Low Carbon Cities: Bridging Science & Engineering

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Outline

- Metabolism of Megacities
- Low Carbon Infrastructure Strategies for Cities
- Non-equilibrium Thermodynamics of Cities

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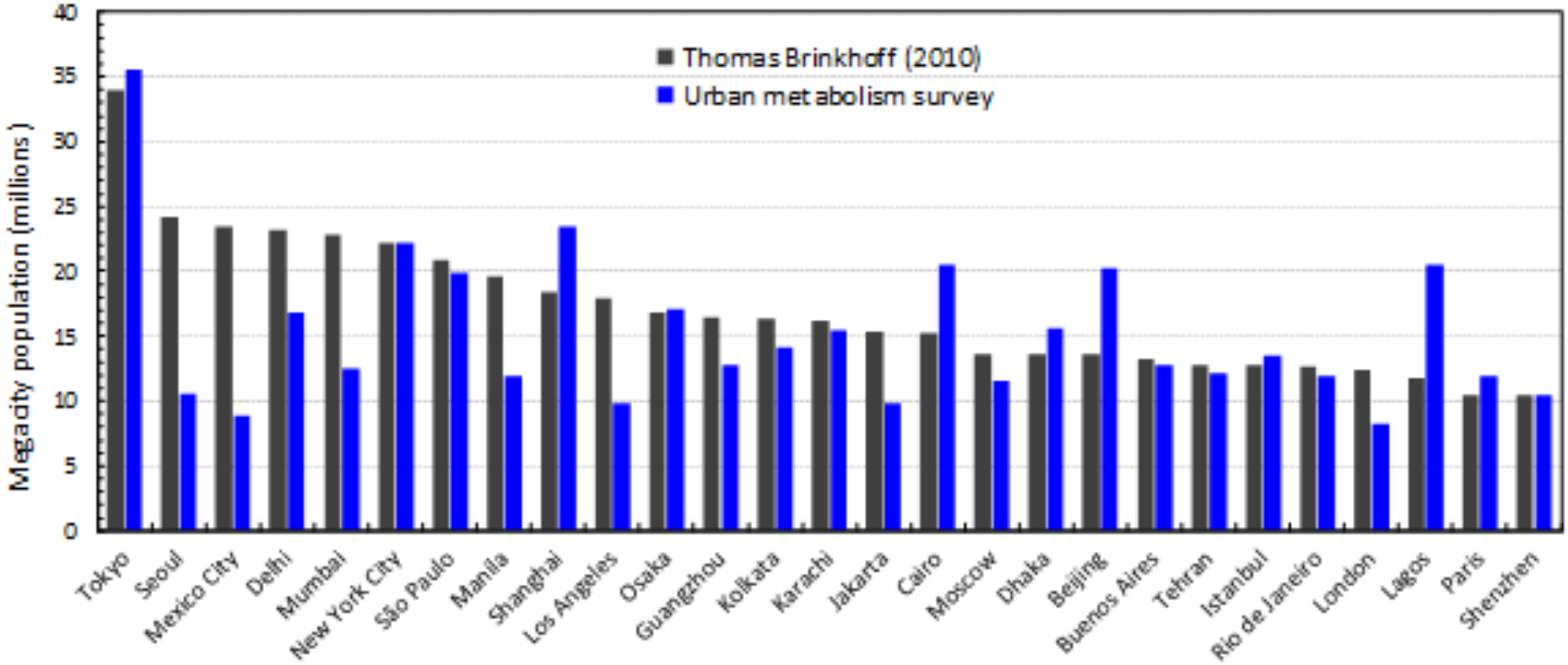
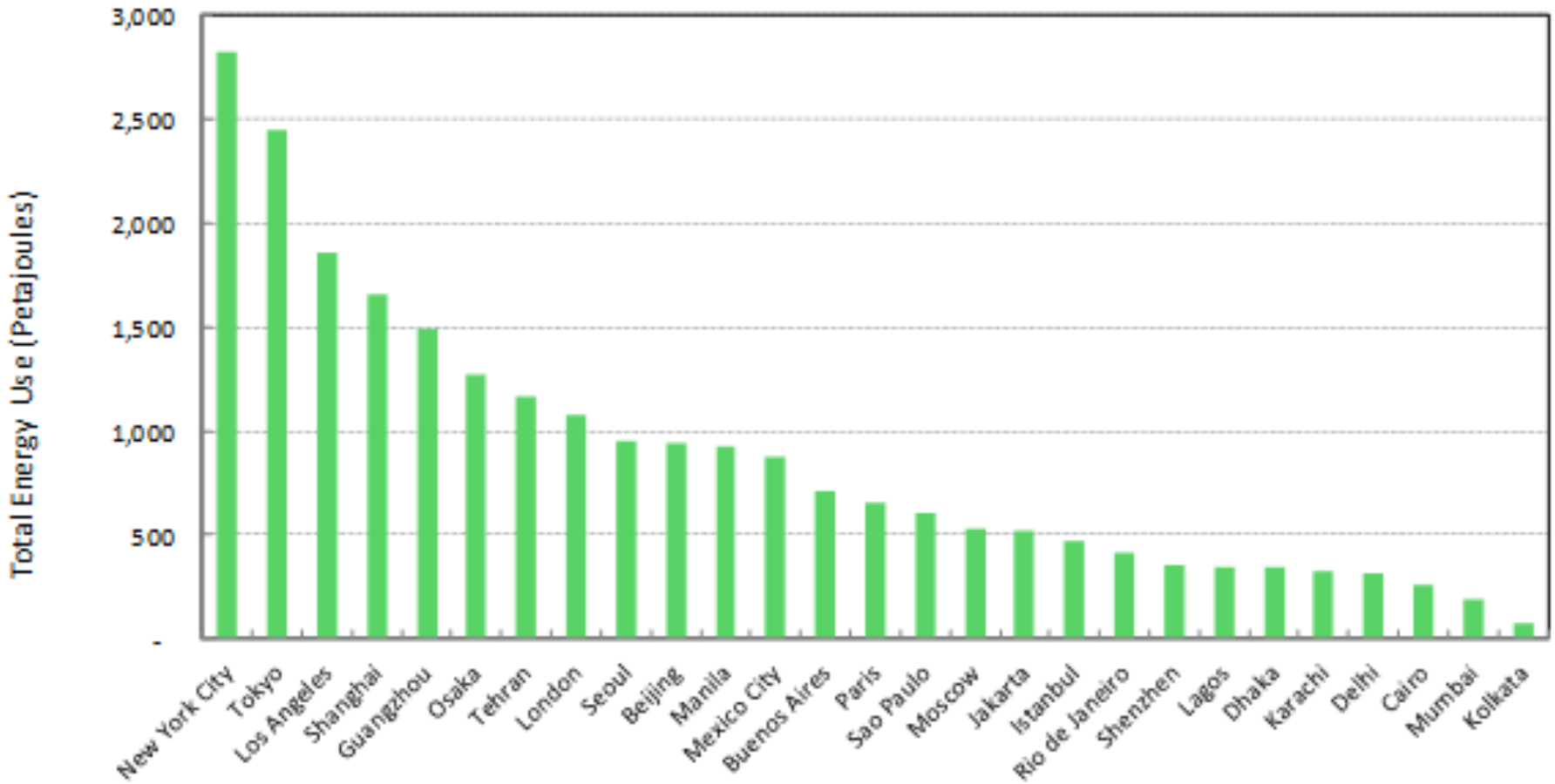
Energy for Knowledge

