How urbanization affects energy-use in developing countries

Donald W. Jones

This paper identifies mechanisms whereby urbanization affects energy consumption. Industrialization and urbanization accompany each other during economic development, but urbanization exerts a number of independent influences on energy-use. It permits economies of scale in production but requires more transportation. Food must be transported to urbanized populations and relatively smaller agricultural populations must modernize, entailing considerable increases in agricultural energy-use. In cities, a number of production activities which were domestically provided in rural areas, using human or animal energy, shift to sources outside the household, using modern energy sources. The largest single source of change in energy-use is personal transportation. Passenger transport in cities is heavily weighted towards fuel-using modes, particularly as incomes increase. To assess the overall impact, a regression analysis of 59 developing countries for 1980 is conducted. Holding constant per capita income and the extent of industrialization, the elasticity of energy consumption per capita and per dollar of GDP is between 0.35 and 0.48.

Keywords: Economic developments; Energy-use; Urbanization

Urbanization is one of the major phenomena of economic development. This paper identifies mechanisms by which it alters energy consumption. Industrialization – the introduction of new equipment and techniques to make both familiar and new products – is closely associated with urbanization but the two are not identical and an attempt is made to separate their respective influences on energy-use. Policies to reduce industrial energy consumption are reasonably well known, even if their implementation is involved – adoption of new, energy-efficient equipment; industrial energy conservation techniques such as improved maintenance practices and implementation of low-cost energy audit recommendations; fuel substitution; etc. However, urbanization itself increases energy-use, but it is less clear what sorts of policies could constrain this growth in energy consumption. Knowing more about how urbanization affects energy-use can give some ideas about where energy policymakers could focus their attention.

The structure of agriculture, as well as that of industry, must change to support urbanization. Agricultural operations mechanize, use more commercial fertilizer and submit more of their output to processing to let food travel further, all of which requires energy not used in traditional agriculture. In cities themselves energy-use changes in both the home and the market. Urban households purchase many goods and services that rural households provide domestically, with an increase in the energy used in their production. Probably the most obvious energy-using change in individual activity occurs in personal transportation. Urban populations are much more likely to travel to work via fuel-using transport modes than are rural populations. Constructing, operating and maintaining urban infrastructure also require energy that rural life generally does not. Finally, the high population and activity densities of cities encourage, and even require, substitution of more compact, modern energy forms for traditional fuels.

Urbanization consistently displaces traditional energy with modern energy, whether the displacement is in the same sector and use or in different ones. Modern energy has a larger proportion of useful energy than traditional fuels do, sometimes by as much as an order of magnitude, but the overall impact of urbanization is to increase the secondary energy intensity of activities substantially while the secondary intensity of traditional energy-use remains the same or falls.

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Table 1. Production and transport cost changes associated with scale of production in the Turkish cement industry.

Scale of operation (thousand tonnes/year)	Average shipment distance (km)	Average variable transport cost (Turkish lira/tonne)	Increase	Average labour and capital cost (Turkish lira/tonne)	Decrease	Net saving/tonne from scale increase (Turkish lira)
150	6	1.50	–	190	–	–
300	31	7.75	6.25	117	73	66.75
450	52	13.00	11.50	101	89	77.50
600	68	17.00	15.50	93	97	81.50
1 350	190	25.00	23.50	75	115	91.50

Source: B. Wälstedt, *State Manufacturing Enterprise in a Mixed Economy: The Turkish Case*, Johns Hopkins University Press, Baltimore, MD, USA, 1980, p 150.

Effects of urban population concentration on energy-use

Scale of production

Larger population concentrations in cities permit larger labour forces to be assembled for employment in larger-scale, more specialized facilities, but inputs must be assembled from greater distances and products must be sold over larger market areas. The larger scale of production reduces unit output costs but considerable increases in transportation are required to sustain the scale increases. Table 1 shows this effect for the Turkish cement industry. Expansion of the market area from a radius of 6 km to 190 km reduced labour and capital costs by 60% but increased transport costs more than 16 times, while still reducing the total delivered cost/tonne by 47%.

Larger-scale, higher-technology industry finds the compactness of modern energy sources perferable to those of traditional sources, apart from any superiorities in technical performance. For example, with 1850s American technology, a moderate-sized, charcoal-fired blast furnace required a 2 000–5 000 acre plantation to supply wood; a 6 ft coal seam covering no more than half an acre, and not necessarily adjacent to the furnace, supplies the same requirements.[1] Clearly, urban land costs encourage more compact fuels as manufacturing moves to cities.

