REDUCING GREENHOUSE GASES IN EXISTING TROPICAL CITIES

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ABSTRACT

Climate change will impact tropical cities severely due to higher temperatures with heat waves and cyclones, variable rainfall affecting food supply, and higher sea level inundation. When this paper reviewed international best practice urban and building strategies relevant to the tropics to reduce greenhouse gas (GHG) emissions, it found that wealthy citizens were responsible for surprisingly large emissions. Best practice tropical urban strategies include Integrated Urban Planning; remodelling of cities rather than demolition; developing high-density, mixed-use zones along best practice transit routes; and reducing the Urban Heat Island effect. The best building strategies include energy upgrades; external shading; free cooling; and residential lightweight construction.

INTRODUCTION

The UN's Intergovernmental Panel on Climate Change (IPCC) has determined with "high agreement and much evidence" that we are on course for a 6°C increase by 2100. For the protection of food security, ecosystems and sustainable economic development we need to carry out urgent and large greenhouse gas (GHG) reductions (IPCC, 2007, p.32).

Due to climate change, particular challenges facing the low- and middle-income nations (UNDP, 2007) that largely populate the tropics (UNFPA 2007, p.59) are:

- Increases in temperature and heat waves,
- Variable rainfall patterns, with subsequent food shortages and disease,
- Many residents in Low Elevation Coastal Zones (LECZs) are affected by:
    - Droughts from glacier melting,
    - More tropical cyclones and floods, and
    - Rising sea levels.

While Africa faces the largest growth in population, Asia faces the largest increase (see Figure 1). Asia will more than double by 2050, with a staggering increase of almost 2 billion people, and has 16% of its urban population in LECZs (UN-Habitat, 2008).

AIMS AND METHOD

The aims of this paper are:

- To investigate the major causes of GHG emissions in tropical cities, and
- To find best practice strategies to minimise GHGs for cities and buildings.

The authors undertook a Pareto analysis of GHG sources, then globally investigated the most effective modern urban and building GHG reduction strategies for existing cities appropriate to the tropics. Best practice strategies to lower GHG emissions are an ever-improving set of methods, and those chosen in this paper, including case study examples, were identified by well-known experts in each discipline eg. urban planning and transit.

The research also investigated cities of highly ubanised nations with low Ecological Footprints and a good standard of Human Development (see Ecological Footprint and Wellbeing section).

This research supports the IPCC's goal to transfer strategies and technologies to low- and middle-income nations, albeit focusing on tropical cities (IPCC, 2007).

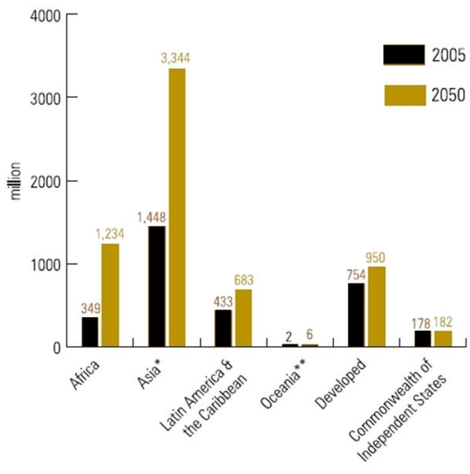

Figure 1. Current and Projected Urban Population by Region, 2005 – 2050

* *Asia - Excludes Japan*

** *Oceania - Excludes Australia & New Zealand*

(Source: UN-Habitat, 2008)

ECOLOGICAL FOOTPRINT AND WELLBEING

Figure 2 shows the Ecological Footprint against Human Development Index (HDI), or Wellbeing, of selected nations, with the top five most populous nations in red.

The Ecological Footprint (Ewing et al., 2008) of a nation is the area in global hectares per person (gha/p) needed to support inhabitants at their standard of living for water, food, energy, resources and waste absorption - taking into account CO_2 emissions.

