

World Energy Outlook – Cities Modelling

Methodology and Assumptions

WEO-2008 featured for the first time a detailed analysis of the energy consumption and energy-related CO₂ emissions of the world's cities. This document gives further details of the methodology and assumptions used in the cities modelling.

GLOBAL

Estimating global city energy use accurately is a difficult task – primarily because data is not readily available on the thousands of cities worldwide. But lack of comprehensive data should not be mistaken for ignorance. There are some cities and regions for which it is possible to estimate city energy use – and these can provide a basis, along with several assumptions, for calculating global city energy use.

The global city energy use estimate is derived by the following 5 steps:

1. **Adjust WEO final energy data to remove non-urban energy use.** WEO data for 21 global regions is adjusted to remove non-urban energy use (for example removing agriculture and mining sectors)
2. **Calculate population scalar.** The result of step 1 needs to be scaled using the ratio of population in cities to regional population (PC_r).

Where

$$PC_r = \left(\frac{\Sigma \text{City}_{-} \text{population}}{\text{regional}_{-} \text{population}} \right) \quad \text{Equation 1}$$

In other words, PC_r is the sum of the regional population living in cities divided by the total regional population. Note that this ratio was calculated by IEA with UN data.

3. **Calculate adjustment scalar.** The results of step 2 need to be scaled again to adjust for the differences (if any) between rural and urban energy use patterns. In other words, we apply the scalar:

$$EPC_{re} = \left(\frac{\overline{ECC_{ce}}}{ECR_e} \right)_r \quad \text{Equation 2}$$

Where:

EPC_{re} is the scalar for region r and energy type e

$\overline{ECC_{ce}}$ is the average final energy use per capita (using UN urbanisation estimates for each region for city populations) for the region's cities c and energy type e

ECR_e is the (non-agricultural) final energy use per capita for the WEO region and energy type e

Scalars EPC_{re} were not available for all regions. Consequently, this analysis used a set of sample scalars from 5 regions (China, Oceania, US and EU19 and EU8). The sample scalars were selected based on regions for which data was available and which represent over half of global energy use.

Each of the five sample region's scalars were calculated using methods appropriate for each region according to data availability, the scalars were then compared to each other to ensure consistency. See regional sections below for detailed descriptions.

The scalars for these 5 regions were then further refined based on selected important cities in other regions for which detailed region-wide city data was not available.

The most appropriate sample scalars were applied to each of the 21 WEO regions based on expert judgement.

4. **Calculate global city final energy use.** City final energy use for each region r , for energy type e , and year t (RCE_{tre}) was calculated as:

$$RCE_{tre} = E_{re} \times PC_r \times EPC_{re} \text{ for time } t \quad \text{Equation 3}$$

Where

E_{re} is the non-agricultural final energy use for region r and energy type e .

Summing outputs from equation 3, global city final energy use for type e , and year t (GCE_{te}):

$$GCE_{te} = \sum_r (RCE_{tre}) \quad \text{Equation 4}$$

Similarly, global city final energy use **by sectors**, and year t (GCE_{ts}) can be calculated as:

$$GCE_{ts} = \sum_r (E_{res} \times PC_r \times EPC_r) \quad \text{Equation 5}$$

Where E_{res} is the final energy use in region r , energy type e and sector s .

5. **Conversion to primary energy use**

The final energy consumption in the cities at the total final consumption level was used to back calculate the power generation (heat and electricity) and thus the total primary energy used in the city (assuming that the city power generation mix and conversion efficiencies are the same as at the regional level) (Thus the conversion rate (β_{re}) was estimated for each region r and energy type e). For OECD regions, the difference between rural and urban per-capita energy consumption is assumed to remain constant over the Outlook period. For non-OECD regions, we assume that the differential converges over the Outlook period towards the urban/rural differential in OECD regions. City energy related CO₂ emissions are calculated using national carbon content factors.

Using outputs from equation 4, global city **Total Primary Energy Supply** for year t ($GCPE_t$) is calculated as follows:

$$GCPE_t = \sum_{re} (RCE_{tre} \times \beta_{re}) \quad \text{Equation 6}$$

Detailed Regional Analyses

In addition to a global analysis, the WEO provided detailed city-based analyses of 4 regions: US, EU, China and Oceania. The following sections describe the different data and methodologies that were used in each regional analysis. Data and methodologies differed in order to make best use of available data. Consistency of results was achieved at two levels. First, all regional teams were provided with WEO national/regional energy data. Second, consistency between regions was ensured by comparison with other available sources for energy data, comparison with IEA national energy data, expert judgement and by aligning assumptions where possible.

