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New Directions: Megacities and global change ☆

Perhaps 3% of the world's population lived in cities around the year 1800 (Brunn and Williams, 1983. Cities of the World. HarperCollins, New York, 506pp.). Subsequently, industrialization and urbanization intensified during the "Anthropocene" (Crutzen, 2002. Nature 415, 23) in the fossil fuel based economy (or carbon-economy). As a result, by 1900 the urban population fraction had increased to 13%, and to 47% by 2000 (UN, 2004; see reference in Table 1). Over the last 50 years, the world's urban population has grown faster ($\sim$2.7% yr^{-1}) than the total population ($\sim$1.8% yr^{-1}). This trend is likely to continue in the foreseeable future marking for the first time in human history that the world will have more urban than rural residents by 2007. The striking offshoots of rapid-and-massive urbanization are the megacities that emerged as a most visible physical sign of anthropogenic global change in the 20th century. In 1950, there were only two megacities, New York and Tokyo with 12.4 and 11.3 million people, respectively. At present there are 20 megacities with a combined population of 283 million (UN, 2004).

Megacities (with a population $\geqslant$10 million) differ from smaller urban areas not only in population size but also in the scale of economy, infrastructure and associated environmental impacts. The majority of megacities are internationally well connected through aviation and/or shipping. According to recent public media reports Mumbai alone contributed to about 36% of India's total income tax revenue in 2003, and Moscow presently has more billionaires than any other city in the world; second is New York City. Megacities cause huge air pollution emissions, as illustrated in Table 1. In some cases, megacities emit carbon monoxide (CO) plumes even greater in size than entire countries. Also, some densely populated smaller countries are very similar in scale as megacities, but the CO emissions are much smaller, which serves to illustrate that megacities suffer from severe air pollution, whereas abatement technology is available in industrialized countries. Fig. 1 illustrates firstly that densely populated countries tend to have the relatively lowest per capita CO emissions, presumably because high air pollution levels have created incentives for emission controls. Secondly some countries in E-Asia and W-Europe seem to have implemented the most stringent air pollution control measures, thus providing examples of achievable emission targets. Note that megacities—apart from Los Angeles—do not fit the scale of the figure in terms of population density, and that megacity emission estimates in the table are highly uncertain. This underscores the need for improvements in emission inventories and it also points to opportunities for knowledge and technology transfer.

The ecological footprint of a megacity encompasses not only the area physically occupied, but also the area that contributes resources and, in turn, is affected by wastes and pollutants (Molina and Molina, Journal of the Air and Waste Mangement Association 54, 644–680). On a positive note, there is a clear connection between high levels of urbanization and high rates of economic growth. However, because growth often takes place rapidly, a number of problems are created; e.g. infrastructure cannot be developed quickly enough to supply domestic water, sanitation, transport, electricity, etc. In 1971–2001, for example, the road length in Delhi increased from 8380 to 28,508 km (i.e. 3.4 times) whereas the number of vehicles increased from 0.18 to 3.46 millions (i.e. $\sim$20 times) leading to inefficient traffic flow and enhanced air pollution. Such concentrated transport and industrial activities within megacities make them to large "point" sources of air pollution plumes. Partly because the lifetimes of pollutants may be prolonged due to the high concentrations in megacity plumes, they can travel across and even between continents. A pollution plume from New York, for example, was detected over Europe (Stohl et al., 2003. Journal of Geophysical Research 108(D12), 4370). Megacity plumes contain large amounts of criteria pollutants, greenhouse gases, ozone precursors and aerosols, therefore, they potentially affect the atmosphere on a large scale (Molina et al., 2004. Journal of the Air and Waste Mangement Association 54, 644–680).

☆ Something to say? Comments on this article, or suggestions for other topics, are welcome. Please contact new.directions@uea.ac.uk, or go to www.uea.ac.uk/~e044/apex/newdir2.html for further details.

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Table 1
Comparison of some megacities and countries, using CO as a proxy for air pollution

Top 5 megacities (in terms of per capita CO emission)	Annual per capita CO emission in 2000 (kg capita^{-1})	Annual CO emission (Gg) in 2000	Population (million) in 2000	Land area (km^2)
Beijing	253	2728	10.8	16,808
Shanghai	167	2158	12.9	6300
Los Angeles	166	1960	11.8	27,800
Moscow	131	1324	10.1	994
Mexico City	101	1820	18.1	5300
5 OECD countries comparable to a megacity (in terms of population size)	**Annual per capita CO emission in late 1990s (kg capita^{-1})**	**Annual CO emission (Gg) in late 1990s**	**Population (million) in 2000**	**Land area (km^2)**
Portugal	110	1095	10.0	91,951
Belgium	101	1026	10.3	30,278
Hungary	73	737	10.0	92,340
Czech Republic	63	649	10.3	77,276
Netherlands	43	680	15.9	33,883

