Integrating Carbon Management into the Development Strategies of Urbanizing Regions in Asia

Implications of Urban Function, Form, and Role

Louis LEBEL, Po GARDEN, Ma. Regina N. BANATICLA, Rodel D. LASCO, Antonio CONTRERAS, A. P. MITRA, Chhemendra SHARMA, Hoang Tri NGUYEN, Giok Ling OOI, and Agus SARI

Keywords

carbon emissions
climate change
co-benefits
global warming
industrial ecology
sustainable cities

e-supplement available on the *JIE* Web site

Address correspondence to:
Louis Lebel
Unit for Social and Environmental Research
Chiang Mai University
Chiang Mai 50200
Thailand
<louis@sea-user.org>
<www.sea-user.org>

Volume 11, Number 2

Summary

The way urbanization unfolds over the next few decades in the developing countries of Asia will have profound implications for sustainability. One of the more important opportunities is to guide urbanization along pathways that begin to uncouple these gains in well-being from rising levels of energy use. Increasing energy use for transport, construction, climate control in houses and offices, and industrial processes is often accompanied by increasing levels of atmospheric emissions that impact human health, ecosystem functions, and the climate system. Agriculture, forestry, and animal husbandry alter carbon stocks and fluxes as carbon dioxide, methane, and black carbon. In this article we explore how carbon management could be integrated into the development strategies of cities and urbanizing regions. In particular, we explore how changes in urban form, functions, and roles might alter the timing, aggregation, spatial distribution, and composition of carbon emissions. Our emphasis is on identifying system linkages and points of leverage. The study draws primarily on emission inventories and regional development histories carried out in the regions around the cities of Manila, Jakarta, Ho Chi Minh City, New Delhi, and Chiang Mai. We find that how urban functions, such as mobility, shelter, and food, are provided has major implications for carbon emissions, and that each function is influenced by urban form and role in distinct ways. Our case studies highlight the need for major "U-turns" in urban policy.

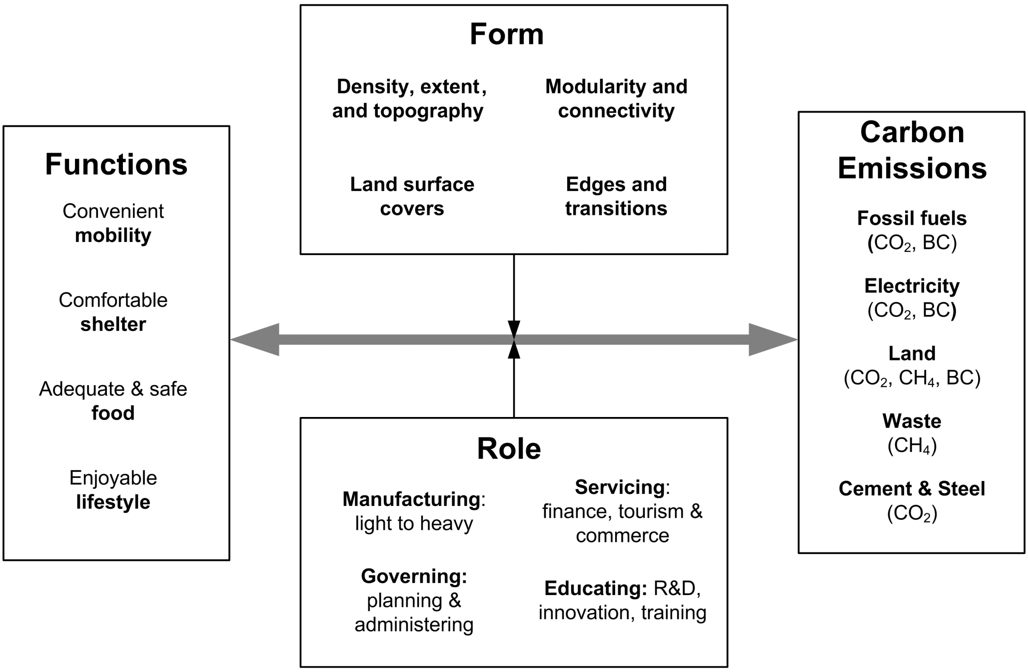

Figure 1 The core functions cities and urbanizing regions provide to residents and visitors are mobility, shelter, food, and lifestyle. How these are provided has a major bearing on emissions and can be modified by urban form and roles. BC = black carbon.

Introduction

Not so long ago, most people in the cities and towns of newly industrializing nations of Asia walked or cycled to work, the market, and school. Compact patterns of settlement with mixed land uses and basic services meant that public transport systems were hardly in demand. Modest incomes meant that few could afford cars even if they wanted them. Most households maintained roots in rural areas, where the vast majority still resided. Towns were centers of commerce in an economy built around agriculture.

The expansion of manufacturing industries urbanized landscapes almost overnight. First, national development policies focused on import-substitution started attracting more and more farmers to the capitals to work, first in the agricultural off-seasons, and then all year round. Urbanizing regions became the place to make a living, but not necessarily a place to which one belonged. With time, urban locations provided people with the services they wanted and needed, much more effectively than comparable rural locations. Second, policies began to shift to encourage foreign direct investment and stimulate trade. Industries and their workers were pushed out of the expanding commercial, retail, and service centers and regathered into industrial estates and special export and investment zones at the urban-rural periphery, drawing further surplus rural labor into manufacturing.

Rapid economic growth fuelled and was made possible by urbanization (Douglass 2000). Urban forms, functions, and roles (figure 1), however, were repeatedly transformed by the interaction of local needs, aspirations, and authority with the demands of competitiveness in the broader regional economy. The speed and complexity of changes, including many impressive gains in health, welfare, and education, also produced multiple environmental and social challenges in urban areas (Marcotullio 2003; Imura et al. 2005; Bai 2003). Social equity often remains low despite expansion of democratic institutions. The poorest continue to be exposed to unacceptably high levels of atmospheric pollution and are ignored in urban planning (Tiwari 2003; Carpenter et al. 2004; Shatkin 2004). The larger cities of Asia dominate lists of the most polluted (Molina and Molina 2004), and direct and deemed (embodied or otherwise attributable) per capita CO_2 emissions continue to grow, but along different trajectories, even in the cleaner megacities (Dhakal 2004). At the same time, the openness of national economies to trade and foreign investment has also created many opportunities for firms to obtain cleaner technologies and upgrade worker skills (e.g., Angel and Rock 2000; Rock and Angel 2005).

Interactions between urban function, form, and role as urbanization unfolds help drive, but may also be constrained by, the associated carbon emissions (figure 1). Fossil fuel and biomass burning produce black carbon, a major component of particulate matter, which affects human health (Ezzati et al. 2004; Han and Naeher 2006) and which also is an aerosol that impacts radiative balances at the regional level (Lelieveld et al. 2000). At the global level, greenhouse gas emissions, especially of carbon dioxide (CO_2) and methane (CH_4), are disrupting the climate system (Field and Raupach 2004; Socolow et al. 1994). Carbon is a key element in atmospheric pollution at multiple levels.

The goal of this article is to explore how carbon management—a carbon's eye view of development—could be integrated into development strategies of cities and urbanizing regions (Global Carbon Project 2003; Lebel 2005). Our emphasis is on identifying points of leverage and opportunities for decoupling growth in carbon-related emissions from improvements in well-being that go well beyond adoption of individual technologies or sector-based regulations. To this end, we explore how changes in urban functions, sometimes moderated by urban form and roles (see figure 1), might alter the amount, timing, and spatial composition of carbon stocks and flows.

Decarbonization—use of less carbon-intensive and even carbon-free energy as major sources of energy—has been a longstanding theme in industrial ecology (Nakicenovic 1997). Much of this research has focused on the role of changes in materials use as a lever for its accomplishment (Gielen 1998; Hekkert et al. 2001). Municipal environmental management and urban metabolism have also been important themes in industrial ecology (Björklund et al. 1999; Burström and Korhonen 2001; Carlsson-Kanyama et al. 2005).[1] This article weaves together these themes with illustrations from urbanizing regions in Asia.

Five Urbanizing Regions

In this article we report on a set of case studies in five developing country cities at roughly similar levels of economic development, where the authors had good understanding of both emission inventories and the social and political contexts under which air quality and emission problems associated with urbanization were unfolding (table 1). Jakarta, Manila, and Delhi are large capital cities with serious pollution problems. Chiang Mai and Ho Chi Minh City are regional centers. Jakarta, Manila, and Ho Chi Minh City have wet tropical climates. Chiang Mai, being inland and further north, has strongly seasonal rainfall and modest temperature variations. Delhi is also seasonal but even drier.

In defining the boundaries of our case studies, we chose to go beyond conventional municipal boundaries, so that our prospective and policy analyses could consider surrounding areas that are not yet, but could soon be, urbanized. For this study, carbon stocks and fluxes include carbon dioxide (CO_2) and methane (CH_4), the two most important greenhouse gases, and black carbon, an aerosol that impacts radiative balances and is also important to public health as a component of airborne particulate matter. We characterized changes in carbon stocks and fluxes for at least 1980, 1990, and 2000 using Intergovernmental Panel on Climate Change (IPCC) standard methods for inventory of energy-related emissions and removals by sectors (Houghton et al. 1997). Much of the effort was expended in disaggregating statistics to fit the urbanizing regions selected. In general, much more previously synthesized information was available for the three larger cities than for either Chiang Mai or Ho Chi Minh City. Details of some of the inventories are presented elsewhere (Ajero 2003; Lebel et al. 2004; Mitra and Sharma 2002).