Food delivery

In traditional agriculture, farmers consume a large proportion of what they produce and correspondingly produce most of what they consume, especially food. Urbanization separates food consumers and producers. In low-income countries, food processing, particularly for non-exported food, is simple, and traditional processing, such as rice husking or grain grinding, may use only human or animal energy. Urbanization permits larger-scale and more efficient food processing, but processing for urban markets is more likely to use fuels than human or animal energy and may require additional, energy-using processing.

In 1963 the USA devoted 7.3% of energy-use to food processing and another 1.92% to transporting food.[2] Table 2 indicates that transport costs of contemporary food delivery to Nairobi are between 9% and 12% of the total energy embodied in the food. For Mexico City, the estimated requirements for processing and transporting food account for half of the embodied energy. Agriculture in Mexico probably takes 3–4% of national energy consumption. Sending one-quarter of Mexico's farm products to Mexico City would use 1% of national energy consumption. Embodied energy could easily equal directly used energy, so a conservative translation of the figure for food delivery only to Mexico City would be 2%.[3] This is roughly two-thirds of Hirst's figure for processing and transportation for an equivalent share of the US population. The figures for Nairobi are somewhat more difficult to interpret but comparison with Parikh's estimates for South Asian countries, in Part B of Table 2, is illuminating.

Food transportation consumes 1.3% of total national energy supplies in India and Pakistan, 2.1% in Burma and 0.5% in Sri Lanka. None of these countries is highly urban (23% in India and 27–28% in the other three) and Parikh attributes Burma's relatively high food transportation energy share to exports. Food processing accounts for 1–3.6% of national energy consumption. Tanzania is only half as urbanized as these countries, so the quantity of food moving to urban populations would be correspondingly less. However, its per capita energy consumption is only one-third that of India, Pakistan and Sri Lanka, and roughly the same as Burma's, so the smaller quantities of energy used in food transportation (see Table 2, Part A) would be measured against a smaller base of national energy-use.

These energy demands are not major claimants on national energy supplies but they are a source of energy demands that are not a major factor among farm dwellers. Even the processing done for on-farm

Table 2. Energy requirements to deliver food to off-farm consumers.

A. Embodied energy estimates for single cities, 1976

	Percentage of total embodied energy in food devoted to transportation and processing	Type of cost
Nairobi	9–12	Transport costs only[a]
Mexico City	47–58	Processing and possibly transport costs[b]

B. Direct energy estimates for countries

	Percentage of national energy consumption devoted to		Percentage of direct agriculture energy devoted to	
	Food processing	Transportation	Food processing	Transportation
India	2.3	1.3	38.9	22.6
Pakistan	3.6	1.3	36.1	13.1
Burma	2.1	2.1	52.2	53.5
Sri Lanka	1.0	0.5	4.9	9.8

[a] Transport cost estimation assumes average haul distance of 100 km, with energy coefficient of 4MJ/kg, the energy requirements for a 7 tonne truck, three-quarters loaded and returning empty.

[b] Derived by assuming zero rural processing and assigning a portion of all-Mexico food processing to Mexico City by its population share (see McGranahan and Taylor, *op cit*, Ref 4, p 29).

Sources: Embodied energy estimates from G. McGranahan, S. Chubb, R. Nathans and O. Mbeche, *Patterns of Urban Household Energy Use in Developing Countries: The Case of Nairobi*, W. Averall Harriman College for Urban Policy Sciences, State University of New York, Stony Brook, NY, USA, April 1979, p 49; McGranahan and Taylor, *op cit*, Ref 4, p 34; Direct energy estimates from Jyoti K. Parikh, 'From farm gate to food plate: energy in post-harvest food systems in south Asia', *Energy Policy*, Vol 14, No 4, August 1986, p 371.

consumption generally uses human or animal labour rather than fuels.

Infrastructure

The concentration of people in cities requires construction and maintenance of transportation, sanitation and water facilities. The assembly portions of construction activity are not particularly energy intensive but construction materials, particularly cement and structural steel, are (see Table 6 on energy intensities in Philippine manufactures). The construction associated with urbanization entails continuing energy expenditures rather than one, big outlay.

