GEA KM18 working paper

Urban energy consumption database and estimations of urban energy intensities

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Purpose and structure of the document

Purpose

This working paper provides a first overview and methodological documentation of an ongoing effort at IIASA TNT to establish a global database on energy consumption at the sub-national level based on bottom up data records. It is an activity within the Global Energy Assessment (GEA) Knowledge Module (KM) 18 on Urbanization and should help improve demand side oriented and spatially explicit energy studies. Like all chapters of GEA it also aims to improve our understanding of links between energy access and attainability of agreed development targets such as the millennium development goals (MDGs). Additional to energy use data (in terms of per GJ/capita values at the total final consumption (TFC) level) therefore also data on socioeconomic energy intensity (EI in terms of MJ per unit of gross regional product (GRP)) are compiled. Results had been obtained for 225 urban areas, covering a population of about 480 million and an energy consumption of about 42 Exajoule (or about 13% of the global final demand in 2005).

Structure

The report is structured in the following way: after a brief introduction about the motivation follows a section on methodological considerations and descriptions of the data sources used for population, energy use and socioeconomic data. The following analysis section includes an overview table with summary results for TFC and EI in total and by main geographic area and detailed sections on per capita energy consumption, per capita income and energy intensity. For illustrative purpose some scatter plots with variable correlations are presented together with general observations. An appendix lists a summary of the data obtained at the urban level,

Motivation and methodological considerations

Motivation

Resulting effects of the scale and concentration of human activity in urbanized areas have been the focus of research in various disciplines. Economists commonly emphasize the benefits of scale of larger labor markets in cities and agglomeration effects of clustering various industrial activities in one locality

(Krugman 1991; Fujita, Krugman et al. 1999; UNIDO 2009; Worldbank 2009). Climatologists are discussing the consequence of urbanization on albedo changes, radiation balances and weather patterns (Kalnay and Cai 2003; International Association for Urban Climate 2006; Souch and Grimmond 2006). Transport planners are concerned to avoid negative externalities of urban density such as traffic congestion. Environmental researchers are studying typical patterns of the generation and distribution of pollutants in urban centers and the exposure of target populations to such hazards (McGranahan, Jacobi et al. 2001; McGranahan 2007). Social scientists are investigating particular urban social structures and challenges, urban cultural modes of creativity and innovation which result from the immediate proximity to many million potential acquaintances in large urban centers.

Understanding the consequences of urbanization on energy use in general on the other hand, is an area of research that did attain surprisingly little attention in empiric studies, given the global urbanization trends, the relevance of urban areas for overall energy demand (Jones 1991; Parikh and Shukla 1995; International Energy Agency 2008), their particular vulnerability to energy supply disruption and their potential to contribute to energy efficiency improvements and climate change mitigation.

Methodological considerations

This paper summarizes an initiative to compile a database of literature values of bottom up derived urban scale energy use cases to improve our understanding of the determinants and variation in energy demand of urban areas. It should contribute to address a wide range of urban energy related research questions, such as for example: What is the role of external framing conditions like climatic and geographic variables for urban energy demand? How do the city size, the urban economic structure and its rank in the system of national and global city networks shape its energy demand structure? What does technological infrastructure, urban form, density and design contribute to direct energy demand (Newman and Kenworthy. 1989; Jenks, Burton et al. 1996; Steemers 2003) ? How do income level, socioeconomic consumption patterns cultural preferences and other behavioral features translate into specificities of energy demand? What are indirect effects of urbanization on global environmental systems? How does energy demand interact with human disruptions of other biogeochemical cycles like water, macronutrients and other resources? To which extend and through which mechanisms are urban areas driving agents of global change? Which technologies are central to mediate and improve the urban-environmental interactions?

The database which focuses on direct energy use is continuously being expanded and is intended to work as a research vehicle and tool towards answering such broad questions. It will be hosted at IIASA – TNT and will be made online accessible to the wider research community to help improve research and our understanding of coupled social-environmental systems.

When moving from these broad declarations of intent and motivation towards more concrete data work, two clarifying questions arise almost immediately: The first one asks how urban areas would be defined in this study, and the second question refers to the definition of energy use applied here.

Defining urban areas

Urban areas are not easy to delineate as statistical units and the criteria used for classification vary frequently between and even within countries. Minimal population sizes and density thresholds are often applied to study urbanization dynamics (Angel, Sheppard et al. 2005). Many urban centers moreover are political and administrative autonomous units, e.g. local authorities, which have governance functions, fiscal and legal rights of their own. Those boundaries are therefore politically derived but also historically variable. Urban centers are obviously also remarkable concentrations of socioeconomic activity, typically dominated by either industrial or service sectors and in some countries the primary urban settlement generates almost half of the national GDP. Socioeconomic criteria are therefore often also used to define urban centers. Nevertheless the complexity and functionally open character of urban settlements as nodes of the global networks of transport infrastructure for goods, information, currency and people, and their inherent growth dynamic, routinely renders administrative units irrelevant to define city limits and complicates data acquisition, particularly for time series studies. Partly in response to these difficulties, this study chooses a cross-section approach, aiming to compare a large number of urban areas from a wide range of regional settings, different geographies, sizes and functions to better understand the ranges and variety of energy use patterns.

Defining energy use

In terms of energy use data, focus is on direct fuel use at the 'final consumption' level. This unit of analysis is assumed to be best defined and comparable among case studies. This level of accounting was chosen to be able to include a maximum number of case studies. Accounts for primary energy equivalents (or even greenhouse gas emissions) require assumptions on boundary definitions, conversion factors and efficiencies, line losses etc. which introduce ambiguity. Also broader definitions of energy use which go beyond direct energy consumption and are aiming to include indirect use were not included here. Such studies account for embodied energy through the consumption of goods produced abroad, and should also consider the export of embodied energy from urban areas. While they address an important aspect in the context of sustainable production and consumption research, the number of such studies is found to be even more limited than reports on direct energy use. Accounting methodologies are also conceptually less harmonized and technically diverse.

In a first step towards the broader goals of analysis, the data collected will be used to calculate energy intensities of socioeconomic activity. If robust patterns of urban energy use and such variables could be identified they could potentially also be used to downscale maps of energy demand to the sub-national level based on demographic and socioeconomic proxy data.

Regional aggregations

Three categories of urban statistical data were brought together in this exercise: population statistics, energy statistics and economic statistics on regional productivity. While population statistics are routinely collected and published at various levels of spatial resolution this is less often the case for both economic and energy consumption data. Coherent datasets could nevertheless be found for 225 urban units of which 160 were from Annex 1 countries and 65 were urban areas located in non- Annex 1 countries.

In terms of regional grouping this report followed mainly the GEA grouping of regional data and distinguished 4 panels at two tires of resolution (see table 1): at the top level it differentiated UNFCCC Annex1 and non -Annex1 countries. At the second tier Annex 1 countries are distinguished into OECD90 and the group of reforming countries who joined OECD since 1990 generally referred to as REF. Non-Annex 1 countries are subdivided in non- OECD Asia on the one hand and the group combining Africa and Latin America on the other hand.