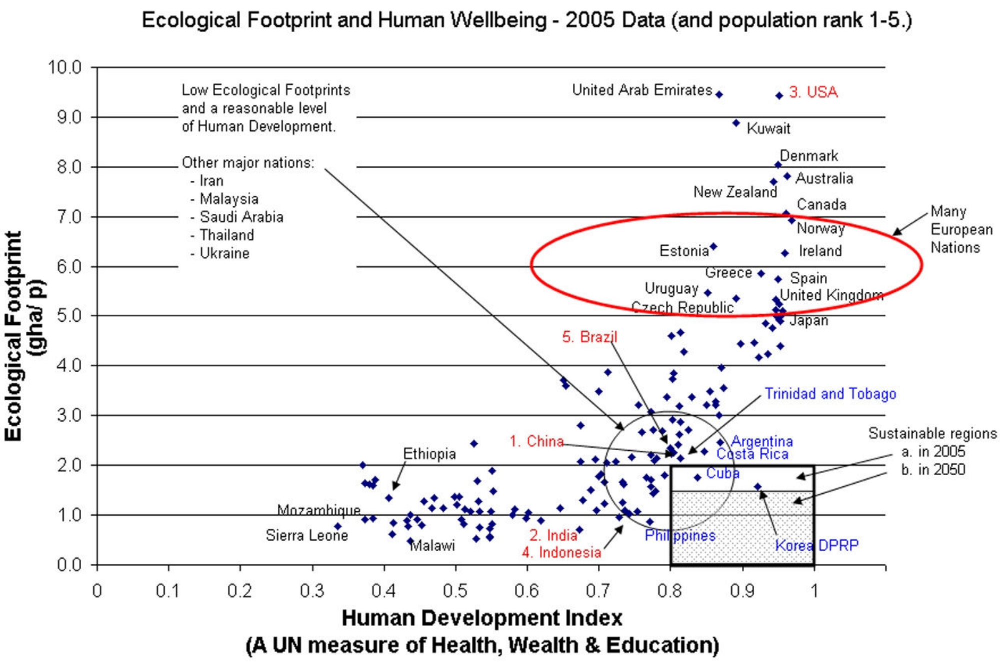

Figure 2. Global Ecological Footprint and Human Development Index (Wellbeing), with ranking of Top 5 most populous nations, a Low-footprint circle, and Sustainable regions

(Source Data 2005 from UNDP, 2008; Ewing et al., 2008; Head, 2008)

The Human Development Index (UNDP, 2007), is a fraction from 0 to 1 used to measure the health, wealth and education of a nation, with 0.8 to 1.0 being high human development.

Less area is left to support each person as the earth's population increases and the standard of living increases. In 2005 there was 2.02 gha/p and in 2050 there will be only 1.44 gha/p (Head, 2008) assuming an HDI of at least

0.8 (high development) for all, with around 9 billion people, which is the UNFPA's medium projection (UNFPA, 2007).

So, the sustainable rectangles are shown in Figure 2 for 2005 and 2050, with Footprints of 2.02 and 1.44, and Wellbeing of 0.8 and 1.0 respectively.

URBAN AND GREENHOUSE GAS TRENDS

Cities now cater for 3.4 billion people in about 2% of the global land area, with over 1 million people migrating to cities *each week* (Thomas, 2008). There is greater potential in cities, than in rural areas, to enrich residents' lives with better access to services such as health, education, employment and knowledge (Thomas, 2008; EEA, 2009).

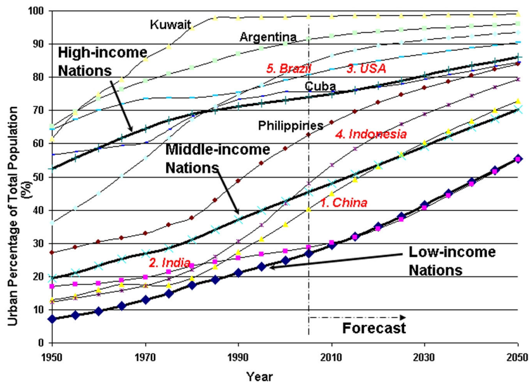

Figure 3. Percent of residents living in cities over time, and predicted, for selected nations & for nations grouped into wealth categories.

(Data from UNESA, 2009)

However, urban areas emit around 90% of all anthropogenic greenhouse gas emissions (Svirejeva-Hopkinsa et al., 2008), and so there is a great opportunity to minimise GHG emissions when expanding existing cities by using best practice strategies.

