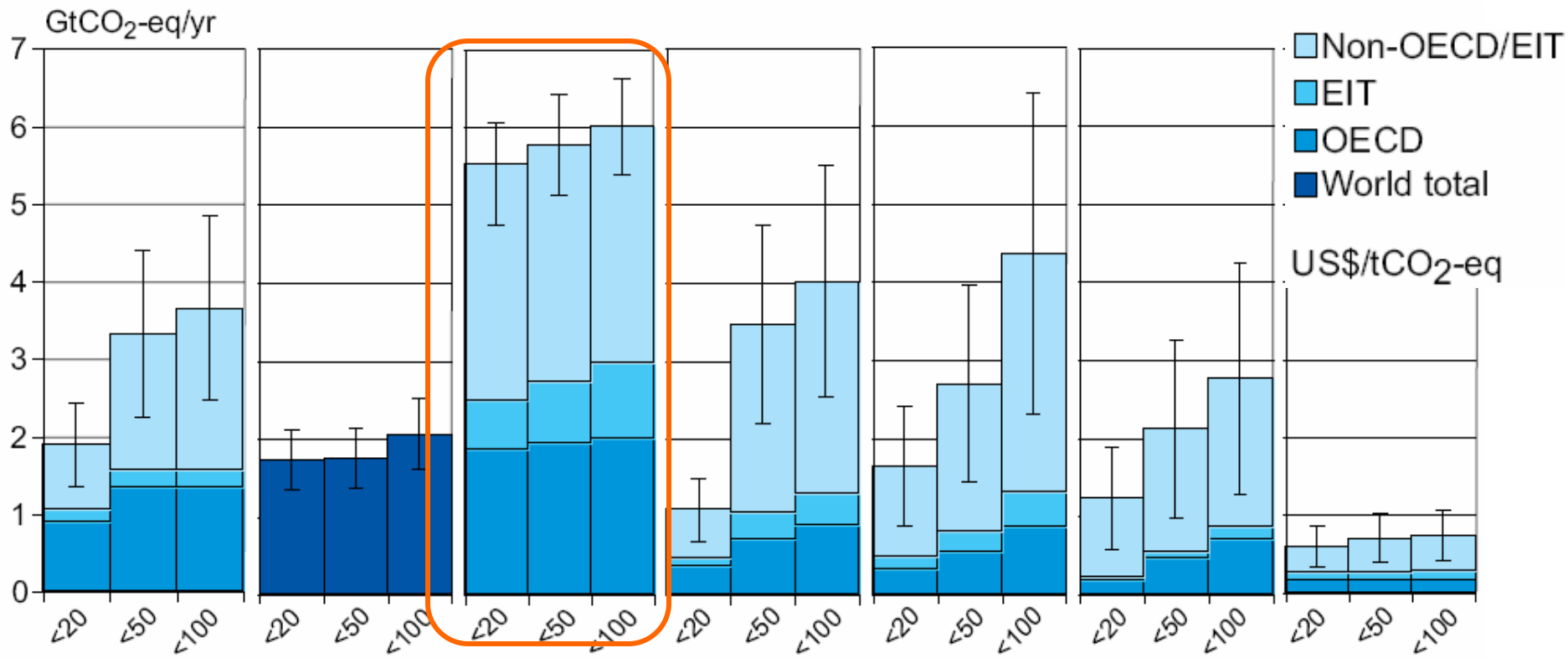
Compared to similarly-sized metropolitan areas, the Portland region has a larger urbanized area and more rural land, with fewer suburbs and exurbs.