Table 1 Basic geographical characteristics of the case study regions in 2000

City region—definition of urbanizing region around focal city	*Study region (urban area) km²*	*Regional population millions*	*Average income U.S.$*
Jakarta—JABOTABEK or Jakarta, Bogor, Tangerang, Bekasia, Depok	4,000 (1,730)	20.9	7,300
New Delhi—National Capital Region Territory	1,500 (750)	13.0	2,900
Metro Manila—Metro Manila + Laguna Lake Basin	3,800 (636)	9.9	8,500
Ho Chi Minh City—Ho Chi Minh City	3,000 (1,000)	5.2	4,695
Chiang Mai—Chiang Mai + Lamphun provincial capital districts and eight neighboring districts	2,900 (180)	0.9	3,400

Note: One square kilometer (km^2, SI) = 100 hectares (ha) ≈ 0.386 square miles ≈ 247 acres.

Two illustrations of changes in overall carbon emissions budgets are given in figure 2. Despite large differences in population size, emissions per capita were similar across all five cities. Patterns over time for different components, however, differed. Electricity consumption in Chiang Mai, for example, has grown relatively fast compared to transport emissions, in comparison to the estimates for Manila (figure 2). Agriculture, although declining in both regions, remains relatively more important to the carbon budget of Chiang Mai than to that of Manila.

We organize the rest of this article around the four urban functions in figure 1. Observations about the significance of urban forms and roles are woven throughout these discussions, where appropriate.

Mobility

Mobility of people and goods within and between cities is important to quality of life and economic gain. How urbanizing regions and cities service the changing mobility demands of their populations has direct and indirect implications for carbon in several sectors.

Modes

For those able to afford it, personal mobility is increasingly met through private vehicles. Vehicle registrations in New Delhi, for example, increased at an annual growth rate of 6.7% between 1991 and 2001, almost doubling in a decade (Mitra and Sharma 2005). In Chiang Mai the numbers of registered passenger cars and motorcycles increased 20-fold between 1970 and 2000, during which time population only doubled. The number of pickups, minivans, and trucks increased more than 40 times (Lebel et al. 2004). In these regions, pickups have had a transformative role in urbanizing regions, opening possibilities for small market entrepreneurs and farmers to bring goods to and from markets.

The implication of massive increases in private vehicle ownership has been a huge increase in consumption of diesel and petroleum in the transport sector. CO_2 emissions from diesel consumption in Delhi, for example, rose fourfold from 1,835 gigagrams (Gg)[2] to 7,225 Gg between 1980 and 2000 (Mitra and Sharma 2005). Emissions in the transport sector in Manila tripled over the same period, contributing 42% of total carbon emissions in 1980, but rising to 52% in 1990 before declining slightly to 51% in 2000 (Lasco et al. 2005).

Cross-country comparisons indicate that car ownership increases strongly with rising income level in Asia, but for motorcycles the pattern is much weaker, with both higher and lower use possible at a wide range of income levels (Nagai et al. 2003). Despite health and accident risks, motorcycles are widely perceived as contributing significantly to lifestyles and livelihoods. In 2000,

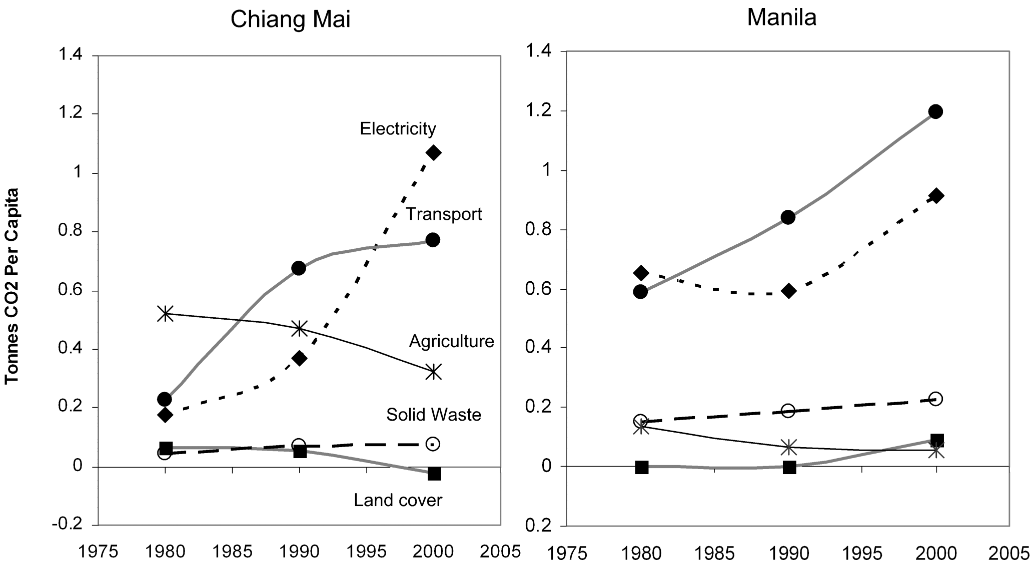

Figure 2 Changes in per capita carbon emissions for two urbanizing regions.

the number of motorcycles per thousand in Chiang Mai was 342, up from 55 in 1980 (Lebel et al. 2004). In Ho Chi Minh City there were 348 motorcycles per thousand population in 2000 (Nagai et al. 2003). Nevertheless, in a study of 84 global cities (Lyons et al. 2003), Ho Chi Minh City ranked lowest in terms of per capita passenger transport emissions of CO_2. Motorcycle ownership in Manila and New Delhi is, relative to per capita income, substantially lower than in the three other cities.

All cities have problems with high level of emissions and consequently episodes of above-standard ambient $PM_{2.5}$ and PM_{10} concentrations (particulate matter less than 2.5 and 10 microns in size, respectively). In Delhi, black carbon emissions from diesel vehicles are compounded by large but falling emissions from coal-fired power generation plants (Mitra and Sharma 2005). Ambient $PM_{2.5}$ levels in Manila are well above the U.S. Environmental Protection Agency annual standard of 15 micrograms per cubic meter(μg/m^3), with 45% being organic matter and 28% elemental carbon (reviewed by Han and Naeher 2006). In Ho Chi Minh City, cement and steel industries are major sources.

One of the key challenges for urban policy in all five cities is to cater to increasing average incomes against a backdrop of persistent and significant levels of poverty. Nonmotorized transport, including cycling and walking, remains an important option for those who cannot afford more convenient and safer ways to move. In Delhi, as much as 64% of trips by the low-income population are nonmotorized, whereas another third are by bus (Tiwari 2003).

All five cities talk about the need for improvement of public transport and the possible contribution that mass transit technologies (buses, trains) can make to multimodal mobility systems. Today's public transport has evolved from combinations of largely private nonmotorized and share-taxi transport into more bus-oriented systems that remain street-bound. In Manila, 70% of trips are on public transport, but still 39% are on diesel "jeepneys" (modified Jeeps) (Hayashi et al. 2004). In Chiang Mai, up until the end of 2005, there had been no inner city bus system for more than a decade; the public transport is still largely based on "songtaews" (modified pickups), three-wheeler motor scooters, minivans, and motorcycles. Licensing and ownership are complex, with many forms of state–private combinations.

In the larger and higher density cities, rail-based mass transit systems are most plausible. In Metro-Manila, support from the World Bank has helped shift urban commuters toward an expanding public rail system, which currently only provides 2.3% of trips. A mass rapid transport system is also being developed for New Delhi that, together with a high-capacity bus system and light rail, should help reduce dependency on roads for daily work-related trips.

In Jakarta, the nongovernmental organization PELANGI and the Swiss Foundation for Technical Cooperation have facilitated the inclusion of air quality and transport issues in public policy agendas. This eventually led to the successful introduction, for example, of dedicated bus lanes. Mass transit systems based on dedicated bus lines are much cheaper than elevated rail or subway systems.

The difficulties with introducing and financing mass public transit systems are a reflection of the political economy of transport and land development, which remains dominated by interests aligned with the automobile industry, transport authorities with mandates to build roads, and insider speculation on real estate pending public infrastructure investments (e.g., Ooi 2000).

Forms

The evolution of urban form in all five cities continues to reinforce the convenience of private vehicles. Sprawling urban growth, in which large areas of land are hard to access for either residential or agricultural use, makes personal vehicles essential. This is most apparent in the largest urbanizing regions, such as Jabotabek and Metro Manila, where major highways connecting what were separate cities become the focus of new ribbon development. As a result, for example, average trip lengths of Metro Manila residents have risen from 5.3 kilometers (km)[3] in 1980 to 6.4 km in 1996, whereas the average commuting times to work rose from 36 to 51 minutes (Lasco et al. 2005).

Road-based radial-centric development patterns dominate recent evolution of urban form in all five cities. In the radial or spiked urban form, moving from one place to another usually requires traveling the central business district, resulting in traffic congestion. For example, approximately 30% of people working in Jakarta actually live in the surrounds or "Bodetabek." Between 1985 and 1993, the number of commuters into Jakarta increased fourfold. Without corrective measures, the number of car-based trips is expected to rise to 56% in 2010 (Sari and Susantono 1999). In Manila, predictions are that the proportion of trips in private vehicles will rise from 21% in 1995 to as much as 34% in 2015 (MMUTIS 1999).

Even the smallest city we studied, Chiang Mai, now has a major set of concentric ring roads, in part because its old center is full of narrow and winding streets unsuitable for cars and trucks, and of such cultural significance and now tourism value that redeveloping it is not really an option. Even in rapidly expanding urban areas, urban form is a product of history. Major buildings, transport routes, and areas of employment, commerce, and cultural significance, such as temples, exert a long-term influence on where people choose to settle and where firms set up shop.