Table 1) Regional disaggregation, number of observations (urban areas) and cumulative population covered in those areas.

Total: (225 observations, population covered: 483 million)		
	UNFCCC Annex 1 Countries (160 observations, population covered: about 185 million)	
		OECD 90 (147 observations, population covered: 156 million)
		REF countries (joined OECD since 1990 – 13 observations, population covered: 33 million)
	Non -Annex 1 Countries (65 Observations, population covered: about 292 million)	
		Non OECD Asia (43 observations, population covered: 247 million)
		Africa and Latin America (22 observations, population covered: 47 million)

Demographic data sources

Principle data source for demographic data was the (United Nations 2008) database which contains in the segment on Urban Agglomerations demographic data in annual time series since 1950 for 588 urban areas with a population exceeding 750k. Moreover it provides population projections for these areas till 2025. This source provided also UN specific country- and city codes for unique identification. While demographic data are collected part of the vital statistics it is still problematic in terms of data quality particularly at higher spatial resolutions. Data sources can vary in their accounting principles (legally registered population versus de-facto population, including “floating population” or visitors). Also daily and seasonal variation in population can be considerable in central business districts and wider urban areas. The progress in transport technology make administrative boundaries of established cities often less useful to describe their functional unit in the sense of a common labor market or travel to work area. For larger urban areas it was therefore aimed to account for the energy use of the entire metropolitan area if available, rather than more granular accounts (e.g. on the level of individual local authorities or boroughs). A number of urban areas were not included in the UN publication, sometimes because their population was smaller than the threshold of 750k, but also sometimes as they were based on other definition of urban areas than those applied by the UN. In those cases the population numbers from other sources was used, particularly if it allowed achieving coherence with the boundaries at which socioeconomic or energy use data was reported.

A general bias of the UN WUP data on urban localities is that it covers only large cities and urban areas of over 750.000 people. The cumulative population covered in the UN WUP database on urban localities includes about 1,3 billion people, just about 43% of the global total UN estimate for population residing in urban areas in 2005. The smaller sized urban areas do not only at present the dominant size segment of global urban population- also projections see this segment as fastest growing in absolute terms of population number over the next 30 years.

Socioeconomic data sources

For some studies there was one coherent source for population figures, socioeconomic data and energy statistics, but those examples were exceptions. In most cases, socioeconomic data at the sub- national level was collected from a variety of publications.

(PriceWaterhouseCoopers 2007) published gross regional product (GRP) estimates for the 151 largest economic urban areas listed in the UN world urbanization prospects in 2005. This publication also included projections about their regional product and rank in 2020. The PWC data however did not cover smaller urban areas with population below 750k or many urban areas of larger population size but relatively low affluence.

For a number of urban areas from Europe, economic activity data was therefore derived from Eurostat, which publishes regional product estimates down to the NUTS 3 level, which typically corresponds to geographic units of about 300.000 (150k-800k) people (Eurostat 2008). For US data points economic data was derived from the US department of Commerce, Bureau of Economic Analysis, Metropolitan Area Annual Estimates[1].

In some cases the reported population size of the socioeconomic data diverged more than 10% from the population reported in the energy statistics. In those cases the population size reported in energy statistics was used, and the socioeconomic data was accordingly scaled, based on the assumption of constant per capita GDP figures. Data on national and regional product retrieved in various national currencies was converted to 2005 US $ in purchasing -power -parity valuations derived from the International Monetary Fund, World Economic Outlook Database[2].

Energy use data sources

The energy use statistics is the data category which varied most in accounting methodology among the various literature sources and consequently in data quality. Sources used in this study include: (Hosier 1993; Reddy 1998; BERR 2007; Dhakal 2009; IEA 2009; Kennedy, Steinberger et al. 2009; Siemens 2009; Hillman and Ramaswami 2010).

Several studies were primarily concerned with energy infrastructure planning and supply security and did not cover traditional or non-commercial fuels. Many studies were conducted with the purpose to construct greenhouse gas (GHG) inventories and therefore focused on primary energy consumption. They cover other GHG relevant activities (such as waste treatment) and sectors like land-use, agriculture and forestry, which have only indirect linkages to the energy system. Not always were detailed accounts of all activities provided (e.g. non-motorized transport, etc) or case specific equivalence factors reported (e.g. carbon intensity of imported electricity or heat). Particularly the treatment of transport and bunker fuels (for national and international freight and person transport activities, e.g. airports, seaports) was not harmonized and is an accounting challenge[3].

Like in the case of demographic and economic data, boundary definitions and population numbers did often vary among sources. Also the reference year was not always 2005. In those cases energy use per capita was calculated with the population figure reported in the energy statistics, and calculations of energy intensity of GDP were conducted using constant per capita values.

In several cases energy consumption data was reported for the same urban area at different levels of spatial granularity. In those cases the largest available area unit was used in this study. In the case of the UK for example Greater London (and other metropolitan areas like Greater Manchester, Greater

[1] http://www.bea.gov/regional/#gsp

[2] http://www.imf.org/external/ns/cs.aspx?id=28

[3] Some studies report transport fuels based on fuels sold within administrative boundaries. Others calculate it from transport activity data (including transit vehicles). Even other sources are based on the vehicle fleet registered within the administrative borders.

Birmingham) were reported as one single urban area here, rather than including all 32 Boroughs of London plus the city of London individually. Also for the Swedish urban areas we used data for the 3 main metropolitan areas (Stockholm, Gothenburg and Malmö) as aggregate units (=counties), rather than all the municipal units they are comprised of individually. While it is regrettable to loose some of the granular detail of energy use information contained in the lower resolution, the socioeconomic data in fact was not available at a similar spatial level of detail.

Analysis

Comparisons of urban scale and national scale data

The following section compares data on energy use per capita, gross regional product (GRP) per capita and energy intensity of GRP at the urban scale with national scale metrics. Table 2 presents the overall results as well as a regional breakdown by status regarding UNFCC Annex 1 / non-Annex 1 assignation and 4 main geographic regions.

Table 2) Comparison of per capita urban final energy (GJ/capita), GRP (1000 int. 2005 $/capita), and energy intensity (MJ/int 2005 $) statistics. Indicator values at the urban and the national level. Data cover 225 urban areas, of which 160 are located in UNFCC Annex 1 countries. Average values and standard deviations (*S.D*) are presented for three sample groups: “lower”: all those cities where urban indicators are below or equal respective national averages, “higher” where they exceed national average, and “total”: indicators for all cities in the sample taken together.