Household Transport CO_2-Emissions in Bay Area: Importance of Public Transport Infrastructure



Source: MTC, 2007

Sectoral economic potential for global mitigation for different regions as a function of carbon price, 2030

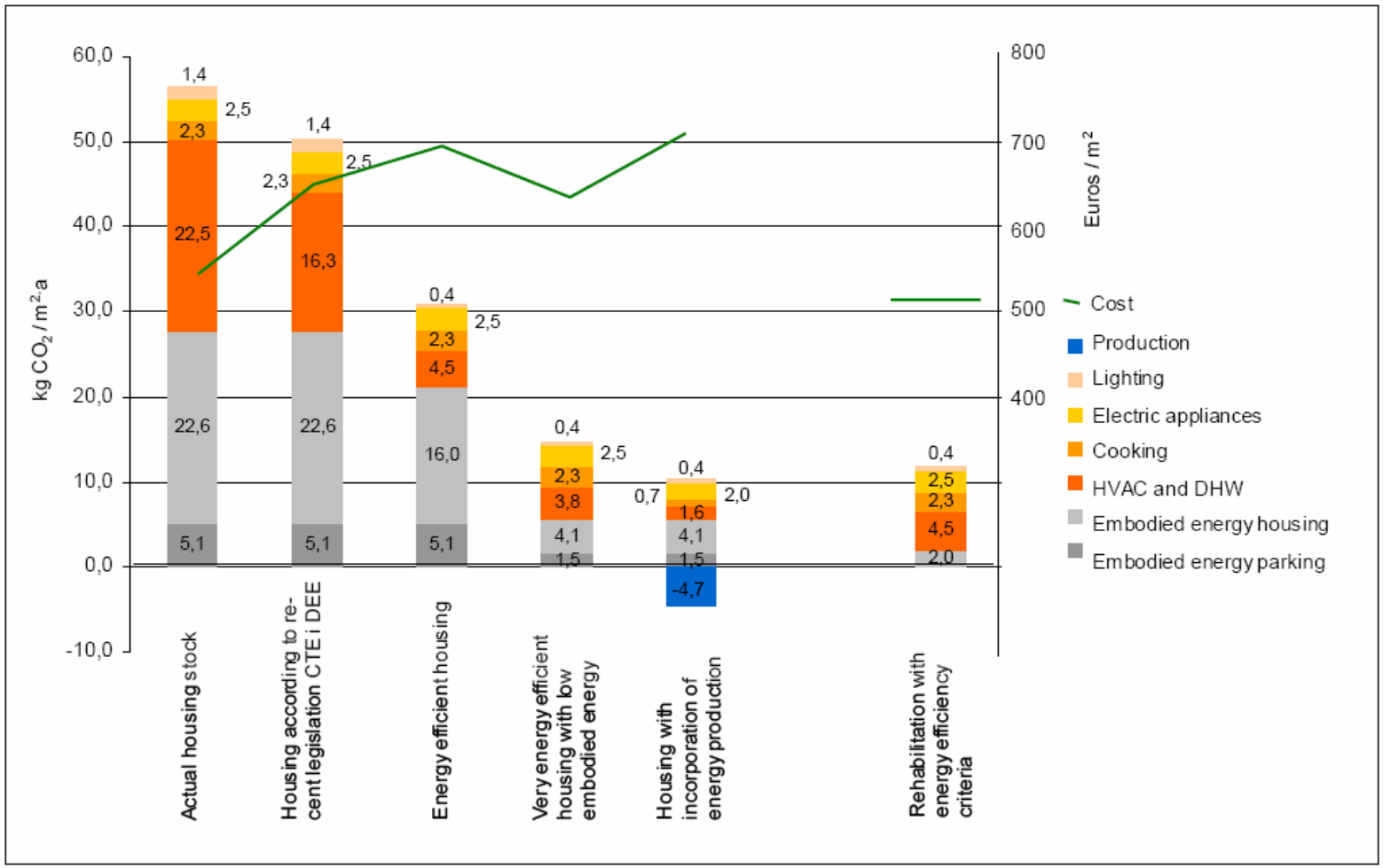


(potential at <US$100/ tCO_2-eq: 2.4 - 4.7 Gt CO_2-eq/yr)	*(potential at <US$100/ tCO_2-eq: 1.6 - 2.5 Gt CO_2-eq/yr)*	*(potential at <US$100/ tCO_2-eq: 5.3 -6.7 Gt CO_2-eq/yr)*	*(potential at <US$100/ tCO_2-eq: 2.5 - 5.5 Gt CO_2-eq/yr)*	*(potential at <US$100/ tCO_2-eq: 2.3 -6.4 Gt CO_2-eq/yr)*	*(potential at <US$100/ tCO_2-eq: 1.3 - 4.2 Gt CO_2-eq/yr)*	*(potential at <US$100/ tCO_2-eq: 0.4 - 1 Gt CO_2-eq/yr)*