United States

In the United States, there is no centralised reporting of energy consumed by individual urban areas, so a number of datasets were brought together to estimate total and per-capita US urban energy consumption (Table 1). Key methodological challenges included defining *urban* and combining datasets of different spatial resolutions. Estimating urban electricity consumption was also a challenge because most existing data cover electricity production rather than electricity consumption. Since many power plants serve both urban and rural areas, difficulties exist in allocating their production between the two.

Table 1: Data sources

Dataset	Spatial resolution	Data	Year	Details
Vulcan Project ⁽¹⁾	10 km grid	CO ₂ emissions	2002	Disaggregated by sector (residential, commercial, industrial, transportation) and fuel (coal, oil, gas)
Energy Information Administration ⁽²⁾	State	Energy consumption	2005	Disaggregated by sector and fuel; Covers fossil and non-fossil sources
U.S. Census Bureau ⁽³⁾	State, urban	Population, urban boundaries	2000; 2005	Disaggregated by sector

⁽¹⁾Gurney et al., 2008. ⁽²⁾EIA, 2005. ⁽³⁾U.S. Census Bureau, 2000.

US definition of urban

The U.S. Census Bureau defines two categories of urban area: *urbanised areas* and smaller, less dense *urban clusters* (Table 2) (U.S. Census Bureau, 2000). Although urban boundaries are not aligned with the administrative boundaries of populated places or counties, they are the most accurate representation of where urban populations live. US urban energy consumption was defined as energy consumed within urban areas (urbanised areas + urban clusters), including electricity generated outside urban borders.

Table 2: Urban classifications in the United States

Classification	Definition	% US land area	% US population ⁽¹⁾
Urban cluster	>2,500 people and >500 people/mi ²	0.5	10
Urbanised area	>50,000 people and >1,000 people/mi ²	2	68
Urban area ⁽²⁾	Urban cluster or urbanised area	2.5	78
Metropolitan area ⁽³⁾	Core urban centre plus adjacent counties	25	80

⁽¹⁾Based on U.S. Census 2000. ⁽²⁾The U.S. Census delineates urban boundaries by aggregating adjacent Census blocks. ⁽³⁾Not used in the analysis, but included for reference.

Vulcan data

The Vulcan project contains detailed data on carbon dioxide emissions for the conterminous United States at a 10 km x 10 km spatial resolution. These data can be used to estimate the proportion of carbon dioxide emissions, and by extension fossil fuel consumption, occurring in urban areas. A key advantage of the Vulcan

dataset is its systematic and comprehensive coverage of the United States at high enough spatial resolution to separate urban and rural data (Gurney et al., 2008).

Estimating urban energy consumption

Urban boundaries were overlaid on the Vulcan dataset using a Geographic Information System (GIS). All Vulcan grid cells intersecting an urban boundary were defined as urban. The ratio of total emissions to urban emissions in each state was computed for each available sector and fuel by summing up the total emissions for urban grid cells and dividing by total emissions for all grid cells (Table 1). The resulting ratios were applied to EIA data on final energy consumption in each state, with the assumption that the ratio between urban and total emissions is the same as the ratio between urban and total energy consumption (EIA, 2005). Coal, oil and gas ratios were applied directly to EIA data for each sector. The ratio between urban and total electricity consumption in each state was assumed to equal the thermal ratio, which was estimated by computing a weighted average of the oil and gas ratios for each sector. The resulting scalars were applied to electricity consumption, and also to consumption of biomass/waste and other renewables. Alaska and Hawaii were excluded from all portions of the analysis due to data constraints.

Estimating per-capita consumption

To compare urban per-capita consumption and average per-capita consumption, population data from the 2000 Census (urban and total population) and the 2005 American Community Survey (total population) were used (U.S. Census Bureau, 2000; ACS, 2005). It was assumed that the ratio between urban and total population in each state remained constant between 2000 and 2005.