Public service infrastructure requires energy to operate. In Nairobi in 1976, supplying people in the poorest income group with water, educational, medical and public lighting services required 5% of the energy those people consumed privately. The comparable figure in Mexico City was 13%. Overall, Nairobi's public service energy expenditure was 3.6% of total private energy purchases; Mexico City's was 6%. A partial check on the reasonableness of these figures is offered by McGranahan and Taylor's estimate of the energy used in rubbish collection in Mexico City, which they calculate at 4% of urban public service energy consumption, or 0.24% of total urban energy consumption.[4] Calculations made from Nath yield an estimate of 0.25–0.33% of average per capita energy consumption of Calcutta residents going to rubbish collection.[5]

Changes in domestic activity

Households use from 40% to 90% of all fuels in Third World countries, so small percentage changes in domestic energy-use can be important. Urbanization increases specialization and division of labour and many production activities conducted within the home in rural areas move outside the household. Some of these activities required fuels in the home (baking, food preservation, water heating for clothes washing) but can be accomplished with lower fuel inputs per unit of output by specialized service providers in the market. Others, such as weaving and sewing, may have used only human energy inputs in the home but use fuel when conducted by firms.[6]

A major difference in domestic activity between rural and urban areas is in transportation. Although farmers may spend a quarter to a third of their total labour time travelling to and from fields, they almost always walk or use an animal power source.[7] In cities, however, fuel-using transportation is more the rule, even among lower-income workers. In Nairobi,

Table 3. Transport energy shares in Nairobi by mode and income group, 1976 (percentages).

Transport mode	Income group 1 (Lowest)	2	3	4	5
Public transport	16	21	9	1.50	0.75
Private car	34	51	85	97.00	98.50
Matatu[a]	20	14	3	1.00	0.50
Foot cycle	30	14	3	0.50	0.25
Percentage of trips on foot or bicycle	80	65	30	<10	<10

[a]A particularly inexpensive taxi-bus with a high load efficiency. It was illegal in Nairobi until shortly before the McGranahan *et al* study.

Source: McGranahan *et al, op cit*, Table 2, pp 31–32; see p 30 on foot and bicycle trips.

25% of direct private energy-use is used in transportation and in Mexico City 64%. In Mexico City, 5% of the transport energy-use is for electric buses and trams and the metro, 23% for buses and 72% for cars (62% for private cars and 10% for taxis).[8]

Table 3 details the modal distribution of Nairobi transportation energy-use by income group. The car is the dominant energy user among all income groups, although 80% of trips in the lower income group are by foot or on bicycle. McGranahan and Taylor do not mention foot or bicycle traffic in Mexico City, and neither does Newcombe for Hong Kong, although the latter's data suggest that there may be substantial foot and bicycle traffic among middle and lower-income groups.[9]

Increased demand for car transportation can be attributed to increases in income at constant prices. As Berndt and Botero demonstrate for Mexican car energy demand, in a developing country, estimation of an income elasticity of demand without allowance for a stock accumulation effect under-estimates the effect that income increases have on energy demand.[10] Their stock accumulation effect increases their estimated income elasticity of demand for petrol for cars by nearly one-third while leaving price elasticities unaffected. Urbanization is a major driver of the stock accumulation effect on car and transportation energy demand.

Urban density and fuel-use patterns: some evidence from Hong Kong

Higher residential density puts a premium on the compactness and portability of domestic fuels. Charcoal is more compact than firewood and kerosene is easier to transport than either. Where installation can be afforded, electricity has urban supply characteristics superior to all the traditional fuels and the transitional modern fuels such as kerosene and LPG. The magnitude of these effects is examined with data from Hong Kong.

Table 4 presents a regression of the traditional fuel share in domestic uses in Hong Kong on per capita energy-use, as a surrogate for per capita income, and population density. A 10% increase in density causes a 2.5% decrease in the firewood and charcoal share. Consistent with the fuel switching effects of total energy-use increases noted above, a 10% induce in energy needs would increase an 11.7% shift away from firewood and charcoal. Other evidence indicates a strong positive correlation between population density and the share of domestic energy derived from kerosene.

Kerosene is preferred over firewood and charcoal at higher population densities and energy-use levels (income levels), except possibly for cooking. Evidence presented earlier indicated relatively higher levels of kerosene use in cities than in rural areas, although the effect was attenuated at higher incomes. The present evidence is from districts *within* a single metropolitan area. As city populations grow, their average densities increase. Continued urbanization alone may encourage a shift from firewood and charcoal to kerosene, independently of per capita income increases.