City authorities have struggled to anticipate needs for mobility, with the consequence that rapid motorization has overwhelmed inner-city roads with spectacular traffic congestion. Congestion leads to inefficient fuel use and local build-up of PM_{10} and other pollutants. Although it is true that per capita road surface area in most Asian cities is well behind Europe and U.S. cities (Sari and Susantono 1999), road lengths per unit area are actually higher on average, reflecting much higher urban densities overall and still reasonable road connectivity (Barter 2000). Moreover, car use across Asian cities is much lower than in comparable U.S. cities, even after adjustment for income (Lyons et al. 2003). Life cycle-assessment suggests that road construction, although initially important to emission inventories, declines over time relative to the emissions associated with the manufacture, use, and maintenance of vehicles (Treloar et al. 2004).

Overall, the impacts of transportation investments on land use are complex (Polzin 1999) but important to understand, because they may provide important levers for reducing harmful emissions. Forward planning can proactively shape the form of new urban areas with prelaid commuter rail and road-based public transport systems and renew old areas by adding stations with integrated service facilities. Proximity to freeway access points in Jakarta, for example, has predictably large impacts on office and retail rent

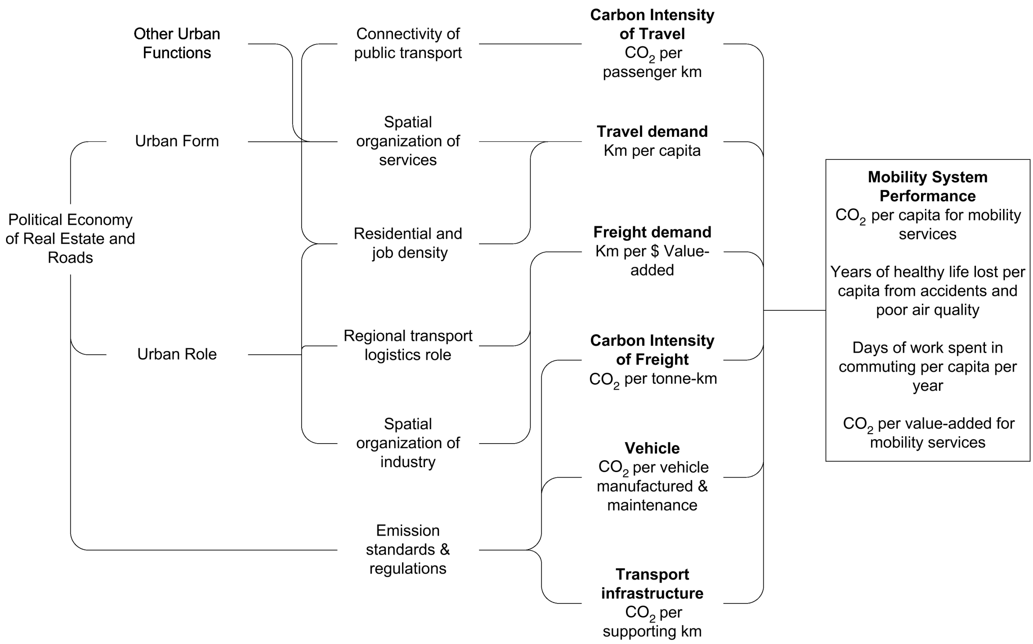

Figure 3 Factors influencing the carbon intensity of mobility systems.

premiums, which could be used, through property taxes, to help recover costs of providing infrastructure more broadly (Cervaro and Susantono 1999).

Freeways are not built only to service the residents and businesses of urban regions, but also to connect them to other places, for example, ports and other cities. Mobility systems may therefore also reflect a city's role relative to its region—in particular, the need to provide transport logistics. This aspect of mobility systems, however, has received little attention in the context of urban development and energy use.

Although we are not yet able to quantify all relationships in providing mobility functions from a carbon perspective, our explorations suggest that urban form helps shape some mobility service-emission relationships. The influence of urban roles, however, is smaller and more indirect, for example, through impacts on property prices and the places the poor are as a result forced to live. Figure 3 summarizes our working hypothesis for how urban form and role modify function-emission relationships. It includes several quantitative indicators, which could be the focus of further measurement and analysis.

Shelter

The way in which commercial and residential buildings are sited, built, and used influences the amount of electricity and other forms of energy consumed.

Designs

Architectural, social, and landscape fashion trends in Asian cities have often driven up rather than helped reduce energy consumption and carbon-related emissions. Urbanization has altered family structures by moving away from extended families sharing homes, and by giving incentives for smaller family sizes, for example, through providing higher education and full-time employment opportunities for women. Poor design is a common feature of many new suburban developments around the case study cities. This is reflected in the failure to incorporate energy design principles following replacement of traditional wood construction materials with concrete and glass, and the shift to closed rather than open structures, which require air conditioning. In 2002, for example, already 7.8% of households in Ho Chi Minh City had air conditioners.

Cement production directly releases CO_2 to the atmosphere, and energy for steel production used in construction is high. These latter emissions often take place outside the regions where material is used and constitute a major proportion of deemed emissions. In Delhi, growth in direct CO_2 emissions slowed in the late 1990s, whereas deemed emissions from steel and cement consumption continued to grow to reach over 50% of estimated direct emissions budgets.

Opportunities in architecture, through better insulation, use of trees to cool down buildings, and attention to cross breezes in traditional warm-location building designs, have generally not been taken up. Lighting is either poor or, through poor placement of windows, results in high needs for air conditioning. Solar water heaters and heat pumps are still relatively uncommon. On the other hand, there are several positive trends with respect to what people put in their houses, such as adoption of energy-efficient fluorescent lighting and refrigerators.

House ventilation, fuel type, and stove design matter in surprisingly large ways for emissions important to human health. Incomplete combustion of biomass fuels creates multiple health risks from indoor air pollution and makes a significant contribution to global budgets of CO_2, carbon monoxide (CO), and nitric oxide (NO) (Ludwig et al. 2003). The trend in all cities has been away from biomass, although there is still substantial use. Thus, in 2002, 39.5% of households in Ho Chi Minh City had electric or gas cookers (Tri et al. 2005).

India has a major shortage of houses. Tiwari (2003) argues that an appropriate energy tax could be used to encourage a switch to materials and building technologies that produce fewer emissions and at same time reduce costs and provide employment. The revenue could be used to subsidize houses for the poorest, who cannot even afford low-cost houses. Much could be learned from pre-electricity architecture for redesigning low-energy but comfortable houses.

Energy efficiency measures in design and operation of workplaces is a second area related to the provision of shelter arguments made above. Government and corporate buildings, because of their larger size and possibilities for standardization of procurement and operating practices, perhaps offer more potential gains than private residences, being more on par with, for example, condominiums and apartments. Improved spatial organization of industrial activities and climate control provisions, for example, may allow waste heat recapture. More sophisticated ecological linking of different firms could help reduce material and energy use through reuse and recycling of "wastes."

Overall, residential and commercial electricity consumption has also grown rapidly with wealth as people purchase, and use, more appliances to make their homes and workplaces more comfortable and convenient. In Chiang Mai, for example, electricity consumption across the study region expanded by an astounding 21% per year between 1990 and 2000 (Lebel et al. 2004). In 1980 electricity accounted for 17% to 18% of carbon emissions whereas by 2000 it had jumped to 46% to 53%, outstripping growth in the transport sector (Lebel et al. 2004). In a similar period, residential electricity consumption in Manila tripled, whereas commercial electricity consumption increased about one-and-one-half times. Industrial use of electricity in Manila, however, has declined since the mid-1990s.

Actual emissions from the consumption of electricity depend on how and where electricity is produced. Growth in electricity consumption is often not directly related to ambient air quality in urban areas, as emissions take place at energy production facilities located elsewhere. Depending on the quality of these facilities, emissions of sulfur dioxide (SO_2) and particulates may be in addition to high greenhouse gas emissions. The power generation mix of the five cities remains dominated by coal, oil, and natural gas. Luzon, the province in which Manila lies, for example, reduced reliance on imported oil: between 1990 and 2000, use of domestic coal jumped from 9% to 47%. Since then, several large natural gas plants have come on line, resulting in a 31% share of energy now being supplied from natural gas. For New Delhi, coal consumption in thermal power plants within the city has decreased and been replaced by natural gas or electricity purchased from the national grid. As a consequence, direct emissions of CO_2 from power generation fell from 4,810 Gg in 1995 to 4,570 Gg in 1999, whereas indirect emissions increased from 7,330 Gg in 1994 to 11,300 Gg in 1998 (Lebel et al. 2004).

The share of renewable energy in power generation mixes is already significant, but could be even larger. For Jakarta, which draws its power from a Java-Bali national grid, the contribution of hydro and other renewable energy sources such as geothermal in 1980 was 20% and despite growing in absolute terms by a factor of 5 had fallen to 15% of the total share by 2000 (Sari and Salim 2005). For Manila, which draws on the Luzon grid, the contribution of hydro and geothermal sources to the power generation mix has remained stable, 30% in 1980 and 32% in 2000 (Lasco et al. 2005).