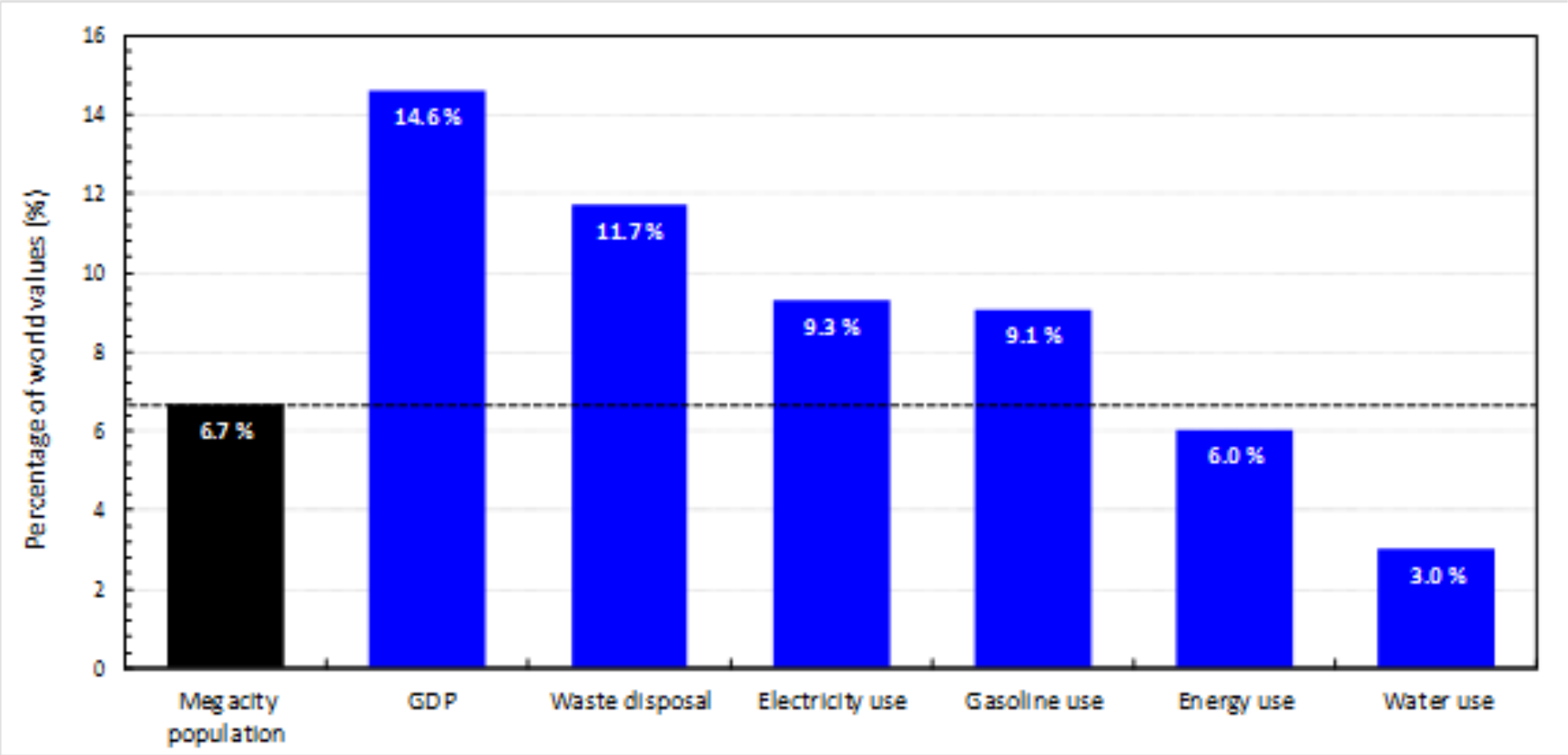
Megacity Populations



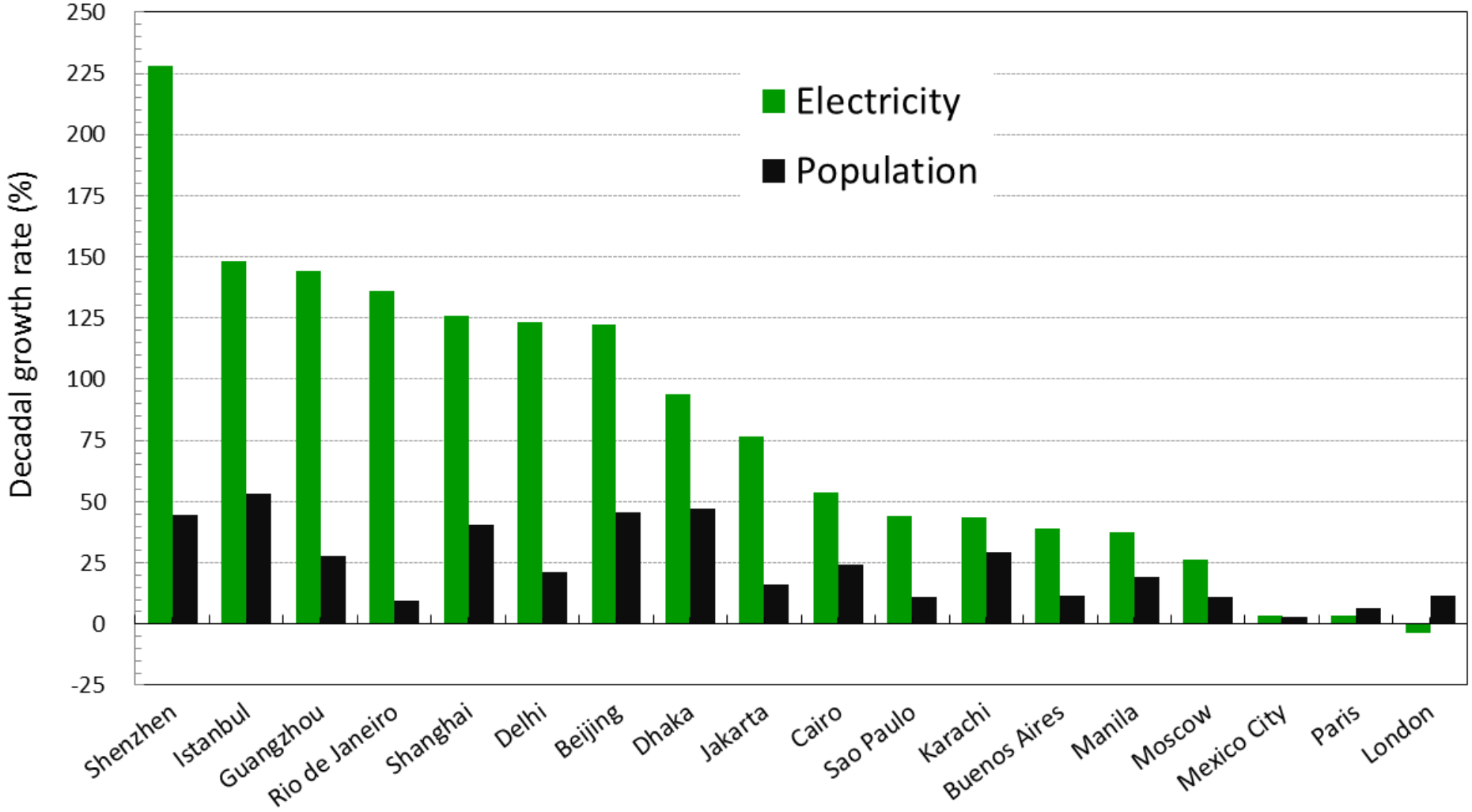
Total Energy Consumption