Berndt and Samaniego find a similar phenomenon with electricity demand in Mexico.[11] The demand for electricity is affected by the cost of the hook-up, which is reduced by urbanization since a higher population density reduces per capita transmission and distribution costs.

Effects of increases in individual income on energy demands during development

Real incomes increase with economic development and in developing countries exhibit substantial urban–rural disparities. Movement to a city can be expected to raise the cash income of the average migrating individual or family – if not immediately, then within a period of time short enough to permit discounted higher future earnings to exceed an initial period of lower earnings. Income elasticities of

Table 4. Income and population density effects on domestic fuel choices in Hong Kong, 1971.

Independent variable[a]	**Dependent variable: firewood and charcoal** as percentage of domestic fuels[a]
Constant	10.245 (19.469)[b] [0.0001][c]
Population density	−0.246 (−6.326)[b] [0.0001][c]
Domestic energy consumption/capita (surrogate for per capita income)	−1.168 (−4.644)[b] [0.0001][c]
No of observations	33
R^2 (adjusted R^2)	0.650(0.626)
F	27.83
F probability	0.0001

[a] All variables are in natural logarithms.
[b] t-ratio in parentheses.
[c] t-probability in brackets.
Sources: K. Newcombe, 'Energy use in Hong Kong. Part III: Spatial and temporal patterns', *Urban Ecology*, Vol 2, 1976, pp 150–51.

demand for energy have been estimated from household survey data for India, Pakistan, Sudan, Mexico, Kenya and South Korea to range between 0.5 and 1.0.[12]

Additionally, higher incomes shift urban consumers away from traditional fuels towards modern energy sources. Part of this effect is induced by appliance purchase and operation and part of it reflects the increased ability to purchase more convenient and desirable fuels.[13] In countries with large enough domestic markets to engage in appliance production, the increased demand for appliances also increases energy demand in metal products.

The income-induced increases in demand for energy may be mitigated by the use of more efficient fuels and combustion technologies by urban consumers. On the other hand, income-induced household fuel substitutions may be inhibited by long-established culinary traditions – kerosene and electricity are poor substitutes for wood and charcoal in grilling food.[14]

Increases in income also drive demands for new consumption items that require more energy for their production. Sometimes this may simply shift the location of production from within the home, where goods and/or services are produced with little or no non-human energy, to outside producers who do use non-human energy. The major source of indirect energy demand during development is from the introduction of new products, particularly those made with metals, plastics, ceramics and paper.

Changes in agriculture

Before the drive towards urbanization and development, roughly three-quarters of the population of a typical developing country is agricultural. Traditional agriculture can, roughly speaking, feed a nation's population if each farm family can feed one-and-a-third families. When the society is fully urbanized, the remaining farm families may be called upon to feed as many as 2.5–4 families each, which requires modernization. Traditional agriculture uses virtually no fuels, while mobile farm equipment uses liquid fuels and irrigation may use either liquid fuels or electricity. In addition, energy-intensive commercial fertilizers displace most farm fertilizers – primarily animal dung and crop residues. Sustaining the higher productivity requires closer input coordination throughout the crop season as well as timely pick-up of harvested crops. This entails the use of modern transportation systems.

Table 5 details the progress of mechanization and commercial fertilizer use in Taiwanese agriculture since the second world war. As late as 1955, two-thirds of farm power came from human labour and one-third from animals, but within 20 years the human-supplied share fell to 35% and the animal share to 7%, while mechanical power rose from zero to 58%. Total direct energy per unit of cultivated land doubled. Chemical fertilizers rose from 8% of nutrient equivalent applications in 1946 to 77% by 1975. As these organizational changes occurred, the

Table 5. Urbanization and the mechanization of agriculture: Taiwan.