Layouts

Trends toward fewer people per dwelling and larger house sizes in wealthier urbanizing areas make it difficult to reduce growth in aggregate electricity consumption. In Chiang Mai, Jakarta, and Manila, much of the rapid expansion in residential building since 1990 took place in gated housing estates with large block sizes and replicate houses, which, because they need more land, were placed in the periurban fringe. Urban planning, in other words, is led by property developers and banks. Uniform and poor architecture for climate are characteristic features of developments based on subdivision of former agricultural fields, often with single remote access to main corridor highways with private transport services, but no local markets or other services, reinforcing car dependence. Land speculation, made possible by the low cost of leaving land idle, has left intermediate land unused, increasing travel distances (Yarnasarn 1985; Pearson 1999).

It is worth underlining that the 1997–1998 Asian financial crisis was started and amplified by the collapse of a real estate bubble made possible by weakly regulated financial institutions. The impacts of that event are still imprinted on the periurban fringes of Chiang Mai, Manila, and Jakarta in partly abandoned housing projects. Realistic and scenario-informed perspectives on regional development and urbanization are important for planning and decision making in both private and public sectors. This includes planning for the unexpected: built environments need to be able to adapt to new social and ecological realities over time (Kay 2002).

An important issue in all cities studied is ensuring the provision of accessible low-cost housing as part of any efforts to improve air quality and reduce exposure in the most polluted locations and of overall carbon management. History suggests that the needs of disadvantaged groups are otherwise likely to be overlooked. Early successes in improving environmental health through the Kampung improvement programs in the city of Jakarta were not always sustained, and some slum areas ended up being converted to commercial business and retail uses and residents displaced (Werlin 1999). Other areas are leveled for freeways. Similar patterns were observed in Manila, where a larger global role led to planning that increasingly ignored needs of low-income earners, with the result that informal settlements expanded in absolute and relative terms (Shatkin 2004). Compactness improves social equity in some regards, for example, by improving access to public transport and other facilities, while being negative in others, for example, availability of lower-cost housing (Burton 2000).

The extent and distribution of vegetation in and around transport routes, including sidewalks and median strips, and in gardens may contribute to, if well designed, climate control, flood protection, air pollution removal, and aesthetics that impact well-being and health. The placement of buildings on a site with respect to shade, sun, and pollution sources also matters. Changes in urban forests and green spaces varied widely across cities.

Overall, green spaces in Jakarta have been contracting with the massive growth in built-up areas (Rustiadi et al. 2004). In contrast, in the New Delhi National Capital Territory there has been an increase in forest cover from around 15 square kilometers (km^2)[4] in 1987 to more than 170 km^2 in 2003 (Mitra and Sharma 2005). In Ho Chi Minh City, approximately 4% of land cover in urban areas is trees. Improved management of the 40,000 hectares of mangroves in the Can Gio Mangrove Biosphere reserve could be an important strategy for the city to conserve biodiversity, at the same time as benefiting from air pollution cleaning and climate control services

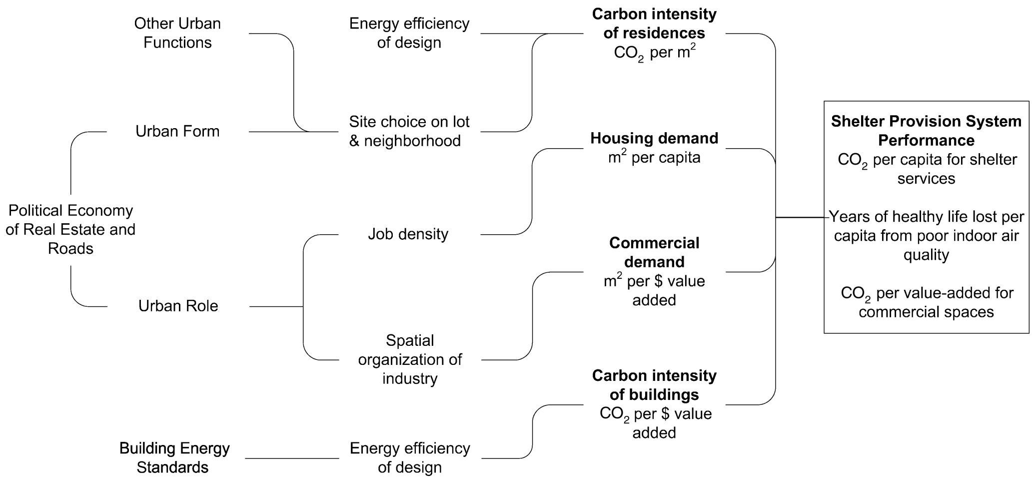

Figure 4 Factors influencing carbon intensity of the urban function to provide shelter.

that this major green space provides the city (Tri et al. 2005).

The contribution of carbon sequestration by green space and parks, however, is fairly limited relative to the magnitude of emissions from urban areas that contain them. Ono and colleagues (2002) estimated the net CO_2 sequestration from vegetation in Metro Manila at 29.4 Gg/yr, which is only 0.2% of annual emissions, estimated at 14,500 Gg/yr (Lasco et al. 2005).

Urban role has had some impact on urban layout. Capital and administrative centers have substantial areas of land administered by government authorities. These vast tracts are often poorly utilized, being largely inaccessible to the public as green spaces, but remaining largely vacant. Historical and cultural legacies, such as those reflecting Chiang Mai's role as a regional center for Buddhism scholarship, have shaped building codes, restricting building heights, and encouraged preservation of narrow streets in older parts of the city, which are also favored by tourists. At the other extreme, special zones to attract foreign direct investment in industrial estates attempt to bring form and role together.

The way shelter is provided affects carbon stocks and fluxes in several discrete ways, with deemed emissions being very significant. Shelter is dependent more on neighborhood-level urban form characteristics (Engel-Yan et al. 2005; Molle and Thippawal Srijantr 2001). The urban role is likely to have larger impacts on commercial buildings than residences. As for the mobility system, we provide a graphic summary of our current understanding of how urban form and role may influence the carbon intensity of shelter-providing functions in cities and newly urbanizing regions (figure 4). Not much up-to-date research has been done in these tropical locations on household energy expenditure, where, for example, use of air conditioning has grown very fast. Some possible indicators and relationships to explore further are suggested in figure 4.

Food

Food systems have reorganized in profound ways to support and help drive further urban-industrial transformation of societies. Diets change with urbanization and contribute to changes in land use inside and in supporting landscapes. The implications for carbon sequestration and emissions of intensified production practices, new consumption patterns, redistribution of rural workforce, and competition between urban and rural land and water use are complex.

Land

People in New Delhi and Chiang Mai are now drinking much more milk. People eat out more, store more food in refrigerators, and throw away more food. Consumption of meat is rising, with implications for landscape, as livestock and poultry ultimately feed on grains. Finally, urbanization can reduce rural population densities, with impacts on how rural land is managed. These various trends have mixed impacts on emissions.

Methane emissions from paddy rice are also large but variable, depending on management practices. In most regions, except Delhi, where very little rice is cultivated, these are declining relative to livestock and other sources as wetlands are converted to urban uses. Thus, for Laguna and Rizal provinces near Manila, the area of rainfed and irrigated rice fell almost 50% since 1980 (Lasco et al. 2005). Estimates of methane emissions have correspondingly changed over time and are expected to fall much further in the next two decades. Around Chiang Mai, methane emissions from paddy fields fell from a high of 410 Gg (CO_2 equivalents) in 1980 to 300 Gg by 2000. In 1980 they represented 50% of the total emissions budget, whereas in 2000 they were only 15% (Lasco et al. 2005).

Enteric fermentation by livestock produces methane. The indirect CH_4 emissions resulting from consumption of dairy products in Delhi have grown from an estimated 85 Gg (CO_2 equivalents) in 1996 to 102 Gg in 1999 (Mitra and Sharma 2005). This is an order of magnitude larger than the approximately 11 Gg produced in 1997 by livestock populations living within the Delhi area. Calculations for Rizal and Laguna provinces around Manila suggest that methane emissions from manure management are similar in magnitude to those from enteric fermentation and that total emissions from domestic livestock have varied, with no clear trend, between 160 and 250 Gg/yr between 1980 and 2004. Taken together, these findings underline the importance of methane to greenhouse gas emissions budgets in these regions (figure 2).

Agricultural land-use changes also reflect changes in livelihoods as rural households are drawn into urban employment opportunities. Land-use-related emissions calculated within urbanizing regions of once forested areas that have been cleared, however, will often decline as more and more of the emissions associated with consumption take place outside, in the ecological footprint of the city. Growth of emissions from other agricultural activities overall in the Laguna-Rizal region has fallen from 800 Gg in 1980 to between 470 and 570 annually from 1990 to 2004 (Lasco et al. 2005).

Where agriculture remains dominant, efforts are often being made to further intensify production systems for export. This invariably implies increased emissions from fossil-fuel energy used to power machinery and cultivation practices resulting in loss of soil organic matter or emitting methane, and indirectly through energy required to manufacture fertilizers.

Activities in the periurban fringe and rural hinterland can be a major source of particulates in urban areas. Thus, seasonally poor air quality in Chiang Mai (Vinitketkumnuen et al. 2002) is due largely to deliberately lit fires used in land preparation in upland fields or in the lowlands to remove crop residues or weed growth on land under speculation for development (Murdiyarso and Lebel 2006). The net impacts of urbanization on biomass burning have not been assessed. Air quality in Jakarta is also affected by biomass burning, especially in the dry phases of the El Niño Southern Oscillation (Murdiyarso et al. 2004).

Water

Most of the direct and easily identified relationships between food system performance and carbon emissions are related to land use for agriculture and forestry. An alternative perspective based on water, however, is also valuable because water management issues interact strongly with land use, being crucial to both agricultural intensification and the costs of flood protection for new urban areas (Lebel 2005).