		Count (# of urban areas) higher/lower than national average			**Statistical values in GEA urban energy data base**											
		Urban per capita TFC vs. national	**Urban per capita GRP vs. national GDP**	**Urban TFC intensity of GRP vs. national**	**average TFC urban**	**average TFC national**	**SD TFC urban**	**SD TFC national**	**average GRP urban**	**average GDP national**	**SD GRP urban**	**SD GDP national**	**average energy intensity GRP urban**	**average energy intensity GDP national**	**SD energy intensity GRP urban**	**SD energy intensity GDP national**
Unit		**count (nr of areas)**			**GJ/cap**				**Intl $/cap**				**MJ TFC/ Intl $**			
Global	lower	151	111	141	87.59	124.52	*33.03*	*45.43*	30,265	29,502	*13,219*	*9,216*	3.47	4.49	*3.19*	*2.59*
	higher	74	114	84	133.76	70.47	*104.53*	*47.46*	17,881	16,002	*12,323*	*12,287*	10.64	5.30	*10.23*	*2.77*
	total	225	225	225	102.77	106.74	*69.02*	*52.57*	26,192	25,062	*14,160*	*12,103*	5.83	4.75	*7.24*	*2.67*
UNFCC Annex I count-ries (=OECD 90+REF)	lower	129	82	116	96.03	137.06	*25.18*	*34.62*	33,639	32,635	*10,681*	*4,647*	3.04	4.11	*0.93*	*0.81*
	higher	31	78	44	187.04	120.42	*127.81*	*29.72*	29,694	28,497	*9,293*	*9,109*	6.80	4.59	*4.49*	*1.84*
	total	160	160	160	113.66	133.84	*69.96*	*34.28*	32,875	31,833	*10,515*	*5,977*	3.77	4.21	*2.59*	*1.10*
Non-Annex 1 count-ries (=Non-OECD Asia+LA, ME+A)	lower	22	29	25	38.08	50.96	*30.38*	*28.31*	10,479	11,130	*8,527*	*7,816*	5.94	6.68	*7.75*	*6.17*
	higher	43	36	40	95.34	34.46	*60.95*	*10.72*	9,364	6,994	*4,999*	*2,201*	13.41	5.81	*12.20*	*3.21*
	total	65	65	65	75.96	40.05	*59.05*	*20.01*	9,742	8,394	*6,367*	*5,207*	10.88	6.10	*11.41*	*4.41*

Non OECD Asia*	lower	6	14	11	55.18	57.83	*54.12*	*52.45*	14,538	14,351	*14,112*	*14,032*	3.98	5.07	*1.94*	*2.17*
	higher	37	29	32	87.88	33.15	*37.77*	*7.77*	9,938	6,802	*4,905*	*1,004*	10.11	5.25	*5.56*	*0.23*
	total	43	43	43	83.32	36.60	*41.27*	*21.31*	10,580	7,855	*6,851*	*5,595*	9.25	5.22	*5.62*	*0.78*
Latin America, and Africa (LA+A)	lower	16	15	14	32	48.39	*12*	*13*	8,957	9,922	*5,133*	*3,768*	6.67	7.28	*8.99*	*7.10*
	higher	6	7	8	141	42.51	*134*	*21*	5,826	8,180	*4,383*	*5,608*	33.79	9.26	*21.19*	*8*
	total	22	22	22	62	46.79	*83*	*15*	8,103	9,447	*5,043*	*4,273*	14.07	7.82	*17.81*	*7.30*
OECD 90	lower	122	80	104		138.70	*25*	*31*	34,365	33,441	*10,471*	*2,724*	3.02	4.04	*0.94*	*0.72*
	higher	25	67	43	208	131.18	*133*	*19*	32,857	32,649	*6,631*	*2,761*	6.60	3.95	*4.28*	*0.59*
	total	147	147	147	116	137.42	*72*	*29*	34,108	33,307	*9,921*	*2,737*	3.63	4.02	*2.36*	*0.70*
REF	lower	7	2	12	73	108.44	*22*	*72*	20,993	18,574	*5,012*	*8,194*	3.47	5.50	*0.59*	*1.11*
	higher	6	11	1	98	75.60	*43*	*26*	16,516	11,195	*6,979*	*3,974*	7.64	7.22	*5.65*	*2.87*
	total	13	13	13	85	93.28	*35*	*56*	18,927	15,169	*6,185*	*7,403*	5.39	6.29	*4.26*	*2.20*

*includes Belgrade (which in fact is in non-Annex 1 REF)

Per capita energy consumption

An initial observation is that almost two out of three urban areas have lower or equal[4] than national average (direct) final energy use on a per capita basis. The trend is more pronounced (129 of 160) among the Annex 1 countries, which are overrepresented in this sample (160 of 225). Among the Annex 1 countries this pattern is more pronounced in OECD 90 countries (122 of 147) than in REF countries (7 of 13).

In non-Annex 1 urban areas the reverse pattern can be observed with about two out of three urban areas having higher per capita final energy use compared to their respective national average. Among non-Annex 1 countries there is pronounced regional heterogeneity: African and Latin American share the prevalence of lower than national average urban per capita final energy use, in contrast to Asia, where urban per capita final energy use is predominantly (37 out of 43 cases) higher than the national average.

An explanation of these differences awaits further corroboration, but preliminary findings suggest that differences in levels of incomes, as well as in economic structure (degree of service versus industry orientation of urban economics) are likely as main explanatory variables. In general it should be noted that the number of observations in rapidly growing economies of non-OECD Asia is much larger in the sample compared to Latin America and Africa (43 versus 22), pointing to the need of improved energy information in urban settlements particularly in those regions.

[4] Includes Singapore and Hong-Kong, where urban area and IEA reported national per capita values coincide.

Figure 1 Final energy consumption per capita (GJ/cap) and cumulative population in urban areas of Annex 1 countries