Date	Urbanization (% of population in agriculture)	Energy source and characteristics: Total (million horsepower days)	From human labour (%)	From animal labour (%)	From machines (%)	Energy per cultivated ha (hp-days)	Fertilizer use: Fertilizer per cultivated ha[a]	Chemical fertilizers (as % of all fertilizers[a])
1946							0.129	8
1950							0.249	40
1952	52.4	36.14	67	33	0	41.26	0.313	53
1955	50.7	37.13	67	33	0	42.53	0.293	49
1960	49.8	41.80	65	31	4	48.10	0.368	57
1965	45.4	50.22	60	23	17	56.43	0.385	60
1970	40.9	62.38	47	14	39	68.93	0.358	58
1975	34.7	81.69	35	7	58	89.08	0.468	77
1979	32.3							

[a] In nutrient equivalents.
Sources: Percentage of population in agriculture from *Taiwan Statistical Data Book, 1980*, Council of Economic Planning and Development, Taipei, Taiwan, 1980, p 57; agricultural data from Thorbecke, *op cit*, Ref 15, pp 147–149, 156–157.

agricultural share of the labour force fell from 52% in 1952 to 35% in 1975.[15]

More direct evidence is available for India. Although actual fuel use in agricultural machinery is quite dependent on local soil and terrain and agricultural practices, aggregate national data can be revealing. In 1983, India reported 502 581 four-wheel tractors. Averaging 750 hours-use/year, at the fuel consumption rate of a well-maintained *two-wheel* tractor, implies an annual fuel requirement of 27.3% of national oil consumption, up from 16.8% a decade earlier. Relatively low motor vehicle use elsewhere in the economy boosts this implied agricultural share of oil consumption, but neither is Indian agriculture highly mechanized.

Another source of energy demand change that accompanies agricultural modernization is the delivery of purchased inputs. Purchased inputs replace farmer-produced inputs in modernized agriculture and they must be delivered. Input delivery would add 37.5% to the direct energy delivered by machinery on a cultivated hectare in Taiwan in 1975.[16]

Industrial composition changes and energy-use

The energy impacts of industrialization exceed those of urbanization, although the energy implications of industrialization in any country may be as difficult to predict as those of urbanization. Industrial activity obviously uses more energy per unit of output, per worker, and undoubtedly relative to other numeraires as well, than does traditional agriculture and even traditional manufacturing. However, projecting changes in industrial energy-use by extrapolating from changes in employment or output structure is unlikely to be accurate for any given country.

General trends in industrial structure

Within manufacturing, the importance of metals increases, partly because of increases in the array of capital goods and consumer durables produced and partly because metal parts are substituted for wooden and leather ones in existing products. A similar substitution occurs with plastics. Both metals and plastics are more energy intensive than wood and leather products. Plastics use fossil fuels, although some subsectors in metals, particularly steel, may get by using charcoal or even with rubber tyres.

The more concentrated manufacturing production is in cities, the more likely it is that fossil fuels will be used in industrial production. The reduced bulk and easier transportability of fossil fuels compared with most renewables will encourage industrial use. Firms can save on the expensive urban land required to store fuel by switching from wood or charcoal to coal or oil. Bulk transportation of coal and oil to large urban markets can reduce transport costs on those fuels.

Firms also find electricity cheaper (lower capital costs per consumer) and more reliable than in rural areas, making urban electricity use more attractive than rural electricity use. Fossil fuels and electricity offer the possibility of greater reliability in heating performance and are probably more reliably delivered than renewable substitutes.

Energy implications

The changes in industrial structure accompanying urbanization and economic development increase fuel consumption per worker and per unit of output, particularly of fossil fuels. There is a consensus that several industries are particularly energy intensive –

Table 6. Energy intensity in Philippine economic sectors, 1981.

Sector	kcal/peso of value added
1. Agriculture and livestock	95
2. Fishing	241
3. Forestry, logging and wood products	203
4. Food processing, beverages and tobacco	186
5. Textiles, garments and leather	223
6. Paper and publishing	594
7. Chemicals and rubber	328
9. Cement	5 724
10. Basic metals and metal products	1 431
11. Other non-metallic mineral products	1 044
12. Machinery, equipment and miscellaneous manufacturing	399
13. Construction	65
14. Trade, communications and storage[a]	136
15. Finance, insurance and real estate	26
16. Services[b]	176
17. Public busline transport	1 590
18. Other public passenger transport	1 132
19. Land freight transport	949
20. Water transport	2 252
21. Air transport	1 142
22. Electricity	8 623

[a] Includes communication, storage and warehousing, wholesale and retail trade.
[b] Includes water, services incidental to transport, government services, education, medical and health, hotels and restaurants, other private services.