European Union

Data on energy consumption by energy type is available for a considerable number of urban areas in Europe. However, comprehensive energy balances at the municipal level are only available for a limited number of cities in Europe. Our method for estimating overall urban energy use is based on the extrapolation of per-capita consumption data from the limited sample population to the overall urban population of the region. The calculation required the following steps:

1. Grouping the available energy consumption data according to 7 categories of energy carriers (coal, oil, gas, electricity, heat, biomass and waste, other renewable and non-grid final energy) and by 5 end use sectors (Industry, Transport, Residential, Services, Total Final Consumption (TFC))
2. Converting urban energy consumption data to per capita values for the urban area using demographic information on resident population.
3. Calculating the population weighted per capita average over all urban areas that reported data.
4. Extrapolating from the per capita average to the regional urban total based on urbanisation figures.
5. Extrapolating from total final consumption in urban areas to primary energy supply equivalents in urban areas using overall regional conversion efficiencies for electricity and heat data.

Definition of urban areas

In most cases the definition of urban area followed administrative definitions of cities rather than functional or morphological classifications of larger urban zones. In the case of Paris, Lyon, Milan and Torino data on energy use at the level of larger metropolitan areas (Isle de France, Greater Lyon, Milan Province and Torino Province) were used to cover the wider urbanised area. In the case of London data was available at the level of the city and all 32 Boroughs which form greater London. Berlin, Bremen, Hamburg and Vienna were reported at the

level of federal states. The term urban area is used in this text to include all urban settlements within this range of administrative categories.

Demographic data

Demographic data (urban and total population) at the national and regional level was based on the UN Population Database, World Urbanization Prospects. Population numbers and administrative area for individual urban settlements were based on city statistics or national publications respectively.

Energy data

Data was found for a total of more than 700 urban areas from various sources. The data quality, coherence and reliability was however quite variable and detailed documentation of reporting methodology was often missing. The Urban Audit program of EUROSTAT and the EU directorate for regional policy for example collects data for almost 500 variables for 258 cities in Europe. While it aims to include 8 variables on urban energy consumption and CO₂ emission data, the limited number and quality of data submissions by participating municipalities in the most recent collection period (2006/2007) led to the decision to exclude the energy category from the most recent publication. Nevertheless some data from earlier collection periods could be accessed and were included here after exclusion of data rated unreliable. For two EU member states (United Kingdom and Sweden) regionalised data on final energy consumption at the local authority level was available from official publications. Also the Italian statistic agency ISTAT reported electricity consumption data for more than 100 cities. Data was also collected from publications of non-governmental organisations such as the Climate Alliance, ICLEI and the research organisation Ambienteitalia. Moreover a good number of municipal governments did report energy saving and climate protection strategies on their websites which we included in our data collection.

Data availability was best for electricity consumption which was reported for 731 urban areas, representing together about 36% of the EU27 urban population. Data on the use of heat in contrast was reported only for 160 urban areas, representing just about 2% of the EU27 urban population. Overall data on TFC was available for 550 urban areas, representing 24% of the urban EU27 population.

Oceania: Australia and New Zealand

A consequence of private sector dominance of the energy supply industries in Australia and New Zealand is that access to consumption information for small spatial areas is restricted. A complete bottom-up analysis of energy consumption is only possible with the co-operation of multiple suppliers for the one area, which has not yet been achieved. A range of alternative approaches needs to be considered in order to determine the extent of energy use in local government areas and cities.

In Australia, the approach used is to analyse energy consumption at a state level and then allocate that spatially to city areas using residential population and the location of businesses. The Australia Bureau of Agricultural and Resource Economics (ABARE) state residential energy consumption for each of the fuels used by Australian households is used to derive per-capita energy use for each of the eight Australian cities included in the analysis. Commercial and industrial sector consumption information is derived in a similar manner, by using ABARE energy consumption data by fuel type and business classification to derive per-employee energy use for each of the eight cities.

Transportation data in Australia is collated by the Australian Bureau of Statistics (ABS), which conducts an annual survey of road transport in each state and differentiates between travel patterns within cities and outside cities.

In New Zealand, a similar approach is used for stationary energy, drawing on consumption data by fuel type as reported by the Energy Efficiency and Conservation Authority (EECA). The EECA source data is national but it is allocated spatially to local government areas on the basis of population but correcting the data for the known location of over 40,000 energy-using commercial and industrial sites.

Transportation data in New Zealand is sourced from Ministry of Transport records of annual distance travelled by various vehicle types registered in each territorial authority. This is combined with average fleet efficiency figures to derive an estimate of fuel consumption in each local government area.