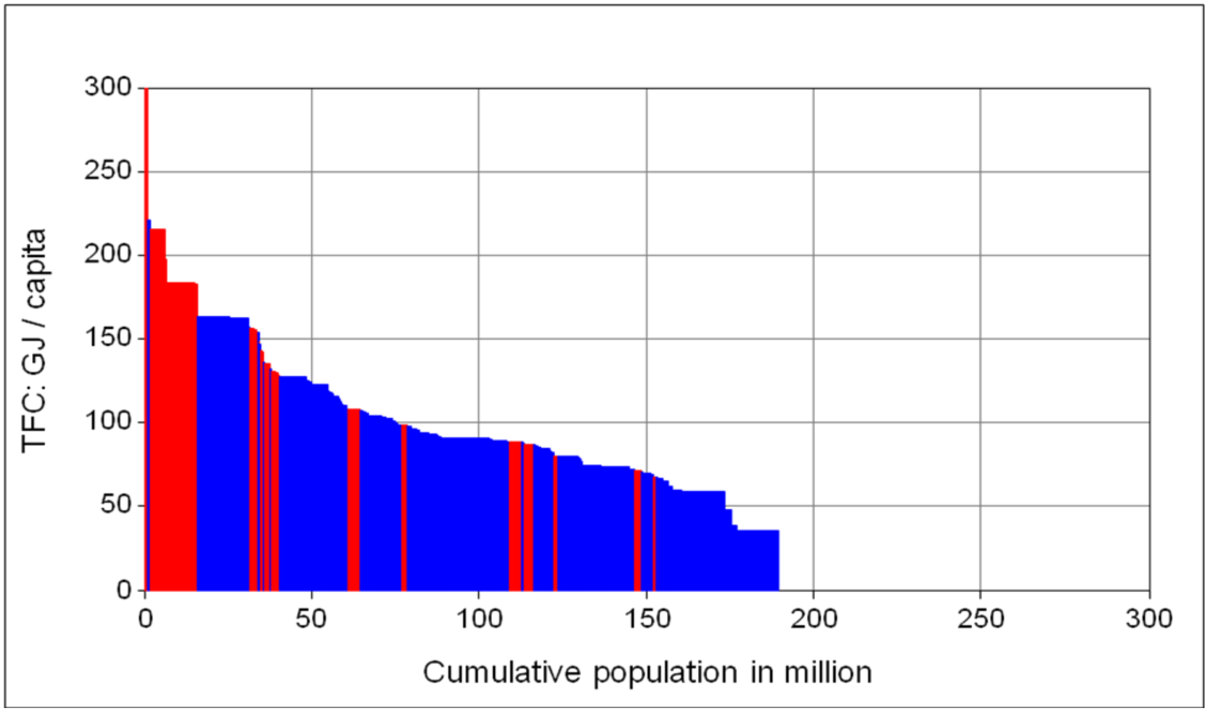
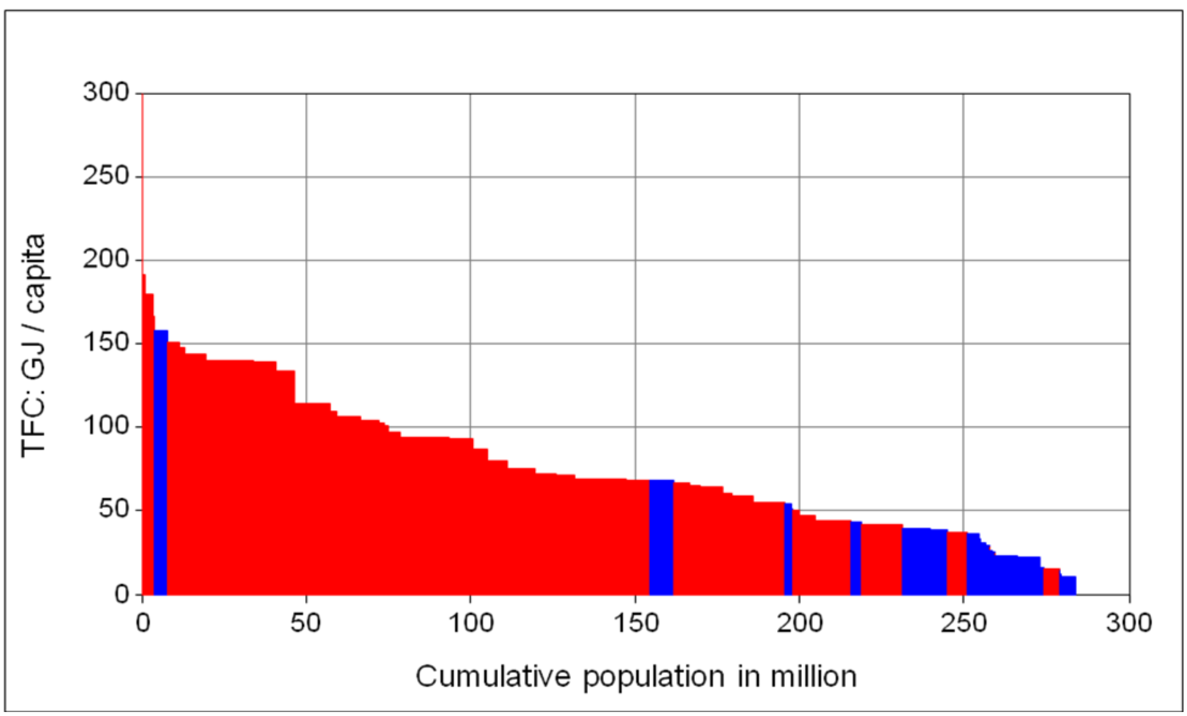


Figure 2: Final energy consumption per capita (GJ/cap) and cumulative population in urban areas of non-Annex 1 countries



Figures 1 and 2 summarize above statistical analysis showing all urban scale observations as cumulative plot (over population) sorted by decreasing per capita final energy use. The color code indicates whether a city is above (red) or below or equal (blue) per capita direct energy use compared to its respective national average. The inverse "energy footprint" of cities in Annex 1 versus non- Annex 1 countries becomes highly visible from this comparison. On average the lower energy using cities in Annex 1 countries have a final energy footprint that is one third lower than the Annex 1 national average. For non-Annex 1 countries the reverse relationship was observed: most non Annex- 1 cities have (about twice) higher per capita final energy use than their respective national averages, being in fact in the same ballpark as the lower energy use sample in the Annex 1 countries (at some 100 GJ/capita).

It needs to be noted that the above conclusions only refer to the (direct) final energy use metric adopted for the comparative analysis of our sample of 225 urban areas.

Evidence suggests that for Annex 1 country cities the lower final energy use is likely to hold only for the production accounting approach adopted for this comparison. Adding "embodied "energy use (corrected for net trade of imports/exports of manufactured goods and services from/to urban economies) is likely to weaken the conclusion of a lower urban energy footprint in cities of Annex 1 countries compared to the national average as lower (direct) final urban energy use likely to be (largely) overcompensated by higher "embodied energy" consumption associated with higher urban incomes. And yet the lower (direct) final energy use of many urban compared to rural areas in Annex 1 countries well illustrates the urban comparative advantage for a sustainability transition: urban areas with their corresponding more energy efficient compact settlement structures and lessened (energy intensive) automobile dependence and greater potentials for efficiency improvements due to energy "recycling" (i.e. cogeneration and heat-cascading) have larger efficiency leverage potentials compared to rural areas. The challenge of reducing the energy and environmental footprint from (over) consumption (i.e. embodied energy) is not unique to urban dwellers as applying equally to rural ones as well in Annex 1 countries.

Conversely, the situation of cities in non Annex 1 countries, particularly in Asia is markedly different. Compared to rural areas, cities not only have a higher (direct) final energy use, they also have generally much higher incomes and often better developed infrastructure (electrification, gas-grid) compared to most African cities. Thus the urban-rural gradient in terms of per capita (direct) final energy use is yet further amplified by higher urban incomes, further increasing the rural-urban energy gradient when considering the "embodied" energy use associated with the consumption. Given the dynamics of urbanization trends it is thus fair to conclude that the sustainability "hot spot" in the decades to come will reside particularly in the rapidly growing cities of non Annex 1 countries, particularly in Asia.

