WATER - ENERGY NEXUS: SUSTAINABLE URBANIZATION IN THE GREATER MEKONG SUBREGION

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Abstract

This paper assesses the current energy demanded by urban water in the Greater Mekong Subregion (GMS), predicts how large the future demands could be, and reviews technical options for resolving the urban water-energy nexus in the GMS. A simple model was constructed for the water and energy uses for the largest 10 cities in the GMS and for each of the national entities, with projections into the future. The model showed that despite the relatively low rates of total population growth in the region, urban populations are likely to rise by about 60% by 2030, but the large cities in the region will only experience a modest increase of about 30%. This implies that there will be big population increases in the smaller cities and towns in the region. The really surprising result is that in the face of a 60% increase in population there will be a doubling in the demands for urban water supply and management because of increasing development and the push toward attainment of the Millennium Development Goals. This implies for Viet Nam a use by 2030 of 91% of the total water used in 2005 just for urban municipal and industrial uses, and as low as 19% for Myanmar. For Viet Nam it may be difficult to meet the needs of agriculture and other water users if its urban needs grow so rapidly. Typically in the region, electricity capacity is increasing to meet demand but, this is not the case with water supply. There are some serious limits on water availability, hence the need to conserve water in this sector. This may be quite difficult given the pressures to expand the actual quantities of water supplied and broaden the coverage of the systems.

1. The Water and Energy Nexus

This paper attempts to put the roles of energy and water into the context of maintaining the viability of the cities in the Greater Mekong Subregion (GMS). Often the word "sustainability" is applied to studies of cities; however, there is nothing that is inherently self-sustaining in modern cities. The word "viability" best describes what can be achieved in the long run for what can be considered humanity's greatest creation: cities. Of course, there is a long list of desirable properties associated with the concept of sustainable cities. Overall, the concept of efficient resource use is fundamental. This is strongly related to urban metabolism and urban ecology. This paper takes a narrower look at the interconnection between urban water and sanitation and attempts to show how the viability, or sustainability, of the cities is likely affected by them.

Currently (2009), of the 20 cities in the world with more than 10 million people, 9 are in Asia, and based on United Nations projections (UNDESA, 2009) out of the 10 largest cities in the world by 2050 seven will be in Asia. Over the same period, the percentage of population that is urban will rise from 42% to 65%. These numbers are unprecedented, but just for one country, The People's Republic of China (PRC), the urban population is predicted to rise to one billion by 2030 (McKinsey, 2009). The UN report forecasts that by 2025 the following Asian cities will be megacities; Tokyo (37 million), Delhi (29), Mumbai (26), Dhaka (21), Kolkata (20), Shanghai (20), Karachi (19), Beijing (15), Manila (15), Osaka-Kobe (11), Shenzhen (11), Chongqing (11), Guangzhou, Guangdong (11), Jakarta (11), and Lahore (10); none of these are GMS cities.

Economic and population growth place an ever-greater demand on energy and finite water resources. Many countries in Asia already face major threats to their ability to provide their people with safe drinking water and food security. Water resources face additional demands with the considerable amounts of water required for energy production to support continuing economic growth. Climate change greatly complicates the water-energy insecurity of many countries. In addition, the demand for food is growing rapidly worldwide and in Asia, but particularly rapidly in East Asia where water and energy are also scarce. Water and energy supplies and limits are crucial to understanding the environmental and ecosystem aspects of sustainable urban development.

2. Why the Focus on the Greater Mekong Subregion?

The overall security of the entire globe is intimately bound up with the success of Asia. Most commentaries on global development view the current era as a period

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when economic and social development will shift from its Western domination to be replaced by the unique development approaches and priorities of Asia. However, many of the same commentators (Goklany, 2007; Cai and Rosegrant, 2010; and Brown, 2011) see serious limitations to the continued economic development of Asia because of population and resource limits, particularly on water and energy.