Source: IPCC AR4, 2007

Buildings Life cycle CO_2 Emissions and Costs per m^2

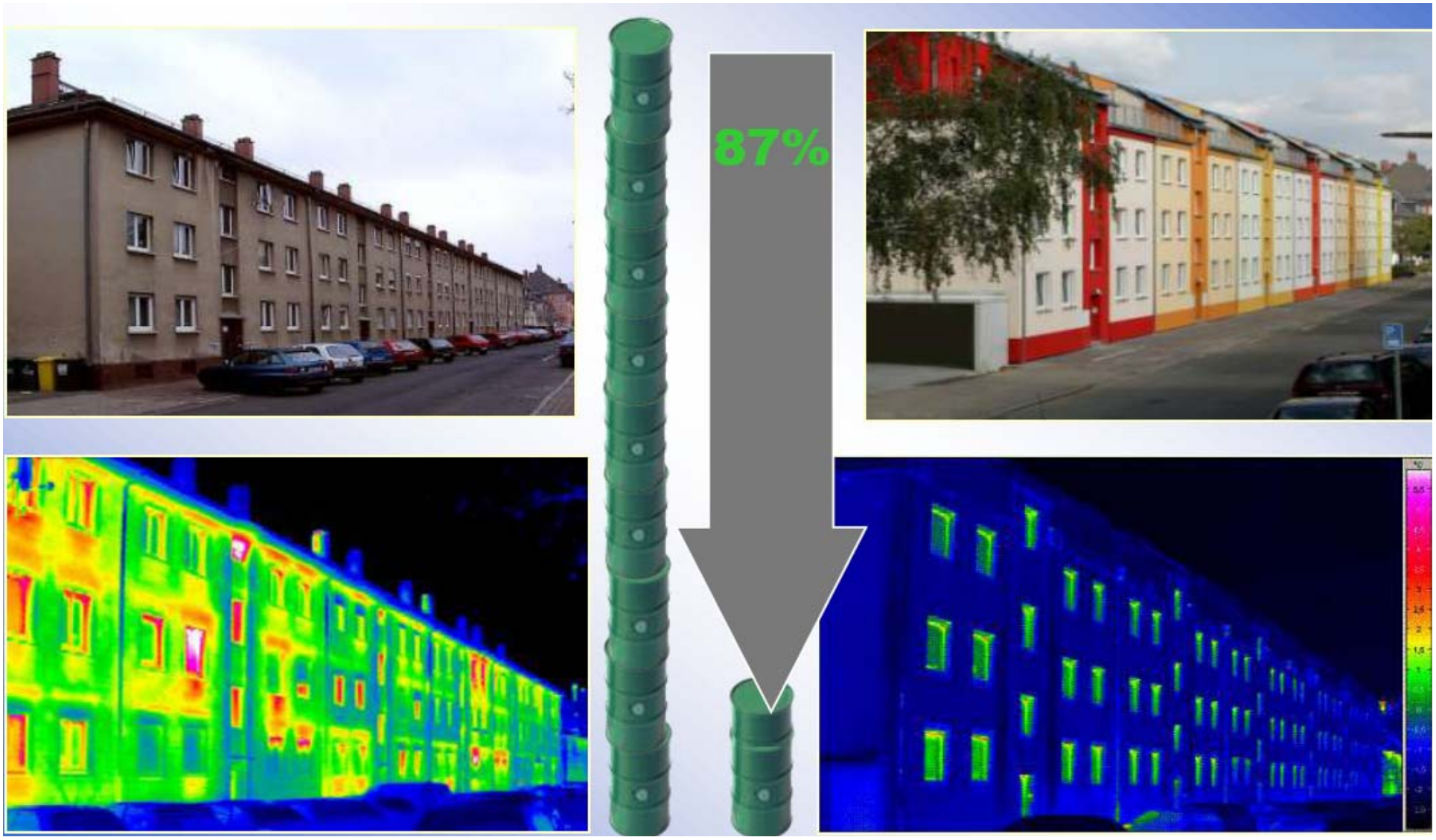
(typical European Mediterranean conditions)