Per capita Income

Regarding per capita income the data sample reveals much more heterogeneity than popular conceptions of invariably rich urbanites would hold. Almost half of the urban areas in our sample had per capita GRP values below the national average. Again there are divergent patterns between Annex 1 countries (where the trend is dominated by the large number of relatively deprived smaller UK-urban centers in the data sample but also such prominent examples like the capital of Germany, Berlin) and non- Annex 1 countries on the other.

In non-Annex 1 urban areas the majority showed above national average per capita GRP values. In Asia, two out of three urban areas had GRP above the national per capita average. In Africa and Latin America, just a bit more than one third of the urban areas had GRP values exceeding the national per capita average, but two thirds rank below.

Energy Intensity

Regarding energy intensity of GRP, the majority of urban settlements studied showed lower than national average energy intensity, indicating the dominance of less energy intensive tertiary sector activities in urban areas. In Annex-I countries more than two out of three settlements show lower than national level energy intensities of GDP, a fact that is even more pronounced among the urban areas from REF countries. These are although in the sample mainly represented through capital cities, which typically harbor a large share of service sector activity. In the non-Annex I countries the general trend reverses with almost two third of cases showing urban energy intensity of GRP exceeding the national average values. Again the Asian urban areas show a very different pattern than those from the regions Latin America, Middle East and Africa. Three out of four urban areas in non OECD Asia have energy intensities exceeding the national average, while four out of five of the African, Middle East, and Latin American urban cases have the same pattern like OECD countries with urban area energy intensities being mainly below their respective national average.

Variable correlations

Figure 3) Comparison of total direct urban energy use (TJ) and urban regional product (GRP, million intl. $)

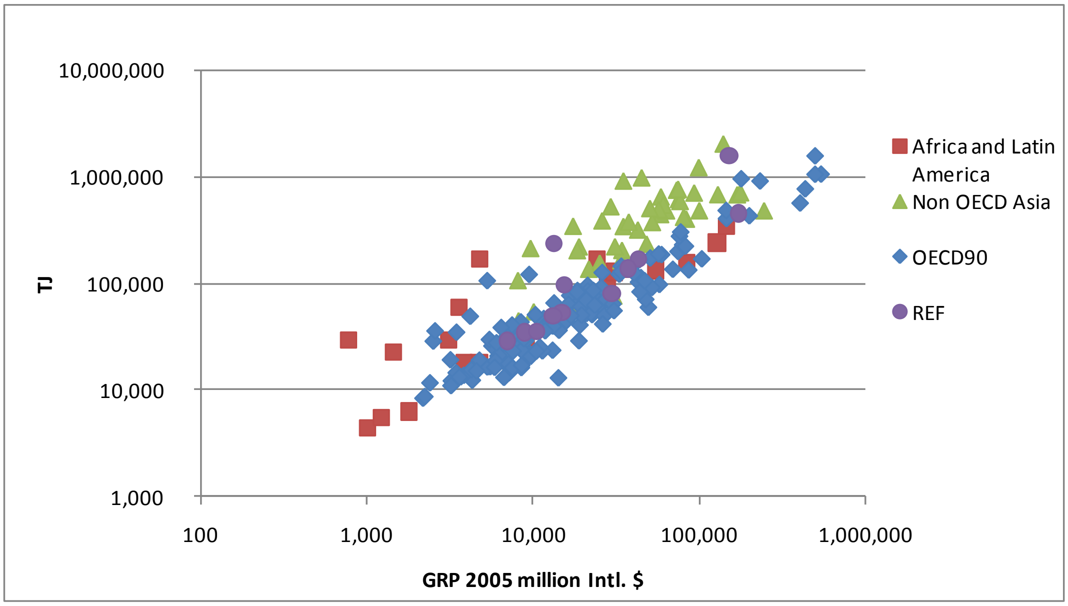


Figure 3 illustrates the order of magnitude of energy consumption and economic activity of urban centers. Several of them reach more than an exajoule of annual energy consumption - more than many mid sized national economies like Switzerland use at a whole. Also the economic product with maximum values around 600 Bn $ exceeds that of entire nations. Both of these measures are even scaled to the available energy consumption statistics which are not always covering the whole population of the greater metropolitan area[5].

The notable positive correlation between overall energy consumption and urban GRP in all 4 panels, is a familiar pattern from national scale data. Variation is largest in the panel "Africa and Latin America". In terms of location within the scatter plot, most of the OECD 90 data points are located below the REF or Non-OECD Asia data points, illustrating the observed tendency of lower energy intensity values described in table 2. The following table illustrates the same relationship as Figure 1, but normalized on a per capita basis.

[5] Tokyo is for example represented as „Tokyo prefecture" with about 12 million populations. The Greater Tokyo Area which includes the cities Yokohama, Kawasaki, Sagamihara, Saitama and Chiba in contrast exceeds 36 million in population and an estimated GRP of 1500 Bn (10^9) US$.

Figure 4) Comparison of urban total final consumption (TFC) per capita (GJ/cap) and urban GRP per capita (intl. $ / capita),

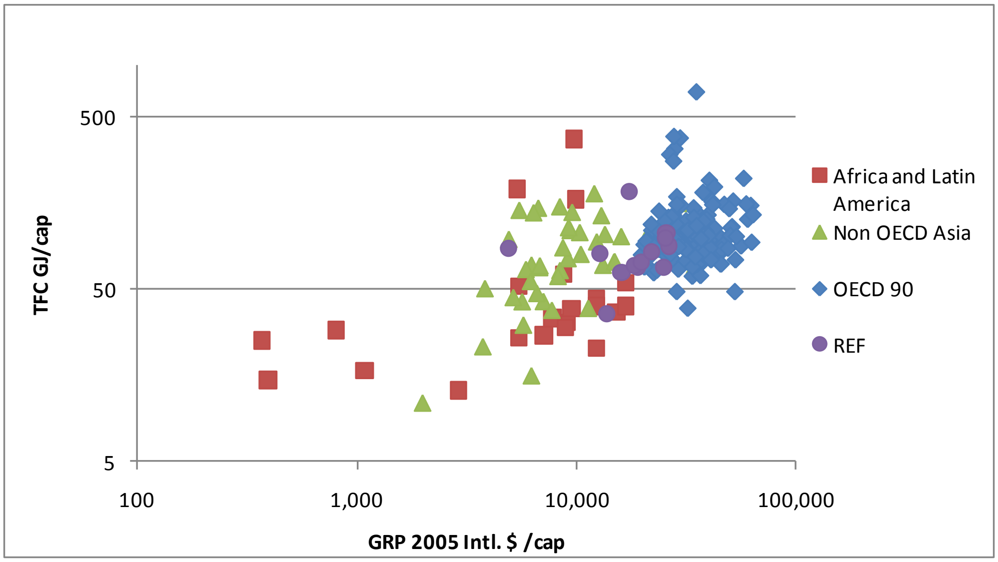


Figure 4 presents the previously mentioned relation between final energy consumption on a per capita and GRP per capita basis. – The general positive correlation familiar from the scatter plots of total values is also to be found at the per capita representation, but the variation appears to be larger than in Figure 3. Also within the panel of Annex 1 countries, there still is a large variation in energy consumption per capita (with some urban areas consuming more than 600 GJ/cap). But also in the per capita representation the relation appears to be monotonous: A proposed "turning point" of Income, beyond which per capita TFC would start to decline cannot be identified in this data set which covers GRP ranges up to about 80,000$/cap.