The GMS, consisting of Cambodia, the Guangxi Zhuang Autonomous Region and Yunnan Province of the People's Republic of China (PRC), the Lao People's Democratic Republic (Lao PDR), Myanmar, Thailand, and Viet Nam, has a current population (in 2010) of about 320 million, of which less than 25% are urban. Nevertheless, there are 4 very large cities: Hanoi (6.5 million), Ho Chi Minh City (5.7 million), Bangkok (5.7 million), and Yangon (4.5 million); and 6 other large cities, Kunming (3.2 million), Haiphong (1.8 million), Phnom Penh (1.3 million), Mandalay (1.3 million), Naypyidaw (0.9 million), and Danang (0.8 million), in the one-million population range. Despite the relatively low rates of total population increase in the GMS region (ADB and UNEP, 2004) in comparison with other low-income regions of the world, the rate of increase in urban populations will be much larger because of the already high population densities in the rural areas. The increasing population has no place to go but to the cities.

The prospects of water shortages in Asia, alone, would be a serious resource-allocation problem, but it will be confounded by climate change and its attendant effects on the hydrology of continents, regions, and nations. Water and energy issues have traditionally been researched as single issues, not as an integrated web of opportunities and limitations, particularly in urban regions. The uncertainties of climate change complicate the resource-management challenges. Studies need to go beyond traditional views of a stationary world in which not only is climate known, but also the future economic and social developments are viewed in similar narrow terms.

Becoming aware of these complex interactions, many countries have spent huge amounts of financial resources to improve their water security. Modern examples of such concerns include Israel's National Water Carrier, the Central Valley Project in California, the PRC's current work on the South-North Water Diversions, and India's attempts to interlink some river basins to bring water to water-scarce regions.

Less well known is the competition for water that exists between the demands for food and energy. For example in the PRC, 76% of the water withdrawn for industrial use was used in the generation of electricity; coal-powered generation is the number one consumer of water in the PRC's industrial sector. So as rapid economic growth leads to large increases in the demand for energy and increased food consumption, countries like the PRC and India find themselves in a serious bind; already their existing water resources are almost fully committed to agriculture and food production, leaving little available for meeting increasing urban and industrial demands. The case of the PRC is particularly severe and the Government is taking it very seriously, not only with massive water diversions (over $60 billion) but also by beginning to implement water-saving technologies in both the water sector and the energy sector.

According to Goklany (2007) and Brown (2011), access to water and energy will be the major constraints on moving toward a sustainable planet by 2050. The big consumer of water is agriculture and its ability to feed the global populations is in doubt without major improvement in water-use efficiency in agriculture. This paper focuses more on water access in urban areas and its energy implications than on the conflicts over water for agricultural uses. Many of the destination cities of rural-urban migrants, however, are already badly served, having unsafe drinking water and inadequate sanitation. Not only do the cities typically suffer inadequate supplies of potable water but also they will have to find rapidly expanding supplies for their future growth—not an easy task given the industrial and agricultural demands being placed on the same resource base.

Generally, the relationships among urban water and wastewater treatment and their impact on the amounts of energy and types of energy infrastructure needed to meet these growing demands are poorly understood. Urban water has high embedded energy content, using as much as 1.65 kilowatt-hours per cubic meter supplied (NRDC, 2004). Depending on the nature of the water supply options and the location of the resources, meeting the new water demands could increase the total urban energy demands by 10%–15% and electrical energy by as much as 30%. In the United States, for example, as much as one quarter to one half of the electricity used by cities is consumed at municipal water and wastewater treatment facilities. Unfortunately, many of the modern ways of increasing water availability, such as by recycling, greatly increase the embedded energy demanded. It is commonly accepted that 40% of the cost of desalination and water recovery using reverse osmosis is due to energy. This paper assesses the current energy demanded by urban water in the GMS, predicts how large the future demands could be, and reviews technical options for resolving the urban water-energy nexus in the GMS.

3. Energy Use for Water and Wastewater Management

The amounts and types of energy used in the provision of urban water supply and wastewater disposal depend to a large extent on the current water-use behavior of the populations and the nature of the technologies for supply and disposal. For low-income areas, the per capita water use could be as low as 50 liters per day (lpcd), with only 70% of the population being covered by the water systems and as low as 20% with access to sanitation systems. Working toward attaining the Millennium Development Goals (MDGs) could increase the coverage into the 90% range and increase the demand to 100 lpcd or above. Thus, even without any population increase, the total water demands placed on the GMS urban systems could increase greatly. Rapid population growth will greatly exacerbate the problem.