Low- and Middle-Income Nations

By 2020, nearly 90% of global urbanisation will take place in cities in low- and middle-income nations (WWI, 2007). Figure 3 shows urbanisation rates of nation wealth groups and selected cities.

Behaviour, Wealth and Energy

Urbanisation increases with a nation's production capacity, which attracts the labour force (Satterthwaite, 2009). When GHGs per capita are plotted against urbanisation level for each nation, and categorised by wealth, the large majority of GHGs are produced by the high-income nations (Satterthwaite, 2009).

There are large GHG emission differences between wealthy and poor individuals in high-income nations, and it is the wealthiest individuals who are responsible for 80% of the world's GHG emissions (Satterthwaite, 2009).

Others conclude that reducing consumption is very important to reduce GHG emisions (IPCC, 2007; EEA, 2009). One report in Australia (ACF, 2007), a high-income nation, found its consumption of food as well as goods and services accounted for a large 60% of the household GHG emissions, using a lifecycle analysis including embodied energy.

Many tropical nations are lower income nations that use more biomass than richer nations as their source of energy, also contributing to lower GHG emissions (WEC, 2007).

URBAN STRATEGIES

Table 1 presents best practice GHG-reduction strategies and results for case studies of urban remodelling or new development. They were chosen because of their effectiveness and to represent the range of strategies available.

Integrated Urban Planning (IUP)

Integrated Urban Planning with social equity is needed for harmonious cities. (UN-Habitat, 2008).

Arup in its Dongtan master plan (see Table 1) refined IUP using biomimicry principles (Benyus, 2002) forming a technique called "virtuous cycles of benefit" (Head, 2008). This minimises resource flows (such as energy, water, waste and minerals) between rural and urban systems by analysing interdisciplinary synergies.

Remodelling Existing Cities

Rather than demolish sections of a city, or build completely new suburbs, usually more GHG emissions will be saved by refurbishing buildings, because new low-Carbon buildings use much more embodied energy than refurbished ones (Connaughton et al., 2008)

Urban Form

Many benefits accrue when city centres and districts are redeveloped into higher density, spatially complex and mixed use zones along good transit routes, rather than developing urban fringe areas (Trubka et al., 2008; Lehmann, 2007; UN-Habitat, 2008; Kenworthy, 2003). Benefits include large savings in GHG emissions; faster average travel times; less pollution; lower infrastructure development costs; and reduction in health costs, with more active residents.

Transit Systems

The best practice transit systems for high urban passenger-kilometres (Kenworthy, 2003) are rail or highly-effective busway systems (with large, efficient, reliable buses and feeder networks, dedicated lanes in dense, mixed-use development), such as in European and Asian cities, or the Brazilian cities of Curitiba or Sao Paulo.

Outstanding examples of cities saving passenger transport GHG emissions are:

- Manila in the Philippines, with its effective "jeepney system and para-transit-like motorised tricycles" (Kenworthy, 2003, p.5) lowering the private-use share of its small total passenger emissions of 500kg/p/yr CO_2-e, to a very low 22% (Kenworthy, 2003), and
- Bogota's best-practice bus transit system that lowers the private-use share of the same small total passenger emissions of 500kg/p/yr CO_2-e, to a low 44% – see Table 1 (Kenworthy, 2003).