Figure 5) Comparison of urban energy intensity of GRP (MJ/ intl. $) and urban GRP per capita (intl. $ / capita),

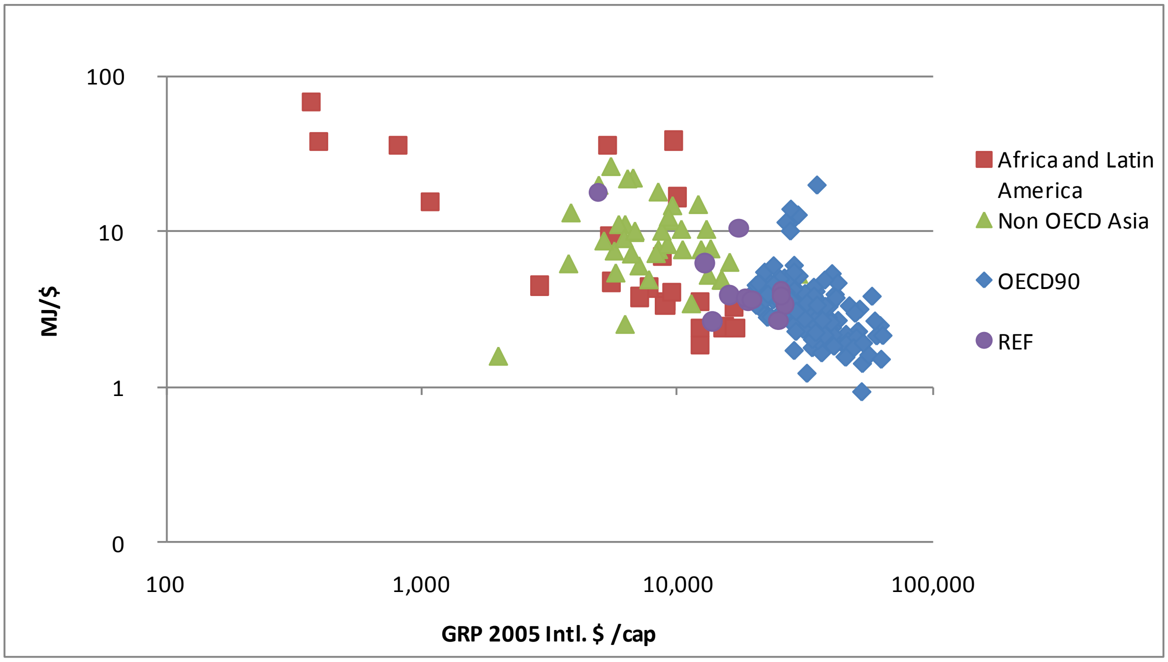


Figure 5 illustrates the relation of GRP per capita and energy intensity of GRP. It indicates a general negative correlation of these variables, a trend that is most pronounced in the OECD90 data. Also the group “Africa and Latin America” indicates this general pattern, but the energy intensity data is much more scattered in that case. Most likely this is at least partly due to the variation in estimates for non-commercial energy use.

General observations

At least three general patterns of energy use and intensity can be described for the non-OECD urban areas.

One is the lower end, with energy consumption values under 30 GJ /capita. GDP per capita is mostly under 5000 $/cap in those cases and energy intensity is quite variable: either relatively low, below 5MJ/$ or - if estimates for traditional fuel use are included- with larger energy intensity values mainly explained by large shares of inefficient biomass fuel use combined with low economic activity rates.

The medium range of per capita energy use lies between 30 and 100 GJ/cap (exceeding some of the energy efficient urban areas of OECD)and coincides with a wide range of incomes, and energy intensity ranges typically between 5 and 10 MJ/$.

The third group is characterized by heavy industrial urban areas which show higher per capita energy use with per capita consumption up to 350 GJ/year and quite variable higher income ranges. In practically all urban settlements of the third group energy intensity is above 10MJ/$ (up to 39 MJ/$ in this sample).

In contrast only six out of the 147 OECD90 and 2 of the 13 REF urban areas show energy intensity values above 10 MJ/$ and the vast majority ranges below 5 MJ/$.

The OECD90 panel in general appears more consistent in energy consumption patterns and the relation between energy intensity and average GRP per capita. Income ranges are typically at the higher end of the GRP per capita spectrum.

For further analysis of this data we plan to conduct regression analysis with various potential explanatory variables, such as geographic indicators, measures of urban economic structure and technology variables.

A caveat regarding the representativeness of the sample should be pointed out: Similar to the UN database on urban locations, our sample has a bias towards larger and relatively wealthier urban settlements. The fastest growth of urban populations on the other hand is expected in small urban areas in low income countries. As the data collected here show, the energy consumption patterns of smaller urban areas varies considerably and general patterns are difficult to detect. Improvements of the data basis about energy use of smaller urban settlements in low income areas are therefore an apparent research priority.

For considerations of urban energy efficiency improvements, these settlements are crucial: Smaller urban areas are potentially still less constrained in the infrastructure configuration compared to larger urban localities where conflicting area demands (e.g. for transport infrastructure, recreational area, residential, commercial or public use) often prevent efficient solutions.

Smaller urban settlements in contrast still have the potential to introduce energy efficient structures like rapid bus transit systems at early stages, which have the potential to allow for energy efficient development trajectories at comparatively low costs. A complicating feature worth mentioning is that smaller cities are typically also characterized by less powerful political-, regulatory- and planning institutions. Targeted climate friendly urban development funds could be potential enabling structures which should be considered.