4. Future Urban Water-Based Demands for Energy

Water supply coverage in the GMS varies widely by country and province. Table 1 reports the most recent United Nations population forecasts (UNDESA, 2011) for the countries of the GMS split by total and urban populations. The table presents population forecasts to 2030 based on 2010 as the starting point. The table suggests that the urban population in the GMS could reach over 150 million. This is quite small in comparison with the PRC's one billion urban dwellers predicted for 2030 by McKinsey (2009); nevertheless, it represents an almost doubling of the urban population in GMS. This huge increase will severely stress the already weak urban infrastructure and could cause water shortages and sanitation breakdowns leading to major epidemics and possibly social unrest.

Kallidaikurichi and Rao (2010) review the data on the adequacy of drinking water in 23 Asian countries. They spent a great deal of effort on developing the best available database for the region, but were critical of the quality of available national and local data for serious policy analysis. Their book developed an index of drinking water adequacy, which could be used for ranking countries from the point of view of access to safe drinking water; they did not include the associated energy inputs. McIntosh (1993, 1997) assessed water management in 50 utilities in Asia for the Asian Development Bank (ADB). He was able to assemble better quality at a more detailed level than Kallidaikurichi and Rao (2010). His compilation of economic data reveals that the majority of the utilities were unable to cover their operational costs from tariffs alone.

In the most recent summary of progress toward meeting the MDG goals, UN-ESCAP (2010) reported on data from 2008 and projected these forward to the 2015 deadline. Thailand outperformed all of the other GMS countries in both water-supply coverage of the population (98%) and

Table 1: Total and Urban Populations, 2010–2030

Country	Urban Population Assuming % Urban for 2020 and 2030								
	2010 Population (million)			2020 Population (million)			2030 Population (million)		
	Total	Urban %	Urban Total	Total	Urban %	Urban Total	Total	Urban %	Urban Total
Cambodia	14.14	21.41	3.03	15.89	27	4.21	17.36	34	5.87
PRC									
Guangxi	47.19	24.01	11.33	53.17	28	14.64	59.90	32	18.91
Yunnan	44.83	24.00	10.76	50.51	28	13.91	56.91	32	17.97
Lao PDR	6.20	34.45	2.14	7.05	48	3.38	7.75	61	4.70
Myanmar	47.96	35.42	16.99	51.69	44	22.57	54.33	53	28.55
Thailand	69.12	33.48	23.14	72.09	39	27.81	73.32	46	33.62
Viet Nam	87.85	30.79	27.05	99.36	37	36.27	101.48	42	42.59
Total	**317.29**		**94.43**	**349.75**		**122.79**	**371.07**		**152.21**

Source: UNDESA (2011); Yunnan and Guangxi projected from ADB-UNEP (2004).

sanitation (96%). Viet Nam had improved its performance markedly for water supply (up to 94%) but still lagged in basic sanitation coverage (75%). Cambodia, Lao PDR, and Myanmar were improving rapidly in water-supply coverage, but still lagged on sanitation coverage. For Guangxi and Yunnan in the PRC, data in Seetharam and Rao (2010) were used for our projection model. Those economies appear to be progressing quite well toward attaining the 2015 MDGs.

5. Modeling the Future Urban Water-Energy Nexus

In order to assess the magnitudes of potential conflict among urban water use, urban energy use, and temporal development patterns, I constructed a simple simulation for the water and energy uses for the largest 10 cities in the GMS and for each of the national entities. As with Seetharam and Rao (2010), major data gaps were found. Obvious sources, such as AQUASTAT of the United Nations Food and Agriculture Organization (FAO), the World Bank's rapid assessment framework (ESMAP, 2010), ADB/UNEP (2004), the International Energy Agency's energy data (IEA, 2008), and the Pacific Institute's global water data (Gleick, 2009) were all utilized to assemble a workable database for initial estimations. The Southeast Asian Water Utilities Network's databases on energy use in water and wastewater utilities in Southeast Asia (SEAWUN, 2005, 2007) were very helpful sources. It should be understood, however, that the combination of data from different sources and slightly different dates can be misleading. Results are given in Table 2; projections of urban water and wastewater supply and treatment by country are made from a 2010 base year until 2020 and 2030. The table reflects the increasing population sizes based on ADB/UNEP (2004) forecasts, on estimates of current water consumption, and estimates of percentage coverage of the population by municipal water supply and sewerage. For future dates, I assumed that the countries are on a path toward meeting the MDGs in terms of coverage and increasing per capita use. Table 2 shows the joint effect of increasing urban populations, increasing coverage by water systems, and increasing per capita use. Over the 20-year interval there is a two-and-one-half times increase in the demand for water services! This should be a wake-up call for urban planners and governments in the GMS countries—recall from Table 1 that there is only a 60% increase of the urban populations over the same period.