Table 1
Best practice urban district case studies

CITY/ DISTRICT	DESCRIPTION & GOAL	GHG REDUCTION STRATEGIES	RESULTS
Havana, Cuba. *Urban agriculture revolution* 1989 Tropical	**Urban Agriculture** Fuel, energy and food shortages in 1990s due to the collapse of Soviet Union & the continued US embargo (WWI, 2007; Girardet, 2008; Rivero, 2008)	A government emergency urban food program began with land inventories, farmer training & market setup; international Permaculture assistance; closed food-waste-fertiliser cycles.	Around *90% of food is produced in and around the city*; 24% reforestation; 350,000 jobs (2008); low GHG emission techniques e.g. inter-planting, 25 times fewer pesticides; food gardens on most spare land.
Bogotá, Columbia. *Transit modelled on Curitiba, Brazil* 2001-2016 *Informal settlements* Cool Temperate	**Governance/ Integrated Urban Planning/ Urban Form/ Public Transit System** New governance began with mayoral elections & less corruption; integrated urban planning; TransMilenio bus rapid transit system needed to improve traffic, air pollution and speed of transport (Candiracci, 2006)	Developed mixed-zone buildings and a network of innovative reserved bus lanes along arterial roads; had 500 metre stops using express, and all-stops, diesel, 160-person buses, with 80-person feeder buses; GPS receivers in artery buses track progress for breakdowns; Financed partly from funds taken from a large ring road.	Public passenger transport is a great 56% of a very low total of 500kg/p/yr CO_2-e for all passenger transport. Carries *750,000 people a day at low cost*, in a great service to the poor; 50% reduced journey time; 40% fewer peak time private cars; 90% fewer accidents on artery roads; 17,300 jobs (including 7,300 full-time); better quality of life.
Dongtan, China. *World's first design of eco-city* 2008 Sub-tropical	**Greenfields site/ Integrated Urban Planning/Urban Form/ Transit/ Agriculture** Zero Carbon city for 500,000 residents by 2050 over 630 ha; Arup design for Shanghai Industrial Investment Corporation (Head, 2008).	54% residential; energy via photo-voltaic (PV) systems wind turbines & biomass; compact urban form with walkable villages and green roofs; zero carbon vehicles; traffic calming and good access; peri-urban agriculture & biodiversity - enhancing the bird habitat.	Ecological Footprint of 2.6 gha/person; *64% reduction in energy* of similar city size, with *savings of 350,000 t/yr CO_2-e;* recover 90% of waste including for energy to heat; *transport savings of 400,000 t/yr CO_2-e;* surrounded by agriculture, wetlands and energy-producing land. *(Construction suspended.)*

USA's Atlanta, in contrast has around 98% private passenger use share of total passenger emissions of 7,500 kg/p/yr CO_2-e (Kenworthy, 2003).

Reducing the Tropical Urban Heat Island Effect

Strategies to reduce the Urban Heat Island (UHI) effect in the tropics are important to reduce GHG emissions (Ichinose et al., 2008). These fall into three main groups: reducing the heat from energy consumption; using less heat-absorbing materials on the ground and on urban structures; and ensuring airflow through cities (Ichinose et al., 2008). Strategies they consider the most effective are:

- Reducing air-conditioning cooling loads, e.g. with external building vegetation,
- Using water-retentive paving,
- Using the albedo effect of light coloured walls and roofs to lower room temperatures,
- Increasing green tracts of land;
- Creating water channels, and
- Relocating green land or business facilities to take account of sea breezes and other prevailing winds.

In the tropics, climate-appropriate urban design strategies (Aynsley, 2006; Rudolph, 2008; Lehmann, 2007) include:

- Reduce heat build-up during the day and shade pedestrians e.g. orientating narrow streets with buildings of appropriate heights,
- Manage street breezeways without creating "wind tunnel" effects, and
- Ventilate districts and convective cool at night.

Informal Settlements

As well as catering for new arrivals, better provision needs to be made for around 1 billion live in informal urban settlements of mainly low- and middle-income nations (UNDP, 2007), including providing low GHG developments (Stern, 2006).

More community consultation is needed to improve the condition of informal settlers (UN-Habitat, 2008), who lack clean water, sanitation and garbage services, leading to 1.6 million deaths per year, depending on a city's size and wealth (WWI, 2007).

Energy

Recent promising research into algae bioreactors indicates they may sequester CO_2 as well as utilise heat from centralised power plants (Head, 2008). Transmission losses for these power systems that need distribution over large areas can be reduced by more *local power generation* (Diesendorf, 2007).

Tropical cities can benefit from local power generation by using power station waste heat as cogeneration, or combined heat and power, for a turbine chiller (Cousins, 2007).

Water, Urban Agriculture and Biodiversity

Tropical cities with food security concerns include Thailand, India and Indonesia (WWI, 2007), and Africa, Egypt and Vietnam (Pretty, 2009).

The Agriculture and Land Use and Forestry Change sectors have large GHG emissions (FAO, 2006) from deforestation and inputs for crops and livestock, including pesticide manufacture, fertiliser use, mechanisation, transport and refrigeration.