China

The energy consumed by individual cities in China is reported in city level statistical yearbooks of selected cities. However, this is inadequate to estimate total urban energy consumption of China for several reasons. Firstly, energy information is available for only a few key cities out of 661 cities (as of 2005). Second, there is considerable variation between cities in China which makes any generalisation of energy use difficult. Third, there are definitional issues relating to the terms “cities” and “urban areas”.

China’s definition of urban

The definition of urban population, which is governed by Ministry of Civil Affairs in China, has been changed several times since the 1950s to serve different policy objectives at the time, starting from the household registration or *Hokou* system in China in early 1950s. The latest definition of urban population, adopted in 1999, is based on “Regulation of Statistics Classification on Urban and Rural Population” of the National Bureau of Statistics, and is based on a number of criteria. Cities in China are defined by an administrative boundary, they contain both urban and rural populations. Similarly, many towns whose population is accounted as urban do not belong to cities but to rural regions. The urban population represents only 32% in City of Chongqing, 82% in City of Tianjin, 94% in City of Beijing and 95% in City of Shanghai in the year 2006 (Dhakal, 2008).

Diverse type of cities

Energy data for selected cities have limitations when generalising across diverse type of urban areas within cities and towns. Within China’s urban population, the major contribution comes from smaller urban agglomerations in cities and rural towns whose information base is weak and difficult to access- about 57% of the urban population comes from agglomeration of less than a million people (UN, 2007). Urban agglomerations greater than five million, where better quality information is available, account for only about 12% of urban population while one-to-five million people agglomerations contribute over 30% (Dhakal, 2008; UN, 2007). A study for 35 Chinese cities further illustrates the fact that even the largest and most important cities of China have very different energy profiles. Dhakal (2008) further shows that per-capita energy use in Beijing, Shanghai, Tianjin and Chongqing has been very different in the last two decades.

Coping with different energy statistical systems

China uses Standard Coal Equivalent (SCE) as a basic unit for energy statistics reporting. SCE is further reported with and without calorific value considerations making comparisons difficult with other energy units used internationally. Most of China’s energy statistical system such as China Energy Statistical Yearbook and China Statistical Yearbook report largely commercial energy use only and do not report biomass and other renewables. Further, the total energy consumption reported in Chinese publications are essentially total primary energy demand, which needed to be converted to total final consumption for our analysis.

Simplified methodological approach

With consideration to the above mentioned complexities a simple method was devised to estimate total urban energy consumption of China. Rather than trying to find an “accurate” number which cannot be validated in absence of other studies, our method would provide a tentative and reasonable picture to better understand Chinese urban energy use. This method estimates urban energy use for Chinese cities and towns largely based on the urban component of the city’s Gross Regional Product (GRP) and the derived energy intensity (energy consumed per unit of GRP) from provincial average figures covering almost 75% of urban population. The remainder, which comes from smaller settlements, were assumed to be the same as that of the county level cities’ average per capita energy use. The detailed methodology for such estimation is available in Dhakal (2008) which essentially derived urban scaling techniques and ratios for Chinese energy statistics and applied these scalars and ratios to the WEO’s China energy statistics to estimate WEO compatible urban energy use.

References

American Community Survey, U.S. Census Bureau, 2005: See: <http://www.census.gov/acs/www/index.html>.

Dhakal, S. (2008), Urban Energy Use and Cities’ Carbon Emissions in China, *Energy Policy*, Elsevier, London, forthcoming.

Dhakal (2005)

Energy Information Administration, US Department of Energy, 2005: State Energy Data System (SEDS). See: http://www.eia.doe.gov/emeu/states/_seds.html. Page last viewed October 31, 2008.

Gurney, K.R., Seib, B., Ansley, W., Mendoza, D., and Miller, C., 2008: Project Vulcan, Purdue University. See: <http://www.purdue.edu/eas/carbon/vulcan/research.html>. Page last viewed October 31, 2008.

UNPD (United Nations Population Division) (2007a), *World Population Prospects: The 2006 Revision*, United Nations, New York.

— (2007b), *World Urbanization Prospects: The 2007 Revision*, United Nations, New York.

U.S. Census Bureau, 2000: See: <http://www.census.gov/main/www/cen2000.html>. Page last viewed October 31, 2008.