Similar patterns are observed in Table 3, which considers the 10 largest cities in the GMS. The urban populations are projected by the United Nations only until 2025. This table shows a 50% increase in populations from 2010 to 2025, and a twofold increase in urban water used for water supply and sanitation. This implies that there will be large increases in urban growth outside these major cities.

One important question is what are the energy and total resource implications of the shifts in demands for water supply and wastewater treatment? Table 4 shows the implications of the demand increases on the water resource base itself and on the current electrical energy

Table 2: Urban Water Use, 2010−2030

Country	Water Use (million cubic meters per year)											
	2010 Urban water use				2020 Urban water use				2030 Urban water use			
	Total mcm	Water %	Waste %	lpcd	Total mcm	Water %	Waste %	lpcd	Total mcm	Water %	Waste %	lpcd
Cambodia	23.20	81	67	21	92.29	90	90	60	214.26	100	100	100
PRC												
Guangxi	1,004.91	96	99	243	1,325.03	100	100	248	1,725.72	100	100	250
Yunnan	471.29	97	99	120	939.14	100	100	185	1,639.76	100	100	250
Lao PDR	54.57	72	86	70	104.90	75	75	85	171.51	75	90	100
Myanmar	124.03	75	86	20	411.90	86	86	50	729.32	75	90	70
Thailand	1,022.07	99	95	121	1,623.99	100	100	160	2,454.55	100	100	200
Viet Nam	2,152.05	99	94	218	3,110.97	100	100	235	3,885.88	100	100	250
Total	**4,852.12**				**7,608.22**				**10,821.00**			

lpcd = liters per capita per day
mcm = million cubic meters
Source: For 2010, AQUASTAT FAO, 2005; coverage and per capita useage based on Millennium Development Goals.

Table 3: Populations and Water Demands of Big Cities, 2010−2025

Big Cities	Population (million)			Water use (mcm)		
	2010	2020	2025	2010	2020	2025
Bangkok[a, b, c]	6.98	7.90	8.47	308.10	461.48	618.31
Danang	0.84	1.15	1.29	66.68	98.30	117.80
Haiphong[d]	1.97	2.43	2.72	156.75	208.60	248.38
Hanoi[a, b]	6.50	7.62	8.43	517.21	653.61	769.24
Ho Chi Minh[a, d]	6.17	8.07	8.96	490.71	691.95	817.33
Kunming	3.12	3.69	3.92	136.48	249.23	357.24
Mandalay	1.03	1.33	1.48	7.55	24.29	37.92
Naypyidaw	1.02	1.33	1.50	7.48	24.35	38.30
Phnom Penh[a, c]	1.56	2.09	2.43	39.91	64.94	88.59
Yangon	4.35	5.46	6.02	31.76	99.57	153.86
Total	**33.54**	**41.07**	**45.22**	**1,762.63**	**2,576.32**	**3,246.97**

mcm = million cubic meters

Note: Hanoi 2020–2025, estimated by author.

a World Bank's Rapid Assessment list (ESMAP, 2010)
b Asian Green City Index list (Siemens, 2011)
c SEAWUN list (2005)
d SEAWUN lists (2005, 2007)

supply for each of the countries (there were no data available for Guangxi and Yunnan). The water supply and sanitation (WSS) water demanded in 2030 will range from 164% of total 2005 municipal and industrial water use for Cambodia to 19% for Myanmar. For the water-sector energy demands as percentages of 2008 electric supply, the 2030 results imply only 1.6% for Thailand and 11.6% for Cambodia (there were no available data for Lao PDR). These results imply that as countries like Cambodia, Lao PDR and Viet Nam become more economically developed, there will be increasing conflicts between agricultural and non-agricultural water use, but their urban electrical energy use behavior will become closer to that of the industrialized world.