Cheapest and most C-effective option: Thermal retrofit of buildings!

Source: Sabaté and Peters, 2008

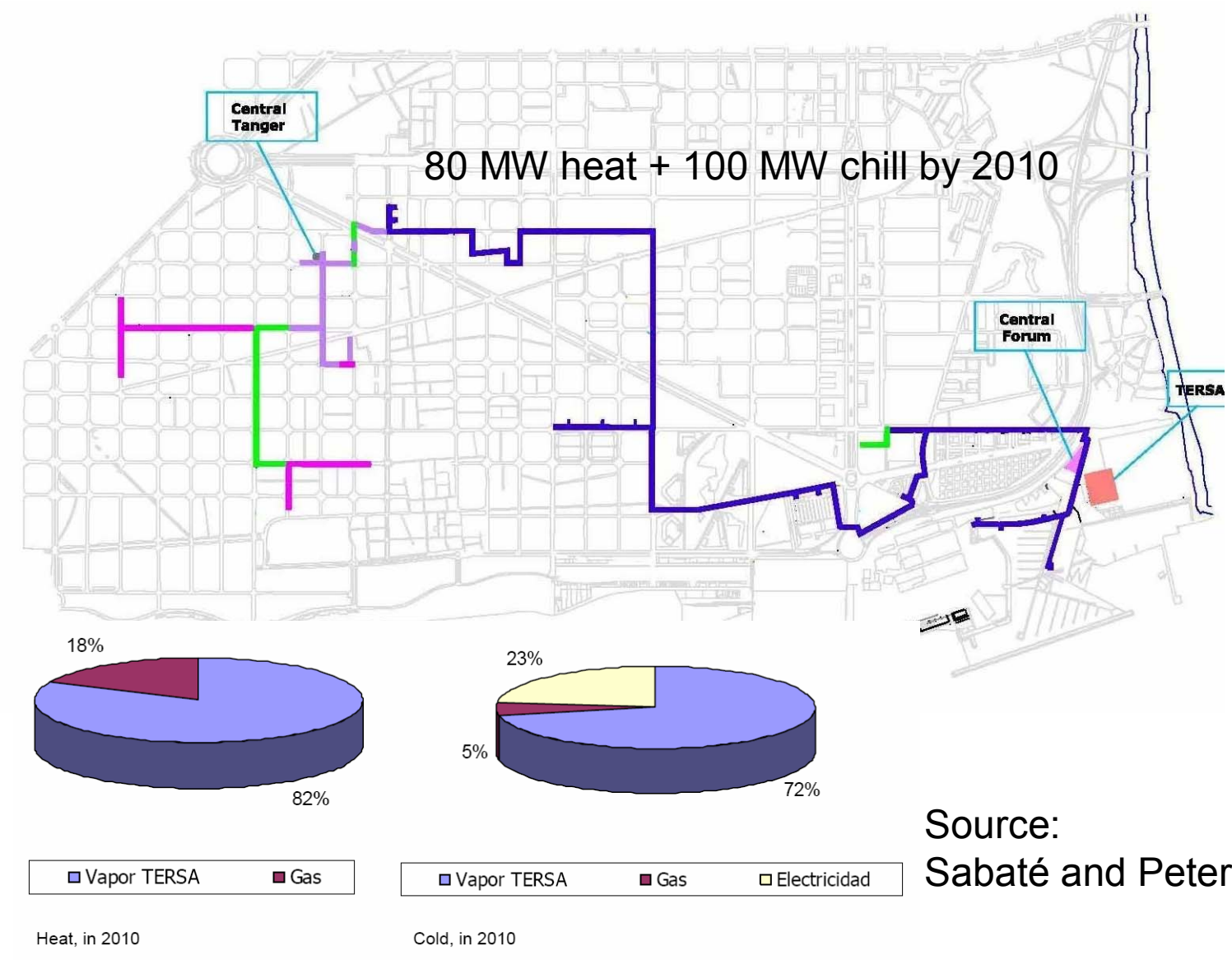
Efficiency Improvement Potentials in Thermal Retrofit of Housing ex. Frankfurt Passiv-House Standard