Megacity resource & waste flows as a percentage of world values



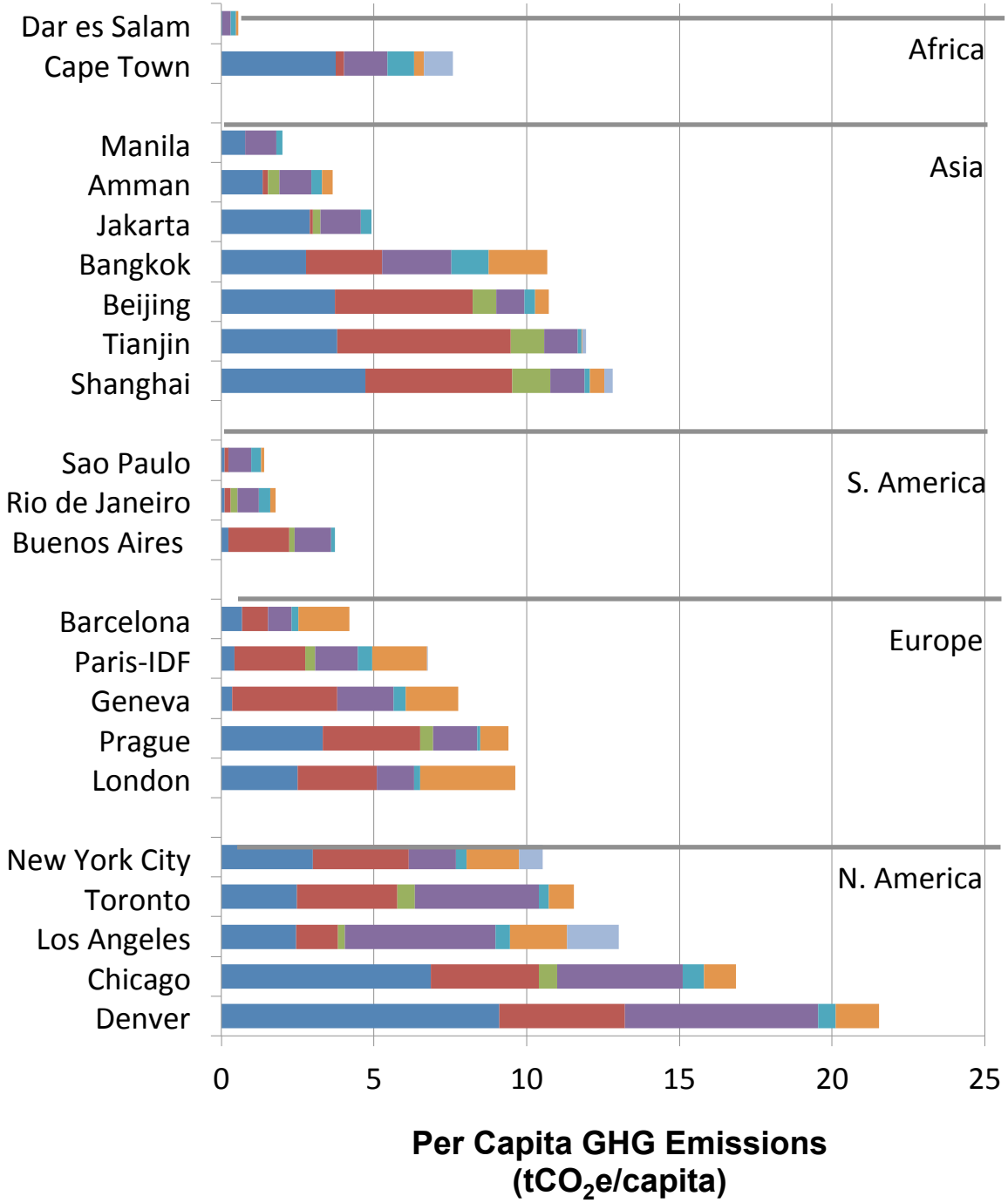
Growth in Electricity Use (2001-2011)