This situation is seen much more clearly in Table 5, which predicts the electrical energy use for the urban water sectors in the 10 large cities in the GMS. The 2030 WSS as a percentage of the 2010 energy use for the cities as a whole takes on some alarming proportions—an average of 15%, with some cities (Mandalay, Phnom Penh, and Yangon), indicating that major attention will have to be given to improving the energy efficiency of the water sector.[2]

Table 4: Water and Energy in 2030 as a Percentage of Current Total Water and Energy Use

Country	Available Water km³	2005 M&I Water Use mcm	Urban % 2030/2005	Available Electricity gwh	2030 Elec WSS gwh	% of 2008 Electricity Supply
Cambodia	476	130	164.81	1,835	214.26	11.68
Lao PDR	334	300	57.17	N.A.	171.51	N.A.
Myanmar	1,046	3,820	19.09	6,672	729.32	10.93
Thailand	410	5,500	44.63	149,032	2,454.55	1.65
Viet Nam	891	4,270	91.00	76,269	3,885.88	5.09

gwh = gigawatt hour
km^3 = cubic kilometer
M&I = municipal and industrial
mcm = million cubic meters
N.A. = not available
WSS = water supply and sanitation

Note: no data available for Guangxi and Yunnan.

Uses average energy usage of 1.0 kwh/cubic meter for entire water/waste cycle.

Source: FAO, 2010; International Energy Agency (IEA) statistics, 2011.

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[2] *Basis for calculating energy intensity.* For estimating the energy intensity of water and wastewater, the following reports were used; for the sake of simplicity a figure of 1.0 kwhe/cubic meter for combined water and waste supply and treatment was used. Cheng (2011) calculates the electrical energy requirement for providing 35 mgd of 0.22 kwhe/cubic meter for water supply alone; the World Bank's Rapid Assessment Framework (ESMAP, 2010) gives a range of 0.1–0.59 kwhe/cubic meter for potable water and 0.21–0.59 kwhe/cubic meter for wastewater; NRDC (2004) reports 0.77 kwhe/cubic meter for potable and waste treatment, and distribution; and the New York State Energy and Research Development Authority (2008) reports a national average of 0.36 kwhe/cubic meter for potable water supply, 1.25 kwhe/cubic meter for secondary treatment, and 1.78 kwhe/cubic meter for tertiary.

Table 5: Energy Use for Water and Wastewater in Major GMS Cities, 2010–2025

Big Cities	Annual Energy Use for Water and Wastewater Together							
	kwh/capita/year	2010 gwh	2010 WSS	2010 %	2020 WSS	2020 %	2025 WSS	2025 %
Bangkok[a, b, c]	2157	12,294.90	308.10	2.51	461.48	3.75	618.31	5.03
Danang	728	610.06	66.68	10.93	98.30	16.11	117.80	19.31
Haiphong[d]	728	1,310.40	156.75	11.96	208.60	15.92	248.38	18.95
Hanoi[a, b]	1000	6,500.00	517.21	7.96	653.61	10.06	769.24	11.83
Ho Chi Minh[a, d]	728	4,171.44	490.71	11.76	691.95	16.59	817.33	19.59
Kunming	2000	6,400.00	136.48	2.13	249.23	3.89	357.24	5.58
Mandalay	100	125.00	7.55	6.04	24.29	19.43	37.92	30.33
Naypyidaw	200	186.00	7.48	4.02	24.35	13.09	38.30	20.59
Phnom Penh[a, c]	93	123.69	39.91	32.27	64.94	52.50	88.59	71.62
Yangon	100	453.00	31.76	7.01	99.57	21.98	153.86	33.97
Total		**32,174.49**	**1,762.63**		**2,576.32**		**3,246.97**	

kwh = kilowatt hour
gwh = gigawatt hour
WWS = water supply and sanitation

Note: Hanoi 2020–2025 estimated by author. Assume Danang same per capita as Ho Chi Minh.