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Appendix 1) energy consumption per capita and energy intensity values

Urban Area	Country	Region	Energy consumption TFC [GJ/ cap]	Energy Intensity [MJ/$]
Ahmadabad	India	ASIA	15.77	2.52
Bangalore	India	ASIA	10.95	1.57
Beijing	China	ASIA	114.49	12.39
Belgrade	Serbia	ASIA	38.89	3.43
Changchun	China	ASIA	68.70	10.06
Changsha, Hunan	China	ASIA	59.61	7.21
Chengdu	China	ASIA	44.94	8.70
Chongqing	China	ASIA	144.36	26.24
Dalian	China	ASIA	134.51	10.33
Fuzhou	China	ASIA	37.88	4.89
Guangzhou, Guangdong	China	ASIA	93.79	4.05
Guiyang	China	ASIA	97.90	19.86
Haerbin	China	ASIA	55.74	9.00
Haikou	China	ASIA	31.07	5.41
Hangzhou	China	ASIA	72.70	4.86
Hefei	China	ASIA	47.48	7.17
Hohhot	China	ASIA	180.47	14.93
Hong Kong	China, Hong Kong SAR	ASIA	68.54	1.98
Iskandar (Johore Baru metro area)	Malaysia	ASIA	101.65	6.34
Jilin	China	ASIA	87.49	10.05
Jinan, Shandong	China	ASIA	80.13	7.63
Krung Thep (Bangkok)	Thailand	ASIA	104.61	7.74
Kunming	China	ASIA	67.06	9.86
Lanzhou	China	ASIA	65.42	11.09
Nanchang	China	ASIA	42.59	6.01
Nanjing, Jiangsu	China	ASIA	69.22	5.23

Nanning	China	ASIA	23.27	6.20
Ningbo	China	ASIA	72.19	4.86
Qingdao	China	ASIA	94.68	7.63
Shanghai	China	ASIA	140.54	14.66
Shenyang	China	ASIA	107.24	10.33
Shenzhen	China	ASIA	94.41	4.05
Shijiazhuang	China	ASIA	69.41	11.10
Singapore	Singapore	ASIA	158.37	5.31
Taiyuan, Shanxi	China	ASIA	151.41	17.98
Tianjin	China	ASIA	139.72	21.86
Ürümqi (Wulumqi)	China	ASIA	110.27	11.74
Wuhan	China	ASIA	75.64	8.25
Xiamen	China	ASIA	103.25	4.89
Xi'an, Shaanxi	China	ASIA	42.48	7.49
Xining	China	ASIA	50.63	13.20
Yinchuan	China	ASIA	148.55	22.11
Zhengzhou	China	ASIA	64.53	7.65
Mexico City	Mexico	LAC	40.01	2.38
Rio de Janiero	Brazil	LAC	22.97	1.87
Sao Paulo	Brazil	LAC	22.97	1.87
Buffalo City	South Africa	MAF	26.00	4.74
Cape Town	South Africa	MAF	44.00	3.57
Dar es Salaam	Tanzania	MAF	16.90	15.63
Ekurhuleni	South Africa	MAF	61.00	6.98
eThekwini	South Africa	MAF	39.00	4.11
Johannesburg	South Africa	MAF	37.00	2.44
King Sabata	South Africa	MAF	13.00	4.49
Mangaung	South Africa	MAF	27.00	3.79
Mbeya	Tanzania	MAF	25.20	68.48

Msunduzi	South Africa	MAF	52.00	9.50
Nakuru	Kenya	MAF	29.10	36.19
Nelson Mandela	South Africa	MAF	30.00	3.35
Potchefstroom	South Africa	MAF	34.00	4.37
Saldanha	South Africa	MAF	374.00	38.47
Sedibeng	South Africa	MAF	192.00	35.83
Shinayanga	Tanzania	MAF	14.90	37.82
Sol Plaatje	South Africa	MAF	32.00	3.53
Tshwane	South Africa	MAF	55.00	3.29
uMhlatuze	South Africa	MAF	167.00	16.75
Amsterdam	Netherlands	OECD90	74.51	1.81
Athens	Greece	OECD90	88.77	3.93
Austin	United States of America	OECD90	147.65	2.97
Barcelona	Spain	OECD90	65.72	2.26
Barnsley, Doncaster and Rotherham	United Kingdom	OECD90	108.05	4.54
Bath and North East Somerset, North Somerset and South Gloucestershire	United Kingdom	OECD90	98.63	2.66
Bedfordshire CC	United Kingdom	OECD90	88.88	3.05
Belfast	United Kingdom	OECD90	48.63	0.92
Berkshire	United Kingdom	OECD90	101.84	1.90
Berlin	Germany	OECD90	80.66	3.65
Birmingham	United Kingdom	OECD90	85.50	2.71
Blackburn with Darwen	United Kingdom	OECD90	93.73	3.69
Boulder	United States of America	OECD90	136.16	2.13
Bournemouth and Poole	United Kingdom	OECD90	77.48	2.22
Bradford	United Kingdom	OECD90	80.55	3.01
Bremen	Germany	OECD90	155.93	3.73
Bridgend and Neath Port	United Kingdom	OECD90	142.87	6.02

Talbot				
Brighton and Hove	United Kingdom	OECD90	67.80	2.01
Bristol, City of	United Kingdom	OECD90	70.42	1.54
Brussels	Belgium	OECD90	86.88	1.77
Buckinghamshire CC	United Kingdom	OECD90	103.23	2.58
Calderdale, Kirklees and Wakefield	United Kingdom	OECD90	99.40	3.57
Cambridgeshire CC	United Kingdom	OECD90	117.68	3.33
Cardiff and Vale of Glamorgan	United Kingdom	OECD90	100.90	2.82
Central Valleys	United Kingdom	OECD90	95.68	4.61
Cheshire CC	United Kingdom	OECD90	183.51	4.86
city of leeds	United Kingdom	OECD90	94.16	1.49
Clackmannanshire and Fife	United Kingdom	OECD90	124.47	4.94
Copenhagen	Denmark	OECD90	80.63	2.13
Darlington	United Kingdom	OECD90	110.71	3.44
Denver	United States of America	OECD90	221.50	3.82
Derby	United Kingdom	OECD90	87.39	2.15
Dublin	Ireland	OECD90	156.46	3.31
Durham CC	United Kingdom	OECD90	96.26	4.57
East Ayrshire and North Ayrshire mainland	United Kingdom	OECD90	119.74	5.47
East Cumbria	United Kingdom	OECD90	156.39	5.46
East Derbyshire	United Kingdom	OECD90	111.93	4.52
East Dunbartonshire, West Dunbartonshire and Helensburgh & Lomond	United Kingdom	OECD90	67.65	3.32
East Lothian and Midlothian	United Kingdom	OECD90	90.23	3.67
East Merseyside	United Kingdom	OECD90	110.47	5.02
East of Northern Ireland	United Kingdom	OECD90	90.68	3.51
East Riding of Yorkshire	United Kingdom	OECD90	106.88	4.52