Best practice agricultural strategies that lower GHG emissions have been employed in Cuba and Brazil (see Table 1), Argentina, Indonesia, Philippines, India (Pretty, 2009). These are also suitable for urban and peri-urban agriculture and include integrated pest management; integrated nutrient management; conservation tillage agriculture; and aquaculture systems with higher protein yields than raising cattle (Pretty, 2009).

Waste, Recovery and Recycling

We can reduce our wastage, and subsequent GHG emissions, with less consumerism; by composting organic waste; repairing recoverable items for their embodied energy (including by employing or rewarding low-income citizens); recycling items; and extracting methane for fuel from landfill sites (Head, 2008; Benyus, 2002; EEA, 2009; Girardet, 2008; WWI, 2007; Lehmann, 2009).

BUILDING STRATEGIES

Table 2 presents case studies that show examples of buildings with best practice strategies to reduce GHGs. They were chosen to illustrate refurbishment (with less embodied energy), or tropical location and features.

The most effective GHG-reducing measures in low- and middle-income nations, adapted for tropical building include (IPCC, 2007):

- Shell retrofit with insulation;
- Efficient lights, especially compact fluorescent lamps (CFL) and efficient ballasts;
- Efficient appliances such as TVs, air-conditioners, refrigerators; and
- Efficient water heating equipment.

Climate-Responsive Tropical Buildings

In tropical climates, low-energy buildings can be designed using biomimicry, bioclimmatic and climate-responsive approaches (Benyus, 2002; Rudolph, 2008; Yeang, 2006; Clarke, 2005; Aynsley, 2006; Lehmann, 2007) e.g.:

- Maximise external wall areas (i.e. one room depth),
- Naturally ventilate roof spaces with convection,
- Use reflective insulation and vapour barriers,
- Shelter walls and openings,
- Have high raked ceilings, and
- Screen and shade outdoor living areas.

Figure 4 (Shiel, 2008) shows the applicability of various climate-responsive energy-saving building strategies (UNEP, 2007) that have been correlated with those in an Australian guide for sustainable homes (DEWHA, 2008).

Table 2
Best practice building case studies

BUILDING	DESCRIPTION & GOAL	GHG REDUCTION STRATEGIES		RESULTS & REFERENCE
		ENVELOPE	SERVICES	
California EPA Head-quarters, Sacramento, CA, USA. Built 2000 ***Refurbished in 2003*** *Behaviour*. Temperate.	High-rise 25-storey office building of 88,000m2 (950,000-square-foot). Wanted to *change occupant behaviour, conduct an energy upgrade, and improve water and waste.*	Used recycled and durable materials; native, drought-resistant grasses, plants, and trees lower storm water runoff & water needs, & reduce heat build up.	Highly efficient HVAC and lighting systems; new PV rooftop panels; a plate and frame heat exchanger to save energy and extend equipment life; worm farm.	First Platinum LEED for Existing Buildings; *changed occupant behaviour* with employee incentives and a facility layout to encourage waste reduction, walking, cycling, carpooling, and alter-native-fuelled vehicles; annual savings of $914,000 (US$ 610,000). (USGBC, 2003).
Zero Energy Office (ZEO) Kuala Lumpur Malaysia ***New, 2006*** Tropical.	High-rise office. Achieve a *zero operational energy* as a demonstration building of technologies for the future.	Good orientation; well-insulated, self-shading, air-tight façade/ envelope; light shelves stop direct radiation; double glazing.	Energy-efficient; air-conditioning - zoning, heat recovery; slab & phase-change pipes; large PV system.	*Zero nett energy* and low GHG emissions; double-glazing; 75% less heat & 50% light, U=1 W/m^2K; chiller uses 25% of normal office energy; external conduction does not require cooling (Tang et al., 2005).
Single dwelling house Darwin Australia ***New*** Tropical.	Modern open plan house; suitable for Australia's Top End tropical climate *without the need for air conditioning.*	Good sun & wind orientation; steel structure; insulated roof; overhanging eaves; veranda deck floor in wet areas.	Solar hot water service; passive features - high ceilings & large openings to promote natural ventilation.	Average annual energy consumption 5,270 kWh. (37.5 kWh/m^2 pa); low GHG emissions compared to air-conditioned tropical house (Troppo, 2009).