Sources: Meta Systems Inc and Center for Research and Communication, *Philippine Petroleum Product Pricing Study*r, Cambridge, MA, USA, November 1984; Russell J. deLucia, *Energy Pricing for Development: Theory, Practice, and Policy Analysis*, report draft, deLucia and Associates, Cambridge, MA, USA, September 1986.

petroleum refining; stone, clay and glass (especially the cement, lime and brick, and structural tile subsectors); primary metals; chemicals; and paper and allied products. The changing importance of these industries as a proportion of the GNP and labour force as development proceeds can be forecast by reference to their progress in the presently developed countries as well as to information available from some developing countries.

Energy-use implications of these industrial composition changes may be derived from the projections of changes in the structure of production, but such projections contain imprecisions which make predictions for specific industries in specific countries problematic. First, indentical products can be made by different processes having different energy intensities. There are wide ranges of energy intensities within specific textile processes and paper products for the USA, and over twofold variation of fuel consumption per tonne of cement among Turkish Cement Corporation plants.[17]

Second, industrial aggregation can conceal considerable product variation, with consequent variations in energy intensity. In the USA, energy intensity varies two- to fivefold among four-digit SIC industries in stone, clay and glass products, primary metals and chemicals classifications, and there are two to tenfold ranges in energy intensity, because of product, process and practice differences, in energy-intensive industries across developing countries.[18]

Third, maintenance and operational procedures vary greatly across countries, particularly between developed and developing countries. Most energy input estimates are derived from developed country experiences or state-of-the-art engineering estimates, which rely on better maintenance than is practical in most developing countries. It is difficult, consequently, to offer precise projections of energy demands on the basis of industrial trend projections, but at worst the impression of increased industrial energy demands in the future is supported consistently.

Fourth, there is considerable learning by doing in industrial and commercial energy consumption. Over a 5–10 year period, a firm in a developing country, producing the same products with the same processes, would become more efficient. Accounting for this phenomenon on an aggregate basis for countries, with different sectors developing at different times, would be problematic.

Evidence from the Philippines

Table 6 offers more specific evidence on direct energy intensity in Philippine manufacturing. Shifting employment from agriculture to anything but construction and finance, insurance and real estate requires additional energy; for most industrial destinations, it will require at least twice as much energy on a *per unit value of output* basis.[19] If labour productivity in agriculture is half what it is elsewhere, shifting workers from agriculture to industry could quadruple *per worker* energy requirements for the people moving. However, if urban migrants initially swell the informal service sector for a number of years, the urbanization–industrialization association could be delayed, bringing a large stock adjustment type of energy consumption increase from industrialization several years after the migration occurs. A trend not shown in Table 6 is that subsequent shifts in the composition of an urbanized economy from manufacturing to modern services, which are becoming dominated by electrical equipment, could bring little or no relief to aggregate, national energy consumption.

Aggregate energy implications of urbanization

So far, the evidence on direct and indirect influences of urbanization on energy consumption has been particularistic and sheds little light on what the overall magnitude of the influence might be. To address this issue, the results of a regression analysis of energy consumption on urbanization and industrialization levels and per capita income for 1980 are reported.[20] Holding constant the level of industrialization and per capita income, the change in modern energy consumption/$ GDP is 0.48 and for total energy (including traditional fuels) is 0.35 with a 1% increase in urbanization:

$$\begin{aligned}\text{Modern energy} &= -7.54 + 1.10\ \text{GDP/capita} \\ &\quad\ (-10.17) \quad (6.84) \\ &\quad + 0.48\ \text{Urban} + 1.08\ \text{Industry} \\ &\quad\ (3.37) \quad + (5.37) \\ \text{Adjusted } R^2 &= 0.89,\ 57\ \text{observations.} \\ \text{Total energy} &= -1.70 + 0.77\ \text{GDP/capita} \\ &\quad\ (-1.95) \quad (4.05) \\ &\quad + 0.35\ \text{Urban} + 1.35\ \text{Industry} \\ &\quad\ (2.09) \quad + (1.45) \\ \text{Adjusted } R^2 &= 0.67,\ 57\ \text{observations.}\end{aligned}$$

The dependent variables are aggregate, secondary energy/$ GDP, with GDP converted to US$ with purchasing power parity corrections. The GDP/capita variable is also converted to US$ with the purchasing power parity correction. The variable 'Urban' is the percentage of the population living in cities as defined by the individual countries and 'Industry' is the percentage of GDP coming from industry. All are in natural logarithms, so the coefficients are interpretable as elasticities. The numbers in parentheses are *t*-statistics.