a World Bank's Rapid Assessment list (ESMAP, 2010)
b Asian Green City Index list (Siemens, 2011)
c SEAWUN (2005)
d SEAWUN lists (2005, 2007)

6. Improving the Efficiency of Urban Water and Energy: Sustainable Cities

When dealing with the approaches to solving the problems of sustainable water resources for urban areas, the type of problem addressed and the scale of the potential solutions must be defined clearly. There is a large and growing literature and databases on sustainable cities. Much of the literature (Hao *et al.*, 2010), however, focuses on smart buildings rather than entire cities. Moreover, the discussion tends to focus on new buildings rather than retrofit of the existing building stock of old traditional infrastructure. The literature also bifurcates into those specializing in actual here-and-now cases and those promoting future potential developments.

Unfortunately, many of cases reported are still largely hypothetical. Hard data on actual cases are difficult to find. For example, hypothetical cases like Qingdao and Dongtan, near Shanghai, are widely discussed (Hao et al., 2010) and promoted because of their widespread integrated energy-water-transport systems approaches, but cases like The Solaire in Battery Park City, New York, or Dockside Green in Victoria, Canada, which have successfully integrated buildings, or multiple buildings with new construction and the rehabilitation of existing cities, receive little attention. While future-oriented studies are helpful in structuring future possibilities, performance data from actual experiences are more useful guidelines as to what is realistically possible.

The examples of Solaire and Qingdao are illustrative of the wide discrepancy between the empirically based data and the hypothetical data used in future-oriented studies. The Solaire has consistently achieved a 48% water-consumption reduction in comparison with comparable residential buildings in New York City and a 56% reduction in wastewater discharge. This water and wastewater reduction is achieved by a combination of wastewater reuse and water conservation where nonpotable water is distributed in closed-loop systems for uses that include toilet flushing, cooling tower make-up, laundry, and irrigation. Each building in The Solaire development is unique and the exact components vary somewhat, but the overall program of wastewater and rainwater reuse remains the same. The Qingdao Eco-city is repeatedly quoted as an excellent approach to making cities more sustainable with 85% water savings and 100% energy savings. Unfortunately, like most of the future-oriented cases, the basis for the calculations is often optimistic or unrealistic. Wherever possible, I recommend that actual performance of integrated water and waste-recycling data be used instead of the hypothetical data.

Hao *et al.* (2010) provide a critical review of city-scale developments aimed at improving the actual water and energy nexus. Hammarby Sjöstad (Sweden) actually has been developed; Dongtan, planned near Shanghai (PRC), is apparently one of the first comprehensive conceptual eco-city developments. The final population was planned to be 500,000 around 2050. However, its construction is currently on hold. For Qingdao (PRC), eco-blocks are the foundational units in Fraker's (2008) concept of the eco-city. A super block is a typical high-rise residential development in the PRC, usually 100–200 ha with 2,000–10,000 residential units housing 6,000–30,000 people. The PRC is now building 10–15 super blocks per day. Two well-funded projects underway are in Tianjin (PRC) with $9.7 billion invested and Masdar (United Arab Emirates), with an expected funding of $22 billion. Two projects already developed in the United States are Treasure Island and Sonoma Mountain Village, both in California.

Table 6, from Hao *et al.* (2010), pulls together some of the salient facts about water and energy conservation in these projects. Note the huge differences between the water savings claimed for the three projects actually developed (Hammarby, Treasure Island, and Sonoma Valley) and those in planning stages. The energy savings reported for the developed projects are remarkably close to those predicted for the remaining projects, implying that energy conservation is inherently easier to accomplish than water conservation at the household and project level. Table 6 also shows the very large range of costs per unit. Fraker (2008) claims that the sustainability initiatives embedded in Qingdao would increase the capital costs by 5%–10% but the value of annual operation and maintenance savings would give payback within 10 years.