The graph indicates that in tropical climates, natural and night ventilation are important strategies for the residential sector, followed by shading, free cooling, mechanical ventilation, lightweight construction, and insulation.

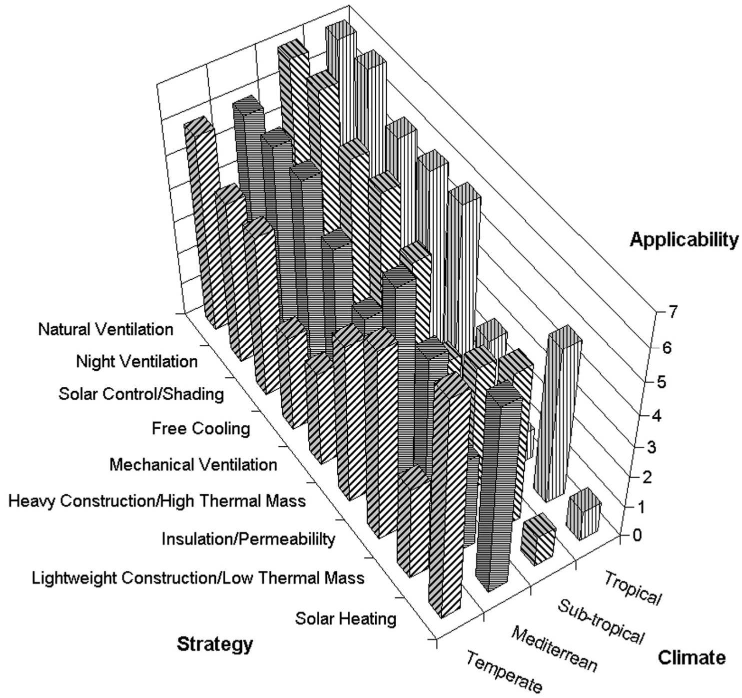

Figure 4: Residential Building Applicability of Climate Appropriate, Energy-Efficient Strategies (Source: Shiel, 2008)

Tropical Offices

There have been interesting sustainable strategies in the past in colonial commercial offices in the tropics eg. using well-ventilated and passive design techniques, and large-shading verandahs.

To reduce GHGs of modern office buildings, an upgrade should be performed, especially with Heating, Ventilation and Air Cooling (HVAC) system tuning (where all set-points are checked); lighting review (for more day lighting, zoning or energy efficient artificial lighting); management of small power i.e. appliances (upgrade them or operate them more efficiently); air-conditioning fan energy review (can use a more efficient fan or increase duct sizes); and chiller maintenance (could use smaller and higher efficiency systems for retrofit, especially in older buildings) (ARUP, 2008; Rudolph, 2008).

In the tropics, the chillers can be reduced in size even further (Rudolph, 2008) if

- The air-tightness of the building is increased to reduce the warm air leaking into the structure (with CO_2 checks to maintain air quality), and
- Standby heat (i.e. from small power appliances) is minimised at night.

Non-CO_2 GHG Emissions

The most common anthropogenic non-CO_2 GHG are: Methane produced from agriculture, transport and waste; Nitrous Oxide emitted from agriculture and transport; and Fluorinated greenhouse gases resulting from artificial cooling (IPCC, 2007).

Methane and Nitrous Oxide emissions are reduced using fewer fossil fuels; integrated urban agricultural strategies; and good urban form and transit systems. Methane emissions are also lowered with fewer livestock and less waste.

Fluorinated gases are reduced by lowering refrigeration and air-conditioning needs.

DISCUSSION

Figure 2 illustrates that many high-income nations have large Ecological Footprints, including high GHG emissions, and the worst impact is from the US, with the world's third largest population.

To be sustainable and have high Wellbeing, nations need be in the Sustainable regions shown in the two rectangles (the larger one for 2005, and the smaller one for 2050). Nations near the circle of Figure 2 have low footprints and reasonable levels of development, and these deserve more research.