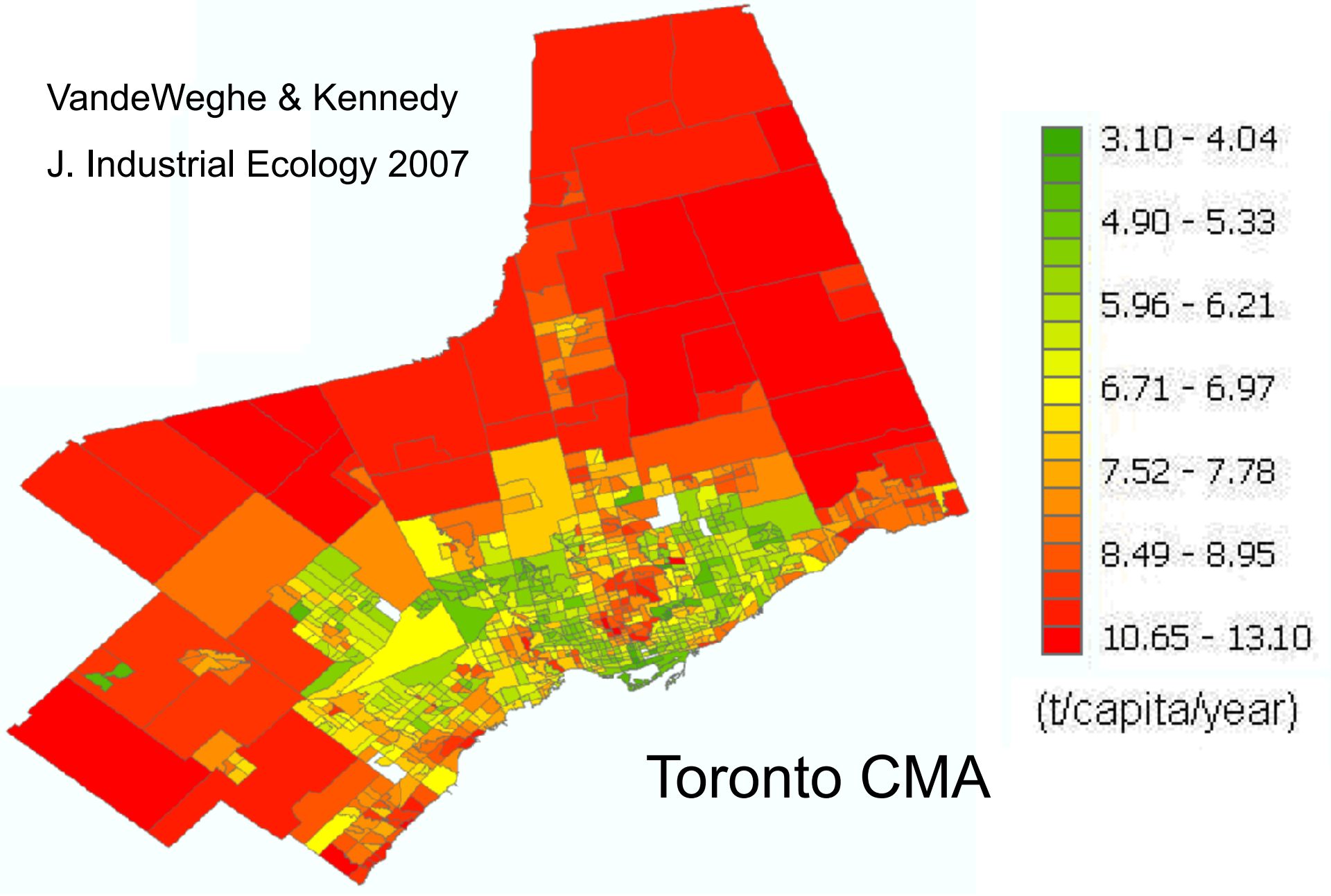


Low Carbon Infrastructure Strategies for Cities

(Kennedy et al., 2014, Nature Climate Change)

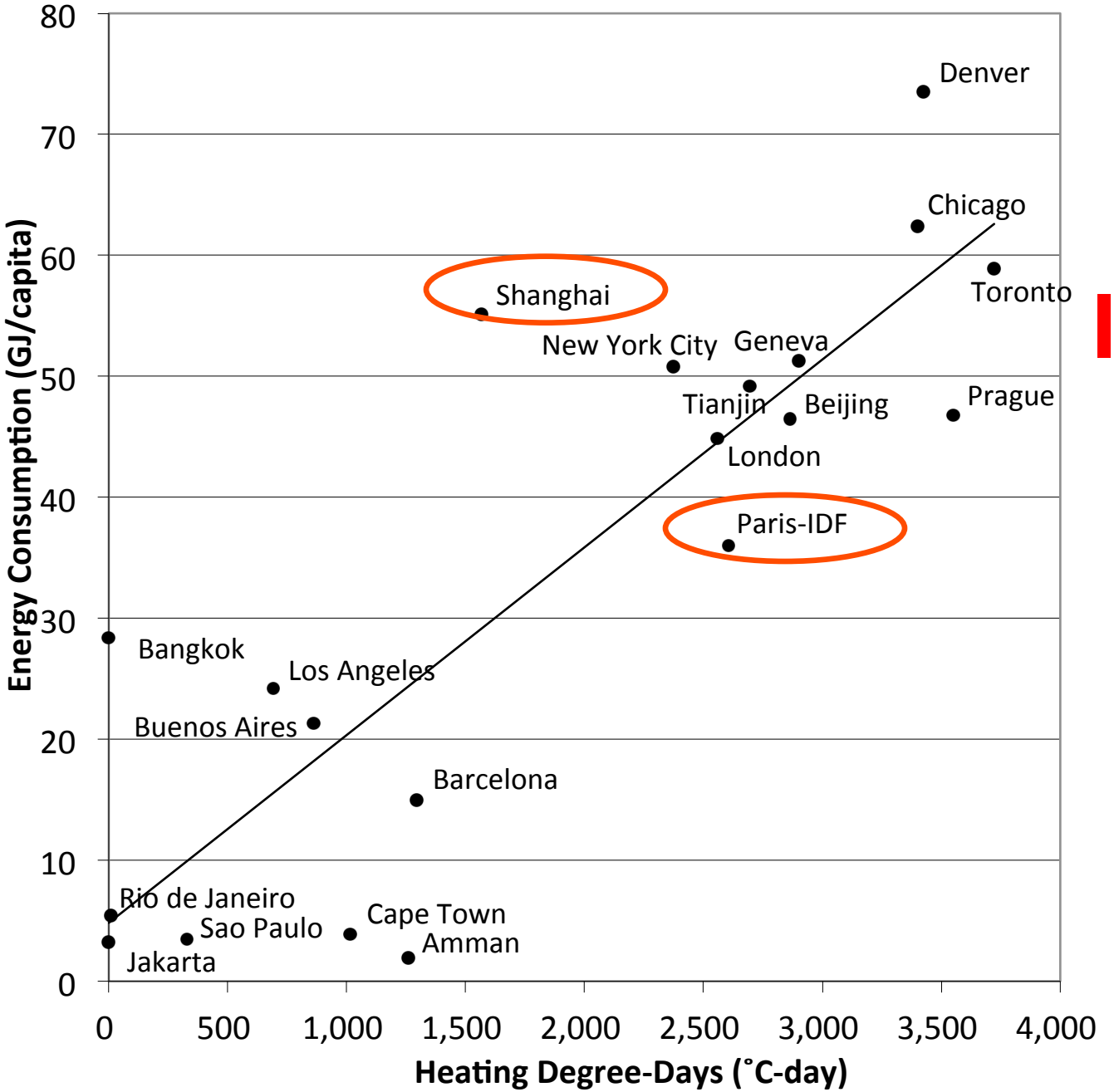
Urban GHG Emissions (~2006)