7. Conclusions

The simple models used in this paper show some unexpected results. First despite the relatively low rates of total population growth in the region, urban populations are likely to increase substantially by 2030, but the large cities in the region will experience a modest increase of about 30%. This implies that there will be big population increases in the smaller cities and towns in the region. The really surprising result is that in the face of this population increase there will be an almost tripling increase in the demands for urban water supply and management because of increasing development and the push toward attainment of the MDGs. This implies for Viet Nam a doubling of available water just for urban (M&I) uses, and as low as a 20% increase for Myanmar. For Viet Nam it may be difficult to meet the needs of agriculture and other water users if it needs so much for urban uses. Based on the electricity available in 2008, the 2030 electricity demands just for urban water supply and wastewater could amount to as much as 12% for Cambodia and 5% for Viet Nam.

For the current large cities in GMS, the electricity demands for the urban water sector could be a much as 71% of the 2010 electricity supplied for Phnom Penh, and as low as 5% for Bangkok. Of course, each city and country

Table 6: Water and Energy Performance in Eco-cities

City	Population Total	Population Density #/ha	Water Use lpcd	% Water Reclamation & Recycle	Water System[a]	% Energy Savings	Green Area m^2/person	Cost $/unit[b]
Hammarby Sjöstad	30,000	133	100	0	Linear	50	40	200,000
Dongtan	500,000 (80,000)[c]	160	200	43	Linear centralized	100	100	~40,000
Qingdao	1500[d]	430	160	85	Closed loop	100	~15	?
Tianjin	350,000 (50,000)[c]	117	160	60	Partially closed	15	15	60,000–70,000
Masdar	50,000	135	160	80	Closed loop	100	<10	1 million
Treasure Island	13,500	75 total area 150 built	264	25	Mostly linear	60	75	550,000
Sonoma Valley	5,000	62	185	22	Linear centralized	100	20	525,000

a Linear system is a once-through flow system from which a portion of used water may be reclaimed and used for another use (e.g., drinking water for irrigation); closed system returns highly treated reclaimed water back for reuse

b Based on average 2.5 members per household

c Phase I

d Qingdao eco-block

Source: Hao *et al.* (2010, Table 2.8).

is currently embarked on extensive expansion of their electricity supply capacity, such that electricity capacity will grow along with the demands. Unfortunately, this is not the case with water supply. There are some serious limits on water availability, hence the need to conserve water in this sector. This may be quite difficult given the pressures to expand the actual quantities of water supplied and broaden the coverage of the systems.

The analysis presented in this paper has two major problems. First and foremost is the absence of reliable data on urban water and electricity use. Equally important is that the model does not really reflect the economic behavior of the consumers who ultimately drive the systems. Nevertheless, this simple model does provide some confidence that there can be a sustainable urban future in the GMS without resort to the fancy integrated water and energy solution promoted in Hao et al. (2010), provided that careful attention be paid to the water management in the cities. One major concern, however, is the potential reduction in water available for agriculture in all the countries in the GMS region; this needs careful study.

For the sake of comparison, consider that London, which was the 30th largest city in 2010 with 8.6 million, did not make it onto the United Nations list of top 30 by 2025. In 2002, London was the subject of a comprehensive study on its resources flow and urban footprint (Chartered Institution of Wastes Management, 2002). For the year 2000 with a population of 7.4 million, Londoners consumed 154,400 gigawatt hours (gwh) of energy (including 85,494 gwh as actual electricity use), 49 million tons of materials (of which 27.8 million tons were used in the construction sector), generated 27.8 million tons of waste, and consumed 6.9 million tons of food, and 876 million cubic meters of water. This was translated by the study into an ecological footprint of 49 million global hectares[3] (the equivalent size of Spain) comprised of 44% for materials and waste, 41% for food, 10% for energy, and only 0.3% for water.

It is apparent that the study did not consider the almost 800 million cubic meters of wastewater as 800 million tons of "waste." Had it done so, water may have been a larger contributor to the ecological footprint. Nevertheless, the contribution of food was extremely important. In the context of the GMS, the food component would be directly related to land and water use in the urban hinterland of the cities. The inclusion of food in this paper would have certainly highlighted the conflicts for land, water, and energy, which would overwhelm the narrow view taken in this paper.

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[3] The global hectare is a measure of bio-capacity.

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