Emission data estimated from Streets et al. (2002) http://www.cgrer.uiowa.edu/EMISSION_DATA/anthro/table/co_2000_final, Air Resources Board (2003) http://www.arb.ca.gov/app/emsinv/emssumcat.php, M.S. Myagkov (personal communication), Molina, L.T. and M.J. Molina (Eds.), Air quality in the Mexico Megacity, Kluwer, Dordrecht, 384pp., 2002. Country level emission data are from the OECD Environmental Data Compendium 2002 (http://www.oecd.org/dataoecd/8/62/2958142.pdf).
Population data from UN (2004) http://www.un.org/esa/population/publications/wup2003/2003WUPHighlights.pdf, and land area from The World Fact Book (http://www.cia.gov/cia/publications/factbook/index.html).

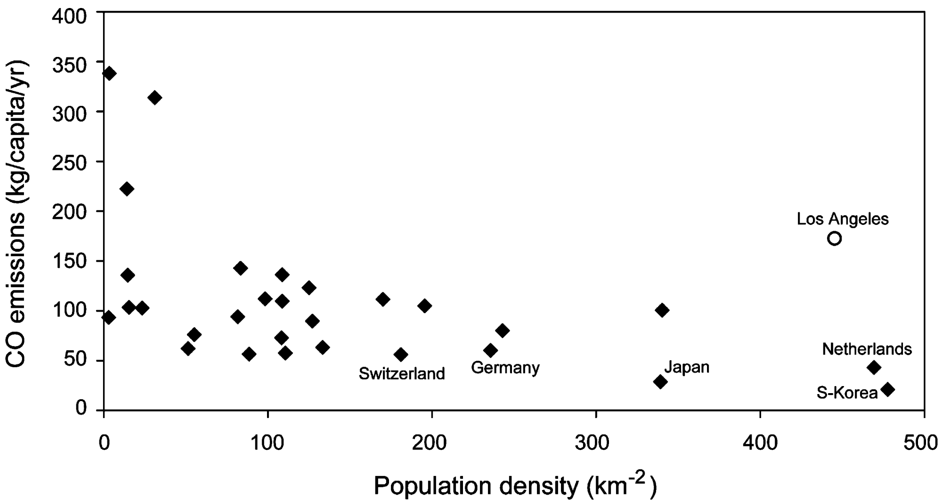

Fig. 1. Population density vs. per capita CO emissions in 29 OECD countries in the late 1990s, suggestive of a relationship between these two factors. Data sources are as shown in the notes for Table 1.

The world urban population is expected to rise to 5 billion by 2030, with Asia alone accounting for more than 50%. By 2015, eight of the top ten megacities will be in developing Asian and African countries. It needs to be determined how the Asian/African megacities will influence the regional-global air chemistry and climate. Lelieveld and Dentener (2000. Journal of Geophysical Research 105, 3531–3551) have predicted that the emerging Asian emissions will increasingly affect hemispheric background ozone in future, to the extent that regional control measures in Europe and USA can be overpowered. As not much is known about atmospheric chemistry in the tropics and subtropics, where much of the world population growth occurs, the study of atmospheric emissions from (sub)tropical megacities will have special significance (Crutzen and Lelieveld, 2001. Annual Review of Earth and Planetary Sciences 29, 17–45). Furthermore, increasing environmental stresses associated with global climate change and less employment opportunities in rural areas force people to migrate towards burgeoning cities. For instance, land erosion/desertification has possibly resulted in 60% of the recent urban growth in Burkina Faso (Srivastav, 2004. TerraGreen 63, http://www.teriin.org/terragreen/issue63/news.htm). Thus, the process of urbanization and growth of megacities appears to be both a cause and a consequence of global change, which calls for an integrated and cross-disciplinary approach in environmental studies.

Research initiatives are presently being made, as described earlier in an earlier New Directions article (Crutzen, 2004. Atmospheric Environment 38, 3539–3540). Additionally, the Globalization and World Cities Study Group and Network (http://www.lboro.ac.uk/gawc/index.html) studies world cities as a key physical manifestation of contemporary globalization. The Federal Ministry of Education and Research (BMBF) in Germany has created a long-term project on the "megacities of tomorrow" in selected developing countries (http://pt-uf.pt-dlr.de/Dateien/Megacities_Call_English.pdf). Noticing the increasing importance and role of megacities in global change, a dedicated international program is needed to coordinate megacity research to collect data, prepare emission inventories, conduct field campaigns, and extend modeling efforts to quantify their local-to-regional-to-global impacts on air quality, climate, and ecosystems.

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