Source: IEA, 2006

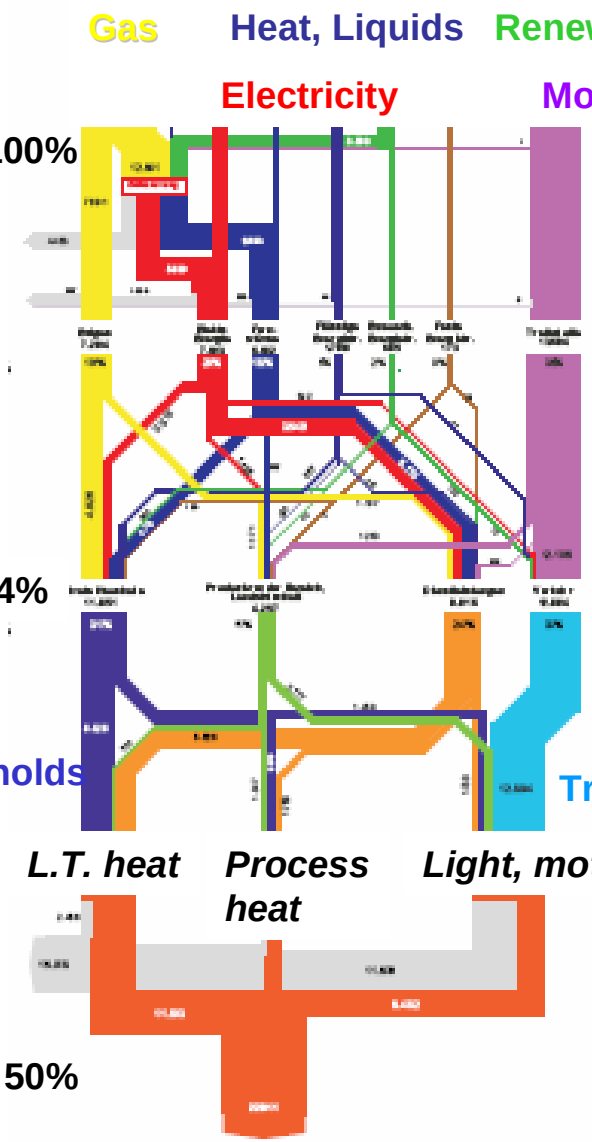
Barcelona Integrated District Heating-Cooling Grid

leads to 51% CO_2 reduction compared to decentralized “stand-alone” mode.



Source:
Sabaté and Peters, 2008

Energy and Exergy Flows Vienna 2006



Secondary Energy: 45 TWh 100%

Secondary Exergy: 171 TJ 100%

Final Energy: 38 TWh 84%

Final Exergy: 140 TJ 82%

Useful Energy: 23 TWh 50%

Useful Exergy: 31 TJ 18%

Source: Wien Energie, 2009; (rough) exergy efficiencies based on Gilli *et al.*, 1996.