Irrigated fields, for example, grown around the huge freshwater lake Laguna de Bay, adjacent to Metro Manila, produce around 2.3 kg CH_4/ha/day,[5] whereas rainfed fields at higher elevations produce about 0.4 (Lasco et al. 2005). It is envisaged that water conservation programs arising out of competition for water with urban and industrial users could lead to further reductions in methane emissions in rice-growing areas.

Around Chiang Mai, expansion of dry-season irrigated land in the 1980s, made possible by new irrigation infrastructure, was followed by contractions in areas planted over the 1990s, as a result of both building over of agricultural fields and insufficient dry-season water storage remaining once urban and industrial user allocations were made (Pearson 1999). The alterations of food regimes in both fields and riparian wetlands along the Ping River could conceivably have impacted methane emissions, but no relevant measurements have been made. Ribbon development disrupts irrigation systems and alters flood regimes, making agricultural uses of land more difficult, even if they are still "temporarily" available in the periurban margins. At the same time, abandoned agricultural land may still complement paddy fields in providing urban areas with flood protection services if it is able to flood during peak flows.

Residential, commercial, and agricultural wastes often make their way into waterways in the urbanizing regions we studied. Such pollution may impact the quality of water supplies for other users downstream (for example, those involved in aquaculture), increase health risks, and raise costs of pretreatment for domestic and commercial uses.

Lifestyle

Apart from the cars we drive, the houses we live in, and the way we eat, there are other aspects of lifestyle and culture to which people aspire and urbanization contributes. Impacts of these other aspects of lifestyle often result in emissions to produce goods and services as well as in their use and, in the case of "stuff," in their disposal.

Work

The mix of livelihood reflects the relationship of an urbanizing region to its wider context, that is, the urban role.

In Manila, Jakarta, and Delhi, for example, national export-oriented development strategies led to industrial estates and export processing zones being established in rural peripheries to take advantage of cheap surplus rural labor and lower land prices. In the case of Chiang Mai, this led to the creation of an industrial estate-town in the neighboring province of Lamphun. Industrial dispersion, whether induced by government policy or by sheer market forces, allowed the metropolitan core to retain its commercial nature, where trading in goods and services is the core economic activity. Shifts in the structure of the economy are reflected in emission inventories.

As a city takes on more commercial and service functions, industrial output may fall, resulting in relatively high deemed but fewer direct emissions, as evidenced by declines in industrial sector electricity use for Manila (Manasan and Mercado 1999; Secretario et al. 2002). Ho Chi Minh City, however, has yet to show much evidence of such a transition. Economically dominant, it produces 30% of the total industrial output of Vietnam, with much of that coming from small and medium-sized enterprises. This has produced a tremendous surge in jobs and wealth, but high levels of obsolete equipment and poor regulatory capacities have also meant rapidly deteriorating air quality. A key issue is whether to relocate or transform the many small industries (Frijns 2001).

Chiang Mai, as a major tourist destination, needs to consider emissions associated with providing services to 3.5 million visitors annually. With an average stay of just over 4 days, but much higher levels of energy use than the average resident, we expect that contributions to annual emissions budgets would be substantial. Air quality and convenient and safe mobility are important considerations of tourists and provide significant motivation to city planners and businesses interested in maintaining the city's competitiveness as a tourist destination. Consideration of emissions associated with air travel of course would be even larger, but are considered largely the responsibility of the "traveling" population.

Culture

People have benefited substantially from urban lifestyles. Literacy rates in Delhi in 1970 were 65%, compared to a national average of 34%. By 2000 the gap was closing but still large: 82% versus 65% (Mitra and Sharma 2005). In 1993, 15% of Delhi's population was below the poverty line, down from 26% one decade earlier, and much less than the nationwide rate of 36%. By 2000 the rate had fallen to 8.2% in Delhi. Likewise, Manila has the lowest incidence of poverty in the Philippines, with 11.5% below in 2002, and a high literacy rate of 95%.

The concentration of better schools and tertiary education in major cities is a significant reason for both rural-urban migration and long-distance commutes for those rural families with the skills and means. In Chiang Mai, Bangkok, and other cities in the region, city schools are points of major traffic congestion, exposing children to high $PM_{2.5}$ and PM_{10} levels. Possible carbon indicators for this urban lifestyle function would be CO_2 or cumulative $PM_{2.5}$ per average year of schooling attained.

In Asia, urban lifestyles leave their mark most clearly as waste. Across Asia, waste generation increases with per capita GDP (Imura et al. 2005). Increased consumption of take-away and prepared foods and material goods is often associated with increasing production of waste, again with implications for emissions from incineration or landfills. Solid waste management is a major issue for all five cities studied. Movement toward localized recycling, composting, and disposal is mixed. Emissions from open and controlled dumps or from incineration facilities can vary greatly. Methane emissions from waste generation in Manila were estimated to have risen from 885 to 2,220 Gg (CO_2 equivalents) between 1980 and 2000. Per capita waste generation over this same period has risen from 0.39 to 0.59 kg/day (Ajero 2003). For Delhi, estimated growth was from 460 to 680 Gg between 1990 and 2000.

Urban areas are the focus of marketing and markets. The more a city aspires to be "on the world map," the more its inhabitants are expected to adopt the lifestyle of the global consumer class (Lebel 2004b; Myers and Kent 2003; Lebel 2004a). They are helped by advertising agencies that go to any lengths to create and widen aspiration gaps. This is dramatically illustrated by the oversized advertising billboards that now line the "superhighway" ring road of Chiang Mai, blocking out Doi Suthep Mountain and its famed temple with scenes of mythical promises of happiness through oversized luxury pickups and beautiful families in white playing in manicured gardens with a backdrop of palatial homes. Television dramas in these cities tell the same stories of consumption and success and are filled with "product placement" opportunities.

Changes in lifestyles are a widely recognized and often the defining feature of urbanization in the cities we studied—a fact that has not passed unnoticed by marketing and advertising agencies. Key lifestyle components can vary hugely in energy and material implications. Urban form, however, appears to have few direct effects on service-emission relationships, except perhaps through quality or diversity of services available in local neighborhoods, which could lead to greater use of services elsewhere. Many impacts are through deemed emissions or the footprint of consumption activities on the rural hinterland or coastal seas.

U-Turns

In the preceding sections, we discussed some of the carbon implications of addressing the wants and needs of residents and visitors to urbanizing regions. Joint consideration of urban functions, form, and role (figure 1) provide a framework for exploring "U-turns" that could help decarbonize development (table 2).

In this concluding section we speculate on how a common urban development strategy of growing fast, keeping wealth happy, staying competitive, and cleaning up the rest later might be transformed into one that does more to improve the well-being of the worst off and, simultaneously, does a much better job of managing carbon stocks and fluxes important to public health and climate protection. Our starting point is that further urbanization is inevitable and indeed desirable from a social development and carbon perspective and could unfold in ways that need not be in imitation of the "modern" cities of the affluent West (e.g., Robinson 2006).

Urbanization as Decarbonization

Needs for mobility in the five cities are likely to continue to grow for some time, even with improvements in spatial organization. The trend in these societies is still mostly away from self-employed, home-based enterprises to employment in firms elsewhere. The prospects of telecommuting, often muted for postindustrial societies (e.g., Tayyaran and Khan 2003), remain, therefore, remote. Moreover, other studies suggest skepticism, as people's choices and use of automobiles, for example, may have less to do with

Table 2 Challenges and opportunities for decoupling social development from emissions growth through changes in the ways four urban functions are achieved

Valued urban services	*Critical service-emission linkages*	*Challenges for integrating carbon*	*Opportunities to integrate carbon into development strategies*
Mobility	Fuel-related including CO_2, and particulate matter (PM)	Wealth-linked rise in personal motorized vehicle ownership Lags and poor initial spatial layout of transport systems relative to work and residences	**Demotorization** High use and density makes mass transit systems economically feasible
Shelter	Embodied in electricity generation and manufacture, especially of cement and steel	Increased use of air conditioning and heating for climate control at work and home	**Green neighborhoods** Waste energy recycling; efficiencies from higher densities Well-being and health
Food	Methane from livestock Carbon from clearing of forests for agriculture	Increased consumption of meat and dairy products	**Healthy and adequate** Protein substitutes Efficient production and processing methods with waste recycling and energy capture
Lifestyle	Energy consumed and other pollutants emitted in manufacturing Indirect and deemed emissions in service sector work	Vicious cycle of overwork to pay off credit card debts from overconsumption Poor regulation or perverse subsidies leading to high pollution intensities of firms	**Modest footprints** Low-energy and -materials goods and services Wise use of information technologies Meaningful work

"going to work" than with needs to make business and shopping trips (e.g., Jarvis 2003; Mokhtarian 2002), which can be expected to expand with increasing wealth.

A key goal must therefore be to introduce less carbon-intensive mobility systems. We expect these to be multimodal but organized around the public mass transit systems that urbanization makes plausible (Hayashi et al. 2004). When well-designed, such systems should help shape urban form rather than just respond to it. Much more investment needs to be put into public mass transit systems rather than roads for private vehicles. Multilateral financial institutions have a major responsibility to reorient their loan priorities away from conventional road building toward financing mass transit systems. At the same time, they need to be designed with midterm flexibility in mind, so that they can be reconfigured over time with changes in demography and behavior. We concur with Barter (2000) and others that restraints on private vehicle ownership and use need to be combined with promotion of and investments in public transport. We also anticipate that in Asian cities this will mean creating much more secure nodes and corridors for nonmotorized transport with good links to public transport infrastructure (Whitelegg and Williams 2000). Core retail, education, and entertainment areas may be closed permanently to aboveground motorized transport.