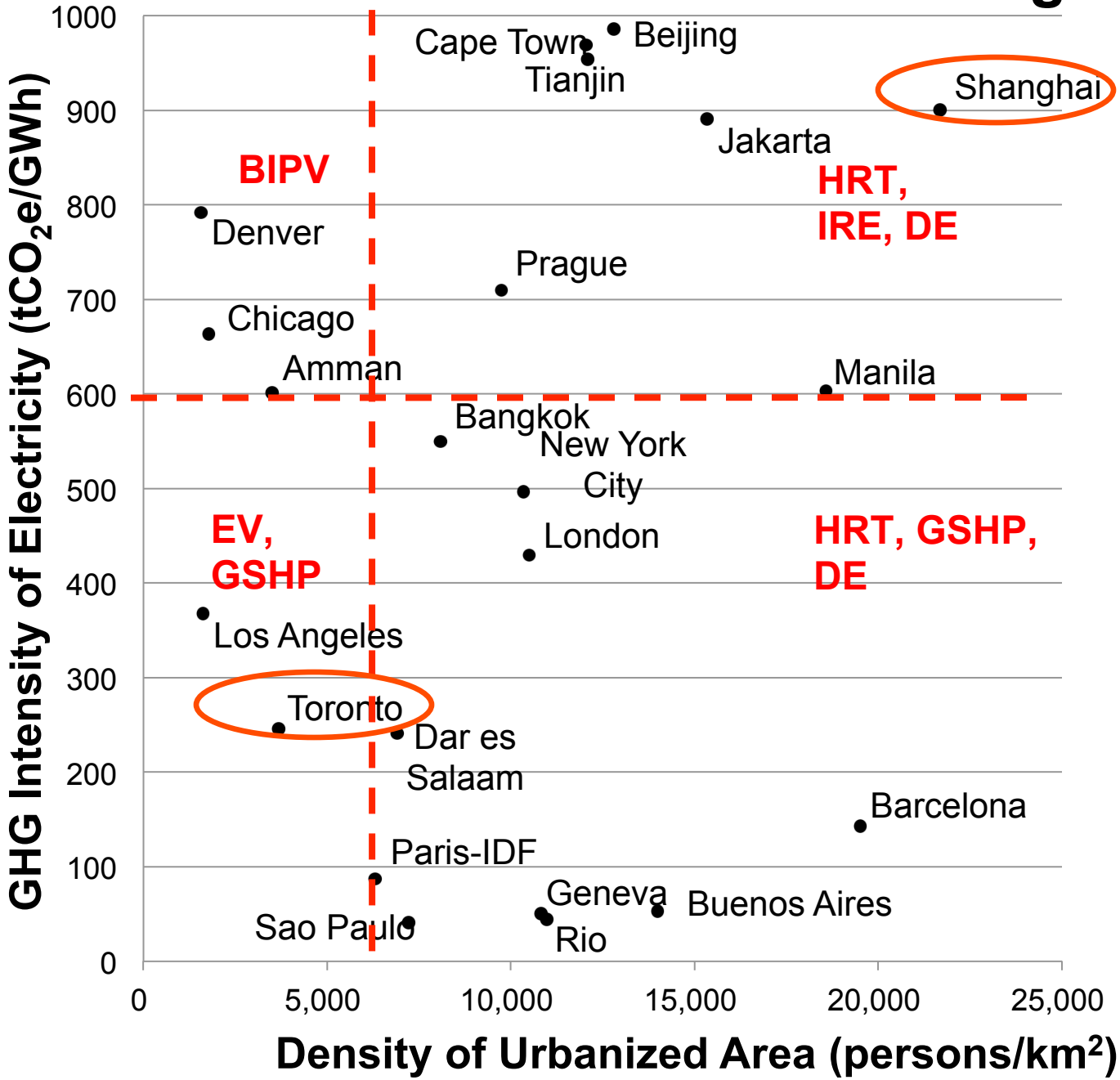


Annual per capita GHG emissions from residential activities

Heating and Industrial Fuels (~2006)