Urban Sustainability Opportunities

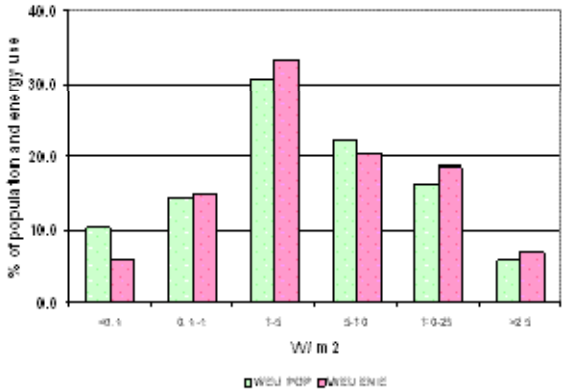
- Co-location of multitude of uses
  → energy cascading (e.g. cogeneration of electricity, steam, chill, heat)
- High metabolism
  → recycling of wastes (heat, materials)
  → wastes as energy resource
- High density
  → feasible economics for high quality public transport
- Agglomeration/network externalities
  → innovation “hubs” and centers
  → mobilization of capital and “action”

Urban Sustainability Constraints

- Energy demand and pollution density
- Heat island effect
- Capital intensity of infrastructure investments
- Consumer “take back” effects
- Policy paradox:
  - largest leverage from systems integration,
  but
  - most difficult due to policy fragmentation

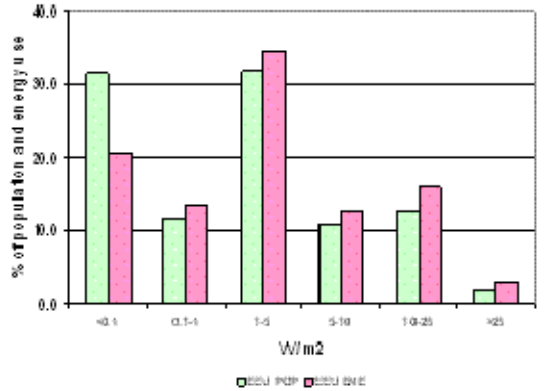
Europe Population vs. Energy Demand Density

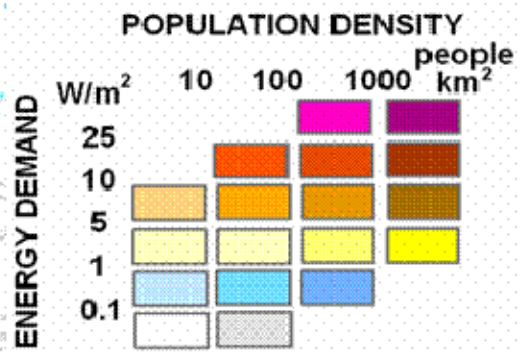
Note in particular renewable supply density threshold of maximum 0.5-1 W/m²



WEU: 21% of demand below renewable density threshold

EEU: 34% of demand below renewable density threshold





Source: Draft IIASA calculations

Energy Use in US Residential Dwellings

kWh/m²/year	Energy for heating, cooling, hot water	Total energy use w/o transport
US average home (2001)	~100	~250*
Passive house	<15	<120
savings per typical home (150 m²) per year		~20,000 kWh
Equivalent transport demand		600 gal. gasoline = 15,000 miles @ 25 mpg = 40 miles/day

*** primary energy equivalent**

Source: DOE Res. HH Survey 2001

GEA KM18 Main Messages (draft)

1. The world is already today predominantly urban (~2/3 of final energy) and will become even more so
2. Rural populations are likely to peak at 3.5 billion and decline after 2020
3. Urban population projected to continue to grow to 6-8 billion by 2050 with largest growth in settlements <0.5M
4. Shrinking cities new phenomenon of demographic decline
5. Cities have specific sustainability challenges (high density calls for ~zero-impact systems)
6. Many still do not have access to basic energy services, which need to be supplied based on economic, social, and environmental sustainability
7. Vast improvement potentials, but most require demand-supply integration and systemic changes (recycling, cascading, transport systems integration,..)
8. "Upstream" energy and CO_2 emission accounts fraught by uncertainty and system boundary ambiguity
9. New sustainability criteria needed, considering the functional interdependence among different systems that are geographically separated
10. Governance Paradox:
    - largest leverage from systemic change, but
    - most difficult to implement in view of policy fragmentation and dispersed, decentralized decision taking

Thank You!

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