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Making cities resilient to climate change: identifying "win–win" interventions

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ABSTRACT
Urbanisation is truly a global phenomenon. Starting at 39% in 1980, the urbanisation level rose to 52% in 2011. Ongoing rapid urbanisation has led to increase in urban greenhouse gas (GHG) emissions. Urban climate change risks have also increased with increase in climate-induced extreme weather events and more low-income urban dwellers living in climate sensitive locations. Despite increased emissions, including GHGs and heightened climate change vulnerability, climate mitigation and adaptation actions are rare in the cities of developing countries. Cities are overwhelmed with worsening congestion, air pollution, crime, waste management, and unemployment problems. Lack of resources and capacity constraints are other factors that discourage cities from embarking on climate change mitigation and adaptation pathways. Given the multitude of problems faced, there is simply no appetite for stand-alone urban climate change mitigation and adaptation policies and programmes. Urban mitigation and adaptation goals will have to be achieved as co-benefits of interventions targeted at solving pressing urban problems and challenges. The paper identifies administratively simple urban interventions that can help cities solve some of their pressing service delivery and urban environmental problems, while simultaneously mitigating rising urban GHG emissions and vulnerability to climate change.

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1. Introduction

Globally, urbanisation is happening at an unprecedented rate. From 39% in 1980, the urbanisation level rose to 52% in 2011. By 2030, the urban population is expected to double, while the urban built-up area is expected to triple (Angel *et al.* 2005). Countries are increasingly becoming urban; for instance, in 2011, 92% of the population in Argentina lived in urban areas (Chen *et al.* 2014). Rapid urbanisation has accelerated energy and transport demand and worsened urban emissions, including greenhouse gases (GHGs) (CO_2, N_2O, CH_4, and SF_6). Cities consume approximately 80% of energy production worldwide (Hoornweg *et al.* 2010). Even though cities in developed countries use comparatively more energy, the cities in developing countries are quickly catching up. For example, city-level energy demand in the European Union is only 94% of the national level. In China, cities demand double (182%) the amount of energy than the national average (IEA 2008). Under a business as usual scenario, the direct energy demand and GHG emissions from China's road transportation is expected to reach 734 million tons of oil equivalent and 2.38 billion tons CO_2e by 2050. The projected increase is 5.6 times more than the 2007 level (Ou *et al.* 2010). As another example, in India, gasoline and diesel consumption for road transportation quadrupled

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between 1980 and 2000 (Singh *et al.* 2008). The triple phenomena of rising urban incomes, overcrowded and unreliable public transport systems, and the increasing affordability of private vehicles are expected to drive vehicle demand and use in the cities of developing countries. In India, car ownership increased almost 7-fold and motorcycle ownership 16-fold between 1981 and 2002 (Pucher *et al.* 2005). The availability of cheaper vehicles, such as Tata Nano and Bajaj RE60, priced at around $3000 has made vehicle ownership a dream come true for the lower middle class and upped vehicle ownership at the household level, especially in cities. Rising incomes and vehicle stock coupled with falling vehicle prices will further build up the vehicle fleet. From 112 million in 2010, the total number of privately owned vehicles is projected to increase to 500–600 million by 2030 (Guttikunda and Jawahar 2010).

Given the local and global socioeconomic and environmental consequences of urban emissions, it is no longer an option to push local waste and emissions problems beyond the local jurisdiction or ignore the problem altogether. Even if cities ignore that their jurisdiction's GHG emissions contribute to global warming, they cannot ignore local impacts that city-based emissions have. Emissions impose monetary burdens that will sooner or later force cities to act, and aggressively so. For instance, urban air pollution-related costs will overwhelm cities and push them to do something about rising urban emissions. Air pollution-related deaths from the transport sector are expected to increase from 49,500 to 158,500 between 2010 and 2030 (Guttikunda and Jawahar 2010). Cities will witness an increase in total monetary burden, which includes personal burden, government expenditure, and air pollution cost, which is already high. For instance, the total monetary burden for the city of Mumbai, is US$113.08 million for a 50-mg/m^3 increase in PM_{10} and US$218.10 million for a 50-mg/m^3 increase in NO_2 (Patankar and Trivedi 2011).