Low Carbon Infrastructure Strategies for Cities



BIPV = building integrated photovoltaics,

DE= district energy,

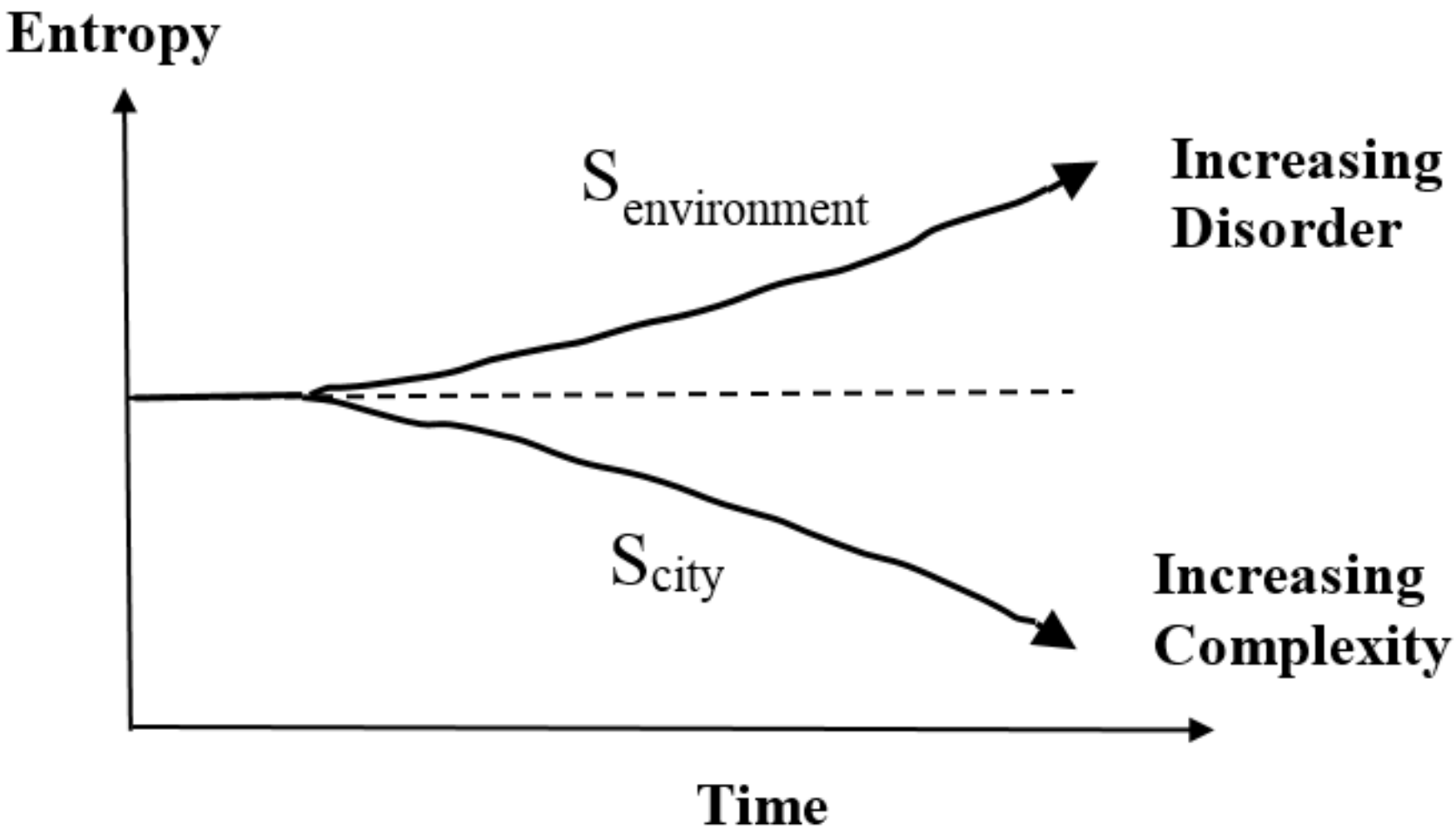
EV = electric vehicles,