Urban land-use and transport infrastructure will need to be much better coordinated, whether this is through planning and regulation or more

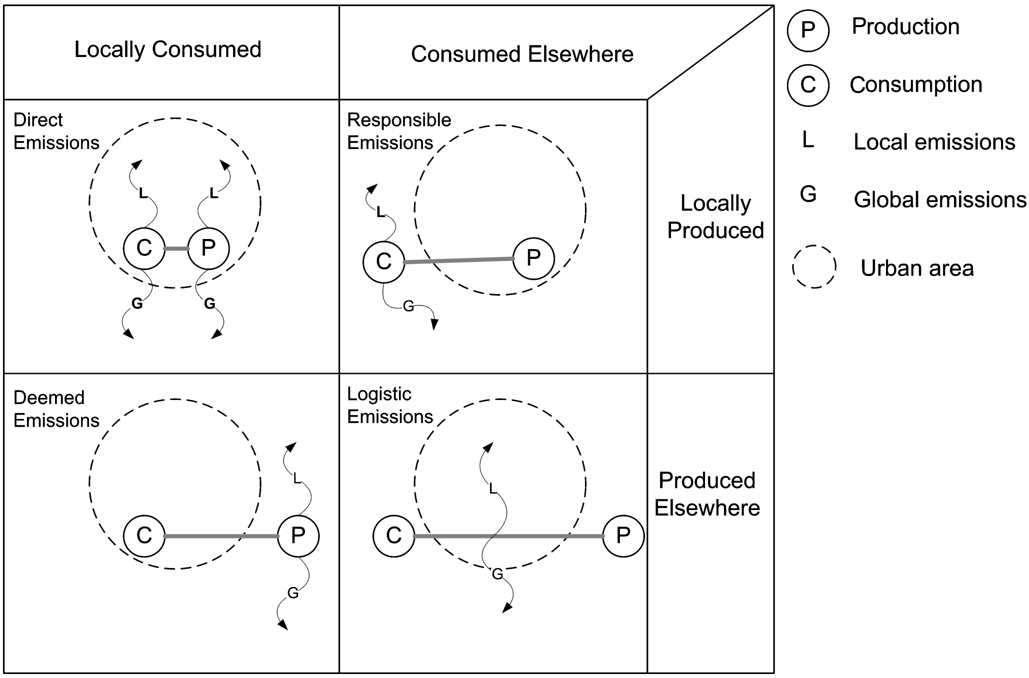

Figure 5 Emission types associated with different consumption (horizontal)-production (vertical) relations.

self-organizing opportunities to rezone and reconfigure. Building designs and layout could allow much higher densities and efficient creation of comfortable indoor climates. Green spaces may also be important in moderating urban heat island effects that can exacerbate demand for air conditioning.[6] Rooftop gardens may be one way to reestablish modest levels of greenness at otherwise very high settlement densities. Parks and large trees may help in lower-density residential developments. The diverse services provided by urban ecosystems need to be better acknowledged in urban planning and management.

Spatial planning is critical and can build on the legacies of market and other social spaces or innovations in decentralized local government. Fun and meaningful cultural activities need not be carbon-intensive. A good example is street closures to create new inner urban social spaces for eating and meeting. Local performances of music and plays in the tropical climate can take place out of doors in the evenings with modest energy requirements. Higher densities mean that better use of public and private space may be warranted, for example, through sharing and multiple uses of venues on weekdays and weekends.

Cities and urbanizing regions are points of convergence of many production-consumption systems (figure 5). They provide opportunities to influence both deemed and direct emissions, for example, through regulations, policy integration, and technological upgrading and by shaping norms and consumer cultures (Munksgaard et al. 2005; Rock et al. 2000). In this study we began exploring deemed emissions related, for example, to production of cement and steel used in construction. We suggest that a better understanding of the implications of urbanization for emissions in production-consumption systems will help with better management of carbon at multiple spatial scales (e.g. McGranahan 2005; Decker et al. 2000).

A Carbon Constituency

Cities are seats of political and economic power and windows to regional and international alliances. But they must navigate through relationships with a formidable range of powerful stakeholders, from automobile manufacturers and their lobbyists through various private-state energy consortia and transport authorities with mandates and budgets to build roads with the help of private contractors and banks. Deliberation is crucial for society to negotiate visions and criteria about the cities it wants to live in. Accountability and transparency of authorities to residents are crucial. Well-informed residents as consumers and citizens can make demands on firms and authorities that give their cities the competitive edge they want to have.[7]

Decentralization reforms have opened anew the possibilities of local urban area stewardship and planning, but at the same time have increased the problems associated with coordination of urban functions, for example, with respect to mobility and underlying energy and water systems. National government line agencies responsible for road building, energy policy, or pollution control do not give up authority willingly to area-based jurisdictions. An ensuing interplay between municipal, metropolitan, and national institutions can be expected when it comes to raising possibilities for carbon management.

For example, public interest litigation initiated by nongovernmental organizations through the Supreme Court of India and using understanding of technical line agencies has been crucial for getting New Delhi authorities to act on their serious air pollution problems (Bell et al. 2004; Badami 2005). In the Philippines, civil society in Manila strongly influenced the introduction of the Clean Air Act of 1999. This comprehensive environmental law includes action plans for research and development on fuel formulas, controlling by-products of combustion, and removing pollutants from fuels (Gallardo 2003). The Act also includes, at the insistence of civil society, a ban on incinerators, which could have been useful in waste management and energy recapture. In Chiang Mai, a persistent urban-oriented nongovernmental organization has played an important role in getting air quality issues, especially high PM concentrations (Vinitketkumnuen et al. 2002), onto local government policy agendas.

The health costs of pollution in Jakarta, one of the most polluted cities in the world, exceed U.S.$220 million per year (Resosudarmo and Napitupulu 2004). Lack of research into urban public health and of political will to take action on pollution remain critical problems. Air quality monitoring equipment was moved to residential areas with lower levels of pollution after WHO labeled Jakarta the world's third most polluted metropolis in the early 1990s (Marshall 2005). Nongovernmental organizations have played an important role in several campaigns to alter urban planning and transport policies. The nongovernmental organization PELANGI has played an ongoing and influential role in improving air quality in Jakarta through its policy research and liaison. One example was an assessment of Jakarta's development that helped provide the impetus for the Blue Skies initiative (Sari and Susantono 1999).

Like others, we conclude that to effectively address climate change, actions are needed at multiple levels, because some of the key emission reduction strategies, for example, related to regional planning and energy policy, are taken at levels well beyond the local community or city (Betsil 2001; Kates and Wilbanks 2003).

Municipalities and citizens that take actions to improve air quality stand to benefit from those efforts. *People are mobilized by dust in their nostrils*. But why should control of greenhouse gas emissions and carbon sequestration for climate protection be a local concern?

Lindseth (2004) notes that in the Cities for Climate Protection Campaign it is the co-benefits, in terms of energy efficiency and security or better urban air quality for health, that are emphasized (Betsil and Bulkeley 2004). We concur but would add that addressing social and environmental injustice could be seen as a third rationale.

Ezzati and colleagues (2004) show that integrating air pollution and GHG reductions for major urban areas in Chile such as Santiago is economically plausible. They also show that the benefits of carbon reduction to public health are even larger than those for climate protection. Li (2002) developed a model for a carbon tax and applied it to Thailand to show that the benefits of considering local health improvements from actions taken to address GHG emissions could reduce the impacts on GDP by almost half.

Energy security is also a major challenge looming for all the countries we studied. Experience with decoupling emissions growth from social development should be beneficial in a future with greater competition for energy resources and much higher prices for fossil fuels. Prospects also exist of increasing international pressure and incentives to reduce CO_2 emissions being applied by developed countries under the emerging environmental regime around the United Nations Framework Convention on Climate Change.

Public investments in infrastructure to support systems of mobility, shelter, and quality lifestyles have not targeted those most in need. The poor living in slums, often underemployed, are frequently forced to live and work in places with high exposure to air pollution. Efforts to incorporate carbon management into development strategies could specifically aim to empower such disadvantaged groups, for example, through consultation on design of accessible and low-fare mobility systems and housing.

Much of the effort required for an effective carbon emissions reduction agenda requires actions by both consumers and producers. A greater emphasis on public declaration of goals and more effective communications of the plans and programs to achieve them is needed. Civil society actors can become conduits for the development of a carbon constituency, which can be used to provide not only support mechanisms for policy initiatives, but also venues to articulate demands, and pressures for city and national governments to act.

Conclusions

Actions to improve air quality and address rapid growth of greenhouse gas emissions in urbanizing regions of Asia remain strongly focused on sector-specific strategies for upgrading technology. These are clearly important to development strategies of cities and urbanizing regions. But, as we have argued in this article, there are other, large and complementary opportunities for decoupling growth in carbon emissions from improvements in well-being within the process of urbanization. These include how urban functions are provided as well as policies that shape form and role. A carbon management perspective may be more strategic than one focused just on energy efficiency or greenhouse gas reductions because it is multilevel, with significant management issues at local ($PM_{2.5}$), regional (aerosols), and global (GHGs) levels.