East Sussex CC	United Kingdom	OECD90	78.52	3.05
Edinburgh, City of	United Kingdom	OECD90	89.69	1.59
Essex CC	United Kingdom	OECD90	91.72	3.10
Falkirk	United Kingdom	OECD90	705.23	20.03
Flintshire and Wrexham	United Kingdom	OECD90	154.38	5.16
Fort Collins	United States of America	OECD90	124.51	3.28
Gävle	Sweden	OECD90	388.43	13.98
Genva canton	Switzerland	OECD90	197.95	4.65
Glasgow City	United Kingdom	OECD90	85.55	1.86
Gloucestershire	United Kingdom	OECD90	104.67	3.15
Gwent Valleys	United Kingdom	OECD90	91.32	4.50
Halmstad	Sweden	OECD90	132.51	4.90
Halton and Warrington	United Kingdom	OECD90	128.47	3.27
Hamburg	Germany	OECD90	104.79	3.14
Hampshire CC	United Kingdom	OECD90	131.28	3.83
Hartlepool and Stockton-on-Tees	United Kingdom	OECD90	131.41	5.01
Helsinki	Finland	OECD90	92.61	2.36
Herefordshire, County of	United Kingdom	OECD90	107.10	4.02
Hertfordshire	United Kingdom	OECD90	96.91	2.39
Inverclyde, East Renfrewshire and Renfrewshire	United Kingdom	OECD90	89.00	3.46
Jönköping	Sweden	OECD90	120.18	4.23
Karlstad	Sweden	OECD90	105.87	3.91
Kent CC	United Kingdom	OECD90	102.67	3.65
Kingston upon Hull, City of	United Kingdom	OECD90	90.68	3.08
Kyoto	Japan	OECD90	72.50	2.33
Lancashire CC	United Kingdom	OECD90	104.26	3.70
Leicester	United Kingdom	OECD90	87.14	2.31

Leicestershire CC and Rutland	United Kingdom	OECD90	125.46	3.97
Lincolnshire	United Kingdom	OECD90	92.17	3.89
Linköping	Sweden	OECD90	99.69	3.60
Lisbon	Portugal	OECD90	48.65	1.70
Liverpool	United Kingdom	OECD90	83.18	2.55
London	United Kingdom	OECD90	74.49	1.40
Los Angeles	United States of America	OECD90	163.47	3.15
Luton	United Kingdom	OECD90	70.19	1.98
Lyon	France	OECD90	135.85	3.41
Madrid	Spain	OECD90	74.79	2.15
Manchester	United Kingdom	OECD90	89.65	2.90
Medway	United Kingdom	OECD90	64.81	2.79
Melbourne	Australia	OECD90	123.34	3.33
Milano (Milan)	Italy	OECD90	108.36	2.78
Milton Keynes	United Kingdom	OECD90	103.44	2.05
Minneapolis	United States of America	OECD90	157.36	2.64
Monmouthshire and Newport	United Kingdom	OECD90	149.32	4.37
New York	United States of America	OECD90	128.07	2.12
Norfolk	United Kingdom	OECD90	97.10	3.42
Norrköping	Sweden	OECD90	279.25	10.09
North and North East Lincolnshire	United Kingdom	OECD90	380.41	12.82
North Lanarkshire	United Kingdom	OECD90	98.28	3.66
North Nottinghamshire	United Kingdom	OECD90	106.51	4.05
North Yorkshire CC	United Kingdom	OECD90	129.91	4.64
Northamptonshire	United Kingdom	OECD90	118.37	3.40
Nottingham	United Kingdom	OECD90	82.45	1.81

Örebro	Sweden	OECD90	104.11	3.64
Oslo	Norway	OECD90	94.78	2.50
Outer Belfast	United Kingdom	OECD90	62.61	2.79
Oxfordshire	United Kingdom	OECD90	113.53	2.66
Paris	France	OECD90	91.38	1.96
Peterborough	United Kingdom	OECD90	99.21	2.16
Plymouth	United Kingdom	OECD90	71.12	2.49
Portland	United States of America	OECD90	114.39	2.25
Portsmouth	United Kingdom	OECD90	73.95	2.04
Roma (Rome)	Italy	OECD90	60.33	1.64
Seattle	United States of America	OECD90	154.20	2.47
Sefton	United Kingdom	OECD90	67.30	3.16
Sheffield	United Kingdom	OECD90	88.75	2.92
Shropshire CC	United Kingdom	OECD90	99.18	4.07
Skane county	Sweden	OECD90	123.43	4.28
Somerset	United Kingdom	OECD90	106.96	3.63
South and West Derbyshire	United Kingdom	OECD90	135.65	4.91
South Ayrshire	United Kingdom	OECD90	109.39	3.80
South Lanarkshire	United Kingdom	OECD90	94.35	3.23
South Nottinghamshire	United Kingdom	OECD90	85.53	3.62
Southampton	United Kingdom	OECD90	70.94	1.92
Southend-on-Sea	United Kingdom	OECD90	77.22	2.89
Staffordshire CC	United Kingdom	OECD90	116.01	4.51
Stockholm county	Sweden	OECD90	70.41	1.55
Stoke-on-Trent	United Kingdom	OECD90	88.62	3.42
Suffolk	United Kingdom	OECD90	94.58	3.23
Sunderland	United Kingdom	OECD90	89.31	2.90
Sundsvall	Sweden	OECD90	305.19	11.48

Surrey	United Kingdom	OECD90	103.91	2.55
Swansea	United Kingdom	OECD90	91.83	3.40
Swindon	United Kingdom	OECD90	116.00	2.26
Sydney	Australia	OECD90	215.96	5.35
Telford and Wrekin	United Kingdom	OECD90	101.69	3.12
Thurrock	United Kingdom	OECD90	329.67	11.76
Tokyo	Japan	OECD90	59.78	1.77
Torino (Turin)	Italy	OECD90	93.47	2.68
Toronto	Canada	OECD90	162.92	3.92
Tyneside	United Kingdom	OECD90	91.57	2.84
Umeå	Sweden	OECD90	173.35	6.05
Uppsala	Sweden	OECD90	90.13	3.01
Västra Götaland county	Sweden	OECD90	38.95	1.21
Växjö	Sweden	OECD90	108.48	3.87
Vienna	Austria	OECD90	80.46	1.96
Warwickshire	United Kingdom	OECD90	143.13	4.11
West Cumbria	United Kingdom	OECD90	109.66	4.60
West Lothian	United Kingdom	OECD90	104.73	3.07
West Sussex	United Kingdom	OECD90	89.81	2.50
Wiltshire CC	United Kingdom	OECD90	116.39	3.93
Wirral	United Kingdom	OECD90	79.60	4.04
Worcestershire	United Kingdom	OECD90	110.84	3.86
York	United Kingdom	OECD90	91.73	2.58
Zurich	Switzerland	OECD90	94.75	2.48
Bratislava	Slovakia	REF	82.80	3.75
Bucuresti (Bucharest)	Romania	REF	72.13	3.67
Budapest	Hungary	REF	98.85	3.89
Istanbul	Turkey	REF	36.15	2.64
Kyiv (Kiev)	Ukraine	REF	87.16	17.78

Ljubljana	Slovenia	REF	105.87	4.13
Moskva (Moscow)	Russian Federation	REF	184.13	10.60
Praha (Prague)	Czech Republic	REF	67.19	2.71
Riga	Latvia	REF	69.18	3.76
Sofia	Bulgaria	REF	80.71	6.28
Tallinn	Estonia	REF	89.56	3.40
Vilnius	Lithuania	REF	62.87	3.93
Zagreb	Croatia	REF	68.02	3.59