GSHP= ground source heat pumps,

HRT=heavy rapid transit,

IRE=import renewable electricity

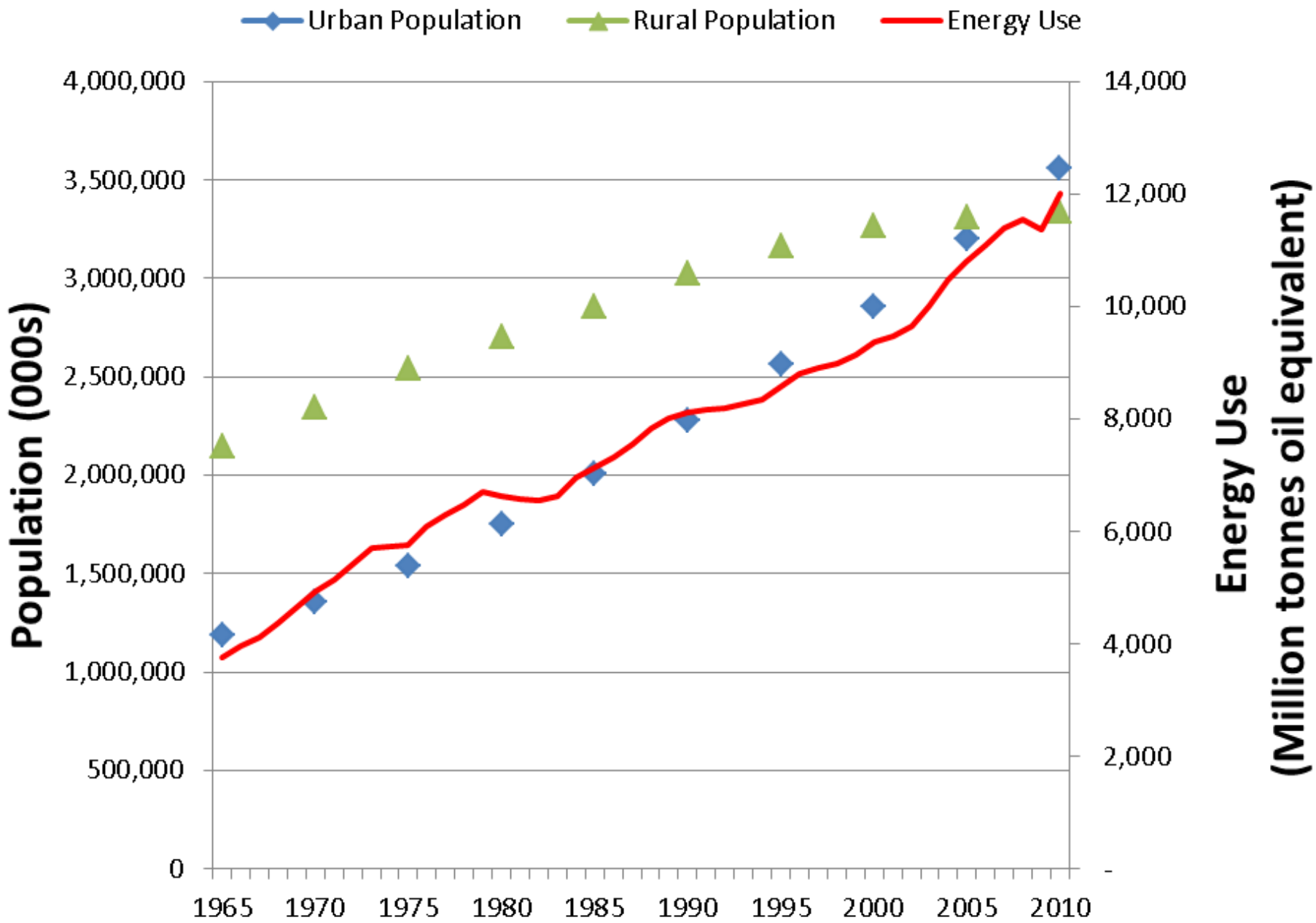
Non-equilibrium Thermodynamics of Cities