A significant trend in Figure 3 is that middle-income nations are rapidly urbanising, like the trend of high-income nations in 1950-1970. Given that much of that increase will be in Asia (see Figure 1), where many residents are in low lying areas, investment will be needed into new or upgraded flood mitigation infrastructure, or in re-settling residents to higher ground. Figure 3 also shows the level of urbanisation of the most populous nations, with China and Indonesia rapidly urbanising.

Table 1 shows three urban best practice case studies. Havana, Cuba, employs 350,000 urban farmers using low GHG food-growing techniques and is a striking example of sustainable agriculture. Bogota, Columbia, has a best practice transit system, which was modelled on Curitiba, being initiated by a change in governance (Mayoral elections) to one of little corruption. The Dongtan, China, design is exemplary Zero Carbon Integrated Urban Planning across the whole city.

Table 2 shows building case studies with a human behaviour example (a major GHG contributor), the Zero Energy Office (ZEO) in Kuala Lumpur, Malaysia, with many best practice initiatives for an air-conditioned office e.g. air-tight envelope. The Darwin residence has no air-conditioning, and is a good example of a low-energy tropical house.

One of the most important sources of GHG emissions is human behaviour and rampant consumption. We need to *reduce consumption* of the wealthy, and the amount of waste generated, particularly for products with a high embodied or production energy, and large volume eg. one-use plastic containers and bags, aluminium cans and foil, steel cans and dairy and red meat products. This is a *most significant area of attention* for wealthy residents of all nations, especially high-income nations, and it will soon become important for middle-income nations.

Another reason for the high GHG emissions of high-income nations is the *use of high Carbon-intensive fuels*, particularly coal, and this trend is starting to happen in low- and middle-income nations. So we need to reduce rapidly the use of these fuels and develop more renewable sources of energy supply.

Two key investment areas to lower GHG emissions significantly are passenger transit and urban agriculture.

Efficient, reliable, high-throughput passenger transit systems in dense, mixed-use development is particularly important for sustainable tropical cities since people will live near work and use public transport, dramatically reducing travel emissions in rapidly expanding cities.

Organic urban agriculture is significant because it has fewer GHG emissions than broadacre farming, and will create employment. However, it will require good water security across potable and grey water systems eg. more water tanks and recycling.

Municipalities will need local adapatations of the GHG strategies whilst accomodating informal settlers. This will allow them to re-model cities quickly to accommodate the global surge of 1 million residents each week.

CONCLUSION

The UNESCO Chair supports the IPCC in identifying effective strategies to reduce GHG emissions for transfer to low- and middle-income nations, and in this case for the tropics.

The *major climate change issues for tropical cities* are temperature increases; variable rainfall patterns - with subsequent food shortages and disease; and sea level rise, more cyclones and floods for residents in Low Elevation Coastal Zones. These add to the infrastructure stresses of rapid urban growth and poor informal settlement conditions

To avoid dangerous levels of climate change, greenhouse gas (GHG) levels need to be drastically reduced. *Consumption of wealthy citizens* is a *most significant contributor to GHG emissions* and more research is needed eg. into consumption patterns, and the most GHG-intensive products and services.

Whilst fast expansion and construction of low-GHG emission tropical cities is a great challenge, *best practice urban strategies* are Integrated Urban Planning using biomimicry and climate-responsive principles; remodelling existing cities instead of demolishing and building new sections; creating CBDs and districts with high-density, mixed-use zones along best practice, high-throughput transit system routes; reducing the Urban Heat Island effect with shading of pedestrians, water channels, water-retentive paving, gardens, green walls and roofs; using heat from local power cogeneration for building chillers; extending urban agriculture; and reducing red meat consumption and waste.

Best practice building GHG-reducing strategies are conducting building energy upgrades where possible (instead of demolishing and reconstructing) using climate-responsive, biomimicry, bioclimatic, and passive-design techniques. The tropical residential strategies include natural and night ventilation; shading; free cooling; mechanical ventilation; lightweight construction and insulation. Air-tightness improves energy efficiency of air-conditioned buildings.

Strategies developed by nations with low Ecological Footprints, high urbanisation rates and a good level of development deserve more research (see Table 1 and Figure 2).

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