Actions taken to reduce fossil fuel dependence in newly urbanizing regions now have co-benefits with respect to public health and energy security well into the future. Current ways of providing mobility and shelter, in particular, are vulnerable to constrained supplies of fossil fuels. Enhancing carbon sequestration with renewed cover of mature trees can help make cities better places to live. Diets based on good agricultural planning and practices can conserve organic matter in productive agricultural soils. Compact and modular forms can help cities function more efficiently. Urban redevelopment and renewal programs should focus on providing cheap, clean, and safe mobility, shelter, work, and food to the poorest. These programs should be funded by those whose lifestyles contribute most to driving rises in harmful local and global emissions. Owners of oversized cars and palatial homes or poorly designed offices and retail outlets are obvious targets within Asia and elsewhere.

Acknowledgments

The cooperation of government agencies, research groups, and civil society organizations in each of the study regions is gratefully acknowledged as well as international researchers contributing to the Global Carbon Project. We thank the Taiwanese Government for their financial support provided through the SARCS secretariat office at the National Central University, the International START Secretariat, and the Asia-Pacific Network for Global Environmental Change Research for their support of the U-TURN network's activities.

Notes

1. *Editor's note:* For a review of urban metabolism studies in industrial ecology, see the article by Kennedy (2007) in this issue.
2. One gigagram (Gg) $= 10^6$ kilograms (kg, SI) $= 10^3$ metric tons.
3. One kilometer (km, SI) ≈ 0.621 miles (mi).

4. One square kilometer (km^2, SI) = 100 hectares (ha) ≈ 0.386 square miles ≈ 247 acres.
5. One kilogram (kg, SI) ≈ 2.204 pounds (lb). One hectare (ha) = 0.01 square kilometers (km^2, SI) ≈ 0.00386 square miles ≈ 2.47 acres.
6. *Editor's note:* For a discussion of urban heat island effects in the context of urban metabolism, see the article by Kennedy (2007) in this issue.
7. *Editor's note:* For a discussion of the role of participatory processes in urban policymaking for sustainability, see the article by Ooi (2007) in this issue.

References

Ajero, M. A. 2003. Emission patterns of Metro Manila. Paper presented at International Workshop on Policy Integration towards Sustainable Energy Use for Cities in Asia, 4–5 February 2003, East–West Center, Honolulu, HI.

Angel, D. P. and M. T. Rock, eds. 2000. *Asia's clean revolution*. Sheffield: Greenleaf.

Badami, M. G. 2005. Transport and urban air pollution in India. *Environmental Management* 36(2): 195–204.

Bai, X. 2003. The process and mechanism of urban environmental change: An evolutionary view. *International Journal of Environment and Pollution* 19(5): 528–541.

Barter, P. 2000. Urban transport in Asia: Problems and prospects for high-density cities. *Asia-Pacific Development Monitor* 2(1): 33–66.

Bell, G. R., K. Mathur, U. Narain, and D. Simpson. 2004. Clearing the air: How Delhi broke the logjam on air quality reforms. *Environment* 46(3): 22–39.

Betsil, M. M. 2001. Mitigating climate change in US cities: Opportunities and obstacles. *Local Environment* 6: 393–406.

Betsil, M. M. and H. Bulkeley. 2004. Transnational networks and global environmental governance: The Cities for Climate Protection Program. *International Studies Quarterly* 48: 471–493.

Björklund, A., C. Bjuggren, M. Dalemo, and U. Sonesson. 1999. Planning biodegradable waste management in Stockholm. *Journal of Industrial Ecology* 3(4): 43–58.

Burström, F. and J. Korhonen. 2001. Municipalities and industrial ecology: Reconsidering municipal environmental management. *Sustainable Development* 9(1): 36–46.

Burton, E. 2000. The compact city: Just or just compact? A preliminary analysis. *Urban Studies* 37(11): 1969–2001.

Carlsson-Kanyama, A., R. Engström, and R. Kok. 2005. Indirect and direct energy requirements of city households in Sweden: Options for reduction, lessons from modeling. *Journal of Industrial Ecology* 9(1–2): 221–236.

Carpenter, J. P., A. G. Daniere, and L. M. Takahashi. 2004. Social capital and trust in South-east Asian cities. *Urban Studies* 41(4): 853–874.

Cervaro, R. and B. Susantono. 1999. Rent capitalization and transportation infrastructure development in Jakarta. *Rurds* 11(1): 11–23.

Decker, E. H., S. Elliott, F. A. Smith, D. R. Blake, and F. S. Rowland. 2000. Energy and material flow through the urban ecosystem. *Annual Review of Energy and the Environment* 25: 685–740.

Dhakal, S. 2004. *Urban energy use and greenhouse gas emissions in Asian mega-cities: Policies for sustainable future*. Kitakyushu, Japan: Institute for Global Environmental Strategies.

Douglass, M. 2000. Mega-urban regions and world city formation: Globalisation, the economic crisis and urban policy issues in Pacific Asia. *Urban Studies* 37(12): 2315–2335.

Engel-Yan, J., C. Kennedy, S. Saiz, and K. Pressnail. 2005. Toward sustainable neighbourhoods: The need to consider infrastructure interactions. *Canadian Journal of Civil Engineering* 32: 45–57.

Ezzati, M., R. Bailis, D. M. Kammen, T. Holloway, L. Price, L. A. Cifuentes, B. Barnes, A. Chaurey, and K. N. Dhanapala. 2004. Energy management and global health. *Annual Review of the Environment and Resources* 29: 383–419.

Field, C. and M. Raupach, eds. 2004. *The global carbon cycle: Integrating humans, climate, and the natural world*. Washington, DC: Island Press.

Frijns, J. 2001. Pollution control of small-scale industry in Ho Chi Minh City: To relocate or renovate? *Green Management International* 34: 55–73.

Gallardo, S. M. 2003. Air pollution studies in Metromanila and catalysis technology towards clean air Philippines. *Pure and Applied Geophysics* 160: 325–339.

Gielen, D. J. 1998. Western European materials as sources and sinks of CO_2: A materials flow analysis perspective. *Journal of Industrial Ecology* 2(2): 43–62.

Global Carbon Project. 2003. *Global Carbon Project. Science framework and implementation*. 1. Canberra: Earth System Science Partnership (IGBP, IHDP, WCRP, DIVERSITAS).

Han, X. and L. P. Naeher. 2006. A review of traffic-related air pollution exposure assessment studies in the developing world. *Environment International* 32: 106–120.

Hayashi, Y., K. Doi, M. Ygishita, and M. Kuwata. 2004. Urban transport sustainability: Asian trends, problems and policy practices. *European Journal of Transport and Infrastructure Research* 4(1): 27–45.

Hekkert, M. P., D. J. Gielen, E. Worrell, and W. C. Turkenburg. 2001. Wrapping up greenhouse gas emissions: An assessment of GHG emission reduction related to efficient packaging use. *Journal of Industrial Ecology* 5(1): 55–76.

Houghton, J. T., L. G. Meira Filho, B. Lim, K. Treanton, I. Mamaty, Y. Bonduki, D. J. Griggs, and B. A. Callander, eds. 1997. *Greenhouse gas inventory workbook*. Paris: Intergovernmental Panel on Climate Change (IPCC), Organization for Economic Co-operation and Development (OECD), and the International Energy Agency (IEA).

Imura, H., S. Yedla, H. Shirakawa, and M. A. Memon. 2005. Urban environmental issues and trends in Asia—An overview. *International Review for Environmental Strategies* 5(2): 357–382.

Jarvis, H. 2003. Dispelling the myth that preference makes practice in residential location and transport behaviour. *Housing Studies* 18(4): 587–606.

Kates, R. W. and T. J. Wilbanks. 2003. Making the global local. *Environment* 45(3): 12–23.

Kay, J. 2002. On complexity theory, exergy and industrial ecology: Some implications for construction ecology. In *Construction ecology: Nature as the basis for green buildings*, edited by C. Kibert et al. London: Spon Press.

Kennedy, C. 2007. The changing metabolism of cities. *Journal of Industrial Ecology* 11(2): 43–59.

Lasco, R., F. Pulhin, and R. Banaticla. 2005. *Integrating carbon management in the development of Metro Manila-Laguna Lake basin, Philippines. USER Working Paper WP-2005-02*. Chiang Mai, Thailand: Unit for Social and Environmental Research, Chiang Mai University.

Lebel, L. 2004a. Transitions to sustainability in production–consumption systems. *Journal of Industrial Ecology* 9(1): 1–3.

Lebel, L. 2004b. Social change and CO_2 stabilization: Moving away from carbon cultures. In *The global carbon cycle: Integrating humans, climate, and the natural world*, edited by C. Field and M. Raupach. Washington, DC: Island Press.

Lebel, L. 2005. Carbon and water management in urbanization. *Global Environmental Change* 15: 293–295.

Lebel, L., J. Manuta, P. Garden, D. Totrakool, and D. Huasai. 2004. *A carbon's eye view of urbanization in Chiang Mai: Improving local air quality and global climate protection. USER Working Paper WP-2004-09*. Chiang Mai, Thailand: Unit for Social and Environmental Research, Chiang Mai University.

Lelieveld, J., P. J. Crutzen, V. Ramanathan, M. O. Andreae, C. A. M. Brenninkmeijer, T. Campos, G. R. Cass, R. R. Dickerson, H. Fischer, J. A. de Gouw, A. Hansel, A. Jefferson, D. Kley, A. T. J. de Laat, S. Lal, M. G. Lawrence, J. M. Lobert, O. L. Mayol-Bracero, A. P. Mitra, T. Novakov, S. J. Oltmans, K. A. Prather, T. Reiner, H. Rodhe, H. A. Scheeren, D. Sikka, and J. Williams. 2000. The Indian Ocean experiment: Widespread air pollution from South and Southeast Asia. *Science* 291: 1031–1036.