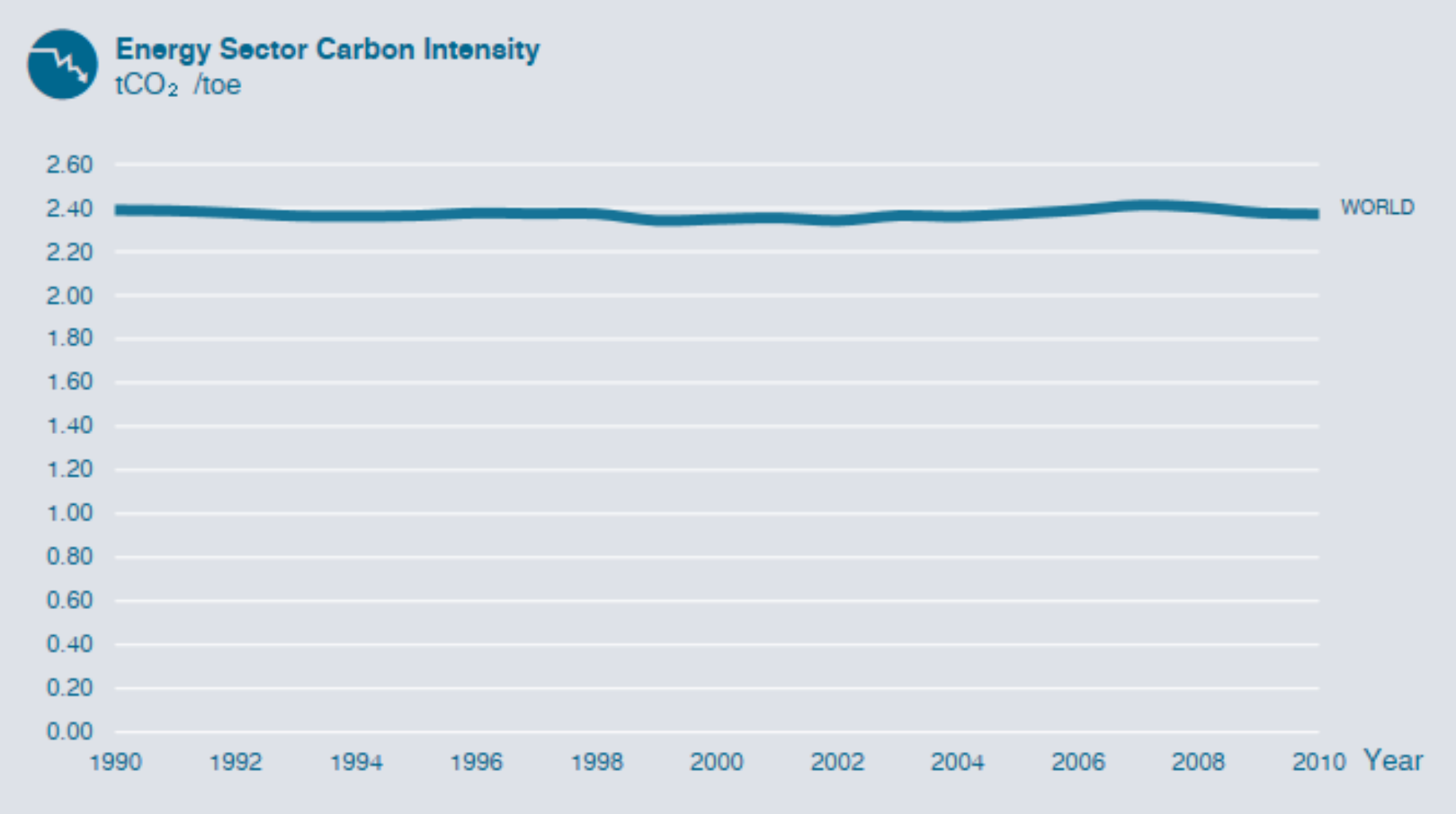
(Bristow & Kennedy, 2015)

Studies of exergy destruction in settlements

Location	**Source**	**Exergy Loss (PJ)**	**Area (km^2)**	**Intensity (W/m^2)**
Beijing (1996)	Liu et al (2012)	1520	1368	35.1
Beijing (2006)		2920		67.7
Cheranatzicurin (1986)	Masera & Dutt (1991)	0.0313	37.1	0.84
Cheranatzicurin (2012)	Martínez-Negrete and colleagues (2013)	0.0351		0.95
Vienna (2007)	Grubler (2012)	163	414	12.5


Urban Population
Rural Population
Energy Use
Population (000s)
Energy Use
(Million tonnes oil equivalent)
4,000,000
3,500,000
3,000,000
2,500,000
2,000,000
1,500,000
1,000,000
500,000
0
14,000
12,000
10,000
8,000
6,000
4,000
2,000
-
1965
1970
1975
1980
1985
1990
1995
2000
2005
2010

CO_2 Intensity of Global Energy Supply (IEA)



http://www.iea.org/etp/tracking/esci/

Issues for Further Research (Thermodynamics of Cities)

1) Mathematical modelling of city growth – using non-steady continuity equation
2) Further empirical study of exergy gradients for cities
3) Intersection of thermodynamic and economic theories of urban growth (parallels with Krugman's model)