All the coefficients in the regression of modern energy are significant at the 99% level, but in the total energy regression, the coefficient of the urbanization variable is significant at 95% and the coefficient of the industrialization variable only at the 85% level. Other regressions using energy per capita and controlling for some product-specific fuel prices tell essentially the same story as these two regressions.[21] The first regression indicates an urbanization elasticity of 0.48 for modern energy, which drops to 0.35 for total energy in the second regression, reflecting the substitution of modern for traditional energy as urbanization proceeds.[22] Both per capita income and industrialization have larger elasticities than urbanization, but urbanization has a large, statistically measurable impact even when per capita income and industrialization are held constant.

Conclusion

Aggregate statistical evidence indicates that a 10% increase in the proportion of the population living in cities would increase modern energy consumption per capita by 4.5% or by 4.8%/$ GDP, holding constant per capita income and industrialization. At the risk of extrapolating marginal statistics to larger changes, consider the cases of China and India, with urbanization shares around 21% and 23% respectively in 1981. Doubling the extent of their urbanization, which is not inconceivable over a two-generation period, to 42% and 46% (not especially high even by developing country standards), then even if per capita income and industrialization remained unchanged, the per capita modern energy consumption of some 2 billion people (more by then) could increase by 45% from the urbanization alone. If this extrapolation is anywhere close to correct, urbanization is a source of energy consumption increase that warrants serious attention.

What sort of attention does the present analysis suggest? Specific policy recommendations are beyond the scope of the present study, but some policy observations can be offered. First, policy could have possibly the greatest impact in reducing energy-use in personal transportation, but indirect policies might be as useful as policies directly focused on urban transport systems. Locational incentives aimed at industrial and housing development would affect the locations of employment and labour forces, directly affecting journey-to-work energy-use and possibly mitigating energy losses associated with traffic congestion. Second, the household sector is a major, if dispersed, energy user even in cities. Opportunities may exist for energy conservation in households and in the service activities they patronize. The dispersion of these activities and the great diversity of practices used in different groups even within a single country increase the difficulty of developing viable policies to affect household energy-use, other than possibly an aggregate, or macro, policy such as pricing reform, which itself can be difficult and constrained in its effects by exigencies of household production conditions. A practical alternative for some countries would be to introduce an energy extension servce along the lines of an agricultural extension service. The USA introduced such a service in the 1970s as part of its agricultural extension programme, and it has worked with low-income urban and rural families. Heating and cooling energy conservation were the principal American targets, but improved cooking practices could also be targeted. Third, the construction industry could be a practical target for energy conservation efforts. Opportunities exist for architectural innovations using natural cooling in high-temperature climates and conserving energy through choice of materials and material processing technologies. Fourth, although energy planners often have little influence within well-established ministries dealing with agriculture and transportation, useful energy recommendations could be aimed at those sectors since urbanization increases their energy consumption. Fifth, policies to foster the relative growth of secondary cities might reduce energy consumption in both personal and industrial transportation, although this should be weighed against potential losses of scale economies in production. Finally, many of the policies that might restrain the growth of energy consumption imposed by urbanization would be components of broader development policies and would be directed by agencies other than energy ministries. As a practical matter, this observation suggests the importance of better coordination and relations among energy departments of developing country governments and donor agencies involved in development projects.

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[1]P. Temin, *Iron and Steel in Nineteenth-Century America: An Economic History*, MIT Press, Cambridge, MA, USA, 1964, p 85.

[2]E. Hirst, 'Food-related energy requirements', *Science*, Vol 184, 1974, p 135.

[3]The ratio of direct energy in agricultural production to embodied energy ranges from one-quarter to one-third for non-irrigated corn in the USA to two-thirds to three-quarters for irrigated corn, or average embodied energy roughly 2.5 times the direct. On average, the embodied-to-direct energy ratio probably is higher in Mexican agriculture than American, so the 1:1 assumption is conservative. See D. Pimentel, ed, *Handbook of Energy Utilization in Agriculture*, CRC Press, Boca Raton, FL, USA, 1980, pp 67–84.

[4]G. McGranahan and M. Taylor, *Urban Energy Use Patterns in Developing Countries: A Preliminary Study of Mexico City*, W. Averall Harriman College for Urban and Policy Science, State University of New York, Stony Brook, NY, USA, December 1977.