Li, J. C.-L. 2002. Including the feedback of local health improvement in assessing costs and benefits of GHG reduction. *Rurds* 14(3): 282–304.

Lindseth, G. 2004. The Cities for Climate Protection Campaign (CCPC) and the framing of local climate policy. *Local Environment* 9(4): 325–336.

Ludwig, J., L. T. Marufu, B. Huber, M. O. Andreae, and G. Helas. 2003. Domestic combustion of biomass fuels in developing countries: A major source of atmospheric pollutants. *Journal of Atmospheric Chemistry* 44: 23–37.

Lyons, T. J., J. R. Kenworthy, C. Moy, and F. dos Santos. 2003. An international urban air pollution model for the transportation sector. *Transportation Research Part D* 8: 159–167.

Manasan, R. G. and R. G. Mercado. 1999. Governance and urban development: Case study of Metro Manila. PIDS Discussion Paper No.99-03. Manila: Philippine Institute for Development Studies.

Marcotullio, P. J. 2003. Globalisation, urban form and environmental conditions in Asia-Pacific cities. *Urban Studies* 40(2): 219–247.

Marshall, J. 2005. Megacity, mega mess. *Nature* 437: 312–314.

McGranahan, G. 2005. An overview of urban environmental burdens at three scales: Intra-urban, urban-regional and global. *International Review for Environmental Strategies* 5(2): 335–356.

Mitra, A. P. and C. Sharma. 2002. Mega-cities: Are these eco-hazards or eco-devices? *Science and Culture* 68(9): 285–291.

Mitra, A. P. and C. Sharma. 2005. Integrating carbon management into the development strategies of cities: Delhi case study. USER Working Paper WP-2005-03. Chiang Mai, Thailand: Unit for Social and Environmental Research, Chiang Mai University.

MMUTIS. 1999. *Traffic environmental study, air and noise pollution in Metro Manila. Metro Manila*

Urban Integration Study. Technical Report No. 10. Manila: Republic of the Philippines and Japan International Cooperation Agency.

Mokhtarian, P. L. 2002. Telecommunications and travel: The case for complementarity. *Journal of Industrial Ecology* 6(2): 43–57.

Molina, M. J. and L. T. Molina. 2004. Megacities and atmospheric pollution. *Journal of Air and Waste Management Association* 54: 644–680.

Molle, F. and Thippawal Srijantr. 2001. *Agrarian change and the land system in the Chao Phraya Delta*. Doras Centre—Delta Project Research Report 6. Bangkok: Kasetsart University.

Munksgaard, J., M. Wier, M. Lenzen, and C. Dey. 2005. Using input-output analysis to measure the environmental pressure of consumption at different spatial levels. *Journal of Industrial Ecology* 9(1–2): 169–185.

Murdiyarso, D. and L. Lebel. 2006. Southeast Asian fire regimes and land development policy. In *GCTE Synthesis*, edited by J. Canadell. Berlin: Springer Verlag.

Murdiyarso, D., L. Lebel, A. N. Gintings, S. M. H. Tampubolon, A. Heil, and M. Wasson. 2004. Policy responses to complex environmental problems: Insights from a science-policy activity on transboundary haze from vegetation fires in Southeast Asia. *Journal of Agriculture, Ecosystems, and Environment* 104: 47–56.

Myers, N. and J. Kent. 2003. New consumers: The influence of affluence on the environment. *Proceedings of the National Academy of Sciences* 100(8): 4963–4668.

Nagai, Y., A. Fukuda, Y. Okada, and Y. Hashino. 2003. Two-wheeled vehicle ownership trends and issues in the Asian region. *Journal of the Eastern Asia Society for Transportation Studies* 5: 135–146.

Nakicenovic, N. 1997. Freeing energy from carbon. In *Technological trajectories and the human environment*, edited by J. H. Ausubel and H. D. Langford. Washington, DC: National Academy Press.

Ono, K., A. Meguro, and K. Iyama. 2002. Carbon circulation and functions for the development of urban green spaces in Metro Manila. In *Metro Manila: In search of a sustainable future (Impact analysis of metropolitan policies for development and environmental conservation)*, edited by T. Ohmachi and E. R. Roman. Quezon City: University of the Philippines Press.

Ooi, G.-L. 2000. Urbanisation in Asia: Prospects for sustainability. In *Tigers' roar—Asia's recovery and its impact*, edited by J. Weiss. New York: M.E. Sharpe.

Ooi, G. L. 2007. Urbanization in Southeast Asia: Assessing policy process and progress toward sustainability. *Journal of Industrial Ecology* 11(2): 31–42.

Pearson, R. 1999. A political economy analysis of the impact of agrarian change and urbanisation on communal irrigation systems in the Chiang Mai valley, northern Thailand. Ph. D. thesis, Department of Anthropology, Macquarie University, Sydney.

Polzin, S. E. 1999. Transportation/land-use relationship: Public transit's impact on land use. *Journal of Urban Planning and Development* 125(4): 135–151.

Resosudarmo, B. P. and L. Napitupulu. 2004. Health and economic impact of air pollution in Jakarta. *The Economic Record* 80: S65–S75.

Robinson, J. 2006. *Ordinary cities: Between modernity and development*. Questioning cities series. New York: Routledge.

Rock, M. T. and D. P. Angel. 2005. *Industrial transformation in the developing world*. Oxford, UK: Oxford University Press.

Rock, M. T., D. P. Angel, and T. Ferihanusetyawan. 2000. Industrial ecology and clean development in East Asia. *Journal of Industrial Ecology* 3(4): 29–42.

Rustiadi, E., B. H. Trisasongko, D. R. Panuju, D. Siddiq, Janudianto, and R. Maulida. 2004. *LUCC and planning studies in Jabotabek Region*. Bogor, Indonesia: Center for Regional Systems Analysis, Planning and Development, Bogor Agricultural University.

Sari, A. and N. Salim. 2005. Carbon and the city: Carbon pathways and decarbonization opportunities in greater Jakarta, Indonesia. USER Working Paper WP-2005-04. Chiang Mai, Thailand: Unit for Social and Environmental Research, Chiang Mai University.

Sari, A. and B. Susantono. 1999. *The blue skies initiative: Voluntary actions to reduce urban and global air pollution in Jakarta, Indonesia*. Jakarta: PELANGI.

Secretario, F. T., K. Kim, K. Doi, and W. Morishima. 2002. Structural analysis of regional economies of Metro Manila based on interregional IO table. In *Metro Manila: In search of a sustainable future (Impact analysis of metropolitan policies for development and environmental conservation)*, edited by T. Ohmachi and E. R. Roman. Quezon City: University of the Philippines Press.

Shatkin, G. 2004. Planning to forget: Informal settlements as 'forgotten places' in globalising metro Manila. *Urban Studies* 41(12): 2469–2484.

Socolow, R. H., C. Andrews, F. Berkhout, and V. Thomas, eds. 1994. *Industrial ecology and global* *change*. Cambridge, UK: Cambridge University Press.

Tayyaran, M. R. and A. M. Khan. 2003. The effects of telecommuting and intelligent transportation systems on urban development. *Journal of Urban Technology* 10(2): 87–100.

Tiwari, G. 2003. Transport and land-use policies in Delhi. *Bulletin of the World Health Organization* 81(6): 444–450.

Treloar, G. J., P. E. D. Love, and R. H. Crawford. 2004. Hybrid life-cycle inventory for road construction and use. *Journal of Construction Engineering and Management* 130(1): 43–49.

Tri, N. H., P. T. A. Chau, N. K. Thanh, P. Duc, P. T. N. Diep, and N. T. B. Ha. 2005. Integrating carbon management into the development strategies of cities: Ho Chi Minh City and surrounds. USER Working Paper WP-2005-05. Chiang Mai, Thailand: Unit for Social and Environmental Research, Chiang Mai University.

Vinitketkumnuen, U., K. Kalayanamitra, T. Chewonarin, and R. Kamens. 2002. Particulate matter, PM 10 & PM 2.5 levels, and airborne mutagenicity in Chiang Mai, Thailand. *Mutation Research, Genetic Toxicology and Environmental Mutagenesis* 519(1): 121–131.

Werlin, H. 1999. The slum upgrading myth. *Urban Studies* 36(9): 1523–1534.

Whitelegg, J. and N. Williams. 2000. Non-motorised transport and sustainable development: Evidence from Calcutta. *Local Environment* 5(1): 7–18.

Yarnasarn, S. 1985. Land-use patterns and land-use changes in Chiang Mai, northern Thailand. Ph. D. thesis, Columbia University.

About the Authors

Louis Lebel is director and **Po Garden** is a researcher in the Unit for Social and Environmental Research, at Chiang Mai University in Thailand. **Ma. Regina N. Banaticla** is an assistant scientist and **Rodel D. Lasco** is the Philippine Programme coordinator with the World Agroforestry Centre (ICRAF) in Laguna, Philippines. **Antonio Contreras** is dean of the College of Liberal Arts at De La Salle University in the Philippines. **A. P. Mitra** is an honorary scientist of eminence at the National Physical Laboratory, in Delhi, India, and **Chhemendra Sharma** is a consultant at Winrock International, Delhi, India. **Hoang Tri Nguyen** is a director of the Center for Environmental Research and Education, at Hanoi University of Education, in Hanoi, Vietnam. **Giok Ling Ooi** is a professor at the Humanities and Social Studies Education Department of the National Institute of Education at Nanyang Technological University in Singapore. **Agus Sari** is country director for ecosecurities in Indonesia.