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Energy Use in Economic Development, ORNL-6432, Oak Ridge National Laboratory, Oak Ridge, TN, USA, 1989.

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[18]Oak Ridge Associated Universities, *op cit*, Ref 17, pp 13–6, 15–2, 16–2; M.Y. Meunier and O. de Bruyn Kops, *Energy Efficiency in the Steel Industry with Emphasis on Developing Countries*, World Bank Technical Paper, No 22, World Bank, Washington, DC, USA, 1984, p 31; M.H. Fog and K.L. Nadkarni, *Energy Efficiency and Fuel Substitution in the Cement Industry with Emphasis on Developing Countries*, World Bank Technical Paper, No 17, World Bank, Washington, DC, USA, 1983, p 15; J.R. Gamba, D.A. Caplin and J.J. Mulckhuyse, *Industrial Energy Rationalization in Developing Countries*, Johns Hopkins University Press, Baltimore, MD, USA, 1986, p 20.

[19]Data for 19 economic sectors in India, for 1978–79, show a similar pattern of energy intensity, with allowance for some differences in sectoral definitions; see S. Subba Rao, M. Raizada, S. Iyer and A. Ramanathan, 'Determination of energy costs and intensities of goods and services in the Indian economy: an input–output approach', in M. Chatterji, ed, *Energy and Environment in the Developing Countries*, Wiley, New York, USA, 1981, p 217.

[20]See Appendix for the countries in the sample and the data sources.

[21]See Jones, *op cit*, Ref 16, for details.

[22]Regressions of per capita energy consumption yielded urbanization elasticities of 0.45 for modern energy, 0.30 for total energy, and zero for traditional energy.

Appendix

Countries and data sources for regressions

Countries

1. Algeria
2. Argentina
3. Bangladesh
4. Benin
5. Bolivia
6. Brazil
7. Burundi
8. Cameroon
9. Chile
10. Colombia
11. Costa Rica
12. Dominican Republic
13. Ecuador
14. Egypt
15. El Salvador
16. Ethiopia
17. Gabon
18. Ghana
19. Haiti
20. Honduras
21. Hong Kong
22. India
23. Indonesia
24. Iran
25. Iraq
26. Ivory Coast
27. Jamaica
28. Kenya
29. Korea, South
30. Malawi
31. Malaysia
32. Mexico
33. Morocco
34. Nepal
35. Nicaragua
36. Nigeria
37. Pakistan
38. Panama
39. Papua New Guinea
40. Paraguay
41. Peru
42. Philippines
43. Rwanda
44. Senegal
45. Sierra Leone
46. Singapore
47. Sri Lanka
48. Sudan
49. Tanzania
50. Thailand
51. Trinidad
52. Tunisia
53. Turkey
54. Uganda
55. Uruguay
56. Venezuela
57. Zaire
58. Zambia
59. Zimbabwe

Sources

Modern sector energy consumption per capita and per $ of GDP: World Bank, *The Energy Transition in Developing Countries*, World Bank, Washington, DC, USA, 1983, Table 2, p 97.

Total energy consumption per capita and per $ of GDP, adjustment to modern energy data made with estimates of percentages of energy coming from traditional sources: United Nations, *Energy Balances 1977–1980 and Electricity Profiles 1976–1981 for Selected Developing Countries and Areas*, UN, New York, USA, 1983; Organization for Economic Cooperation and Development, *Energy Balances of Developing Countries, 1971/1982*, OECD, Paris, France, 1984; United Nations, Department of International Economic and Social Affairs, *1981 Yearbook of Energy Statistics*, New York, USA, 1983, Table 15, pp 282–299.

Percentage of population urban: World Bank, *World Development Report 1982*, Oxford University Press, New York, USA, 1982, Table 20, pp 148–149; United Nations, Department of International Economic and Social Affairs, *Patterns of Urban and Rural Population Growth*, New York, USA, 1980, Table 50, pp 159–162.

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Population density/unit of arable land: World Bank, *World Tables*, 3rd ed, Vol II: *Social Data*, Johns Hopkins University Press, Baltimore, MD, USA, 1983, Social Data Sheet 1.

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Fuel prices: World Bank, *The Energy Transition in Developing Countries*, World Bank, Washington, DC, USA, 1983, Table 11, p 108; Table 12, p 109.