Significant opportunities exist to tackle existing urban problems such as traffic congestion and air pollution through synergistic use well-tested and effective urban interventions. Synergistic use of such interventions will not only help solve current urban problems in cities in developing countries, but also help achieve urban climate change mitigation and adaptation objectives, if any. The main of this paper is to demonstrate that urban climate change mitigation and adaptation objectives in developing countries can be achieved by aligning interventions aimed at addressing present and future urban problems. In doing so, implementation barriers and barrier removal options are also suggested.

2. Cities: culprits or victims of climate change?

When it comes to climate change, cities are both culprits and victims. Climate change poses both physical and economic consequences for cities, broadly classified into as market or non-market impacts. Market impacts directly affect the economy; for example, asset losses due to sea-level rise or floods. Non-market impacts affect humans and the environment in a broad and sometimes substantial way; for example, human health, time use and amenity values, human settlements, and natural ecosystems (Hallegatte *et al.* 2008). These impacts are already too high by developing countries' standards, let alone developed countries' standards (see Table 1), with projected increases in the future. Cities are victims of climate change irrespective of geographical location and level of development and preparedness.

As seen in Table 1, the costs incurred by Yangon, Mumbai, and Banda Aceh and Chennai as a result of extreme weather events are substantial by developing countries' standards. These are only a handful of vulnerable cities; other cities in the Asia and Pacific region are also vulnerable to climate change and climate-induced extreme weather impacts. Frequent severe floods–particularly in 1988, 1998, and 2004 – have disastrous impacts on service delivery in Dhaka, Bangladesh. During the 1998 floods, the eastern part of Dhaka – about 119 square kilometres – was 100% inundated (Nishat *et al.* 2000). As these cities house large clusters of a country's impoverished population, the market and non-market costs incurred is troublesome, as recurrent impacts further diminish their already weak urban resilience. Costs of damage from climate change-related flooding is likely to

Table 1. Urban impacts of climate-induced extreme weather events, 2000–2010.

Popular name	Year of event	Country affected	Type of hazard	City affected	Total number of deaths	Total number of affected	Total damages in 2014 US$
Cyclone Nargis	2008	Myanmar	Tropical cyclone	Yangon	138,366	2,420,000	4.38 billion
Mumbai floods	2005	India	Flood	Mumbai	1200	20,000,055	3.61 billion
South Asian tsunami	2004	Indonesia, Sri Lanka, India, Thailand, Malaysia, Maldives, and Myanmar	Earthquake and tsunami	Banda Aceh, Chennai (some damages)	226,408	2,321,700	10.08 billion
Hurricane Katrina	2005	United States	Tropical cyclone	New Orleans	1833	500,000	137 billion
Dresden floods	2002	Germany	Flood	Dresden	27	330,108	12.3 billion

Source: Adapted from IFRC (2010).

range from 2% to 6% of GDP for Manila, Bangkok, and Ho Chi Minh City. Given its urban flood control infrastructure, a 1-in-30 year flood in Manila could cost between $900 million and $1.5 billion (World Bank 2010). Market impacts will be comparatively large for industrialised coastal cities with high property prices. Cities, such as Dhaka, Mumbai, Shanghai, and the Chao Phraya on the Ganges-Brahmaputra and Yangtze deltas, are highly vulnerable to sea-level rise (Nicholls *et al.* 2007) and may incur greater losses. Large sections of Mumbai and Shanghai are only one to five meters above sea level (de Sherbinin *et al.* 2007). A one meter rise will result in $71 billion in damages without dykes – and $33 billion with dykes – in Mumbai, India (TERI 1996). Likewise, coastal cities in Africa are highly vulnerable to climate-induced sea-level rise. About 8% of Dar es Salaam, Tanzania lies within the low-elevation coastal zone. More than 210,000 people could be exposed to a 100-year coastal flood event by 2070. Assets damaged due to such event are estimated to rise from $35 million in 2005 to 10 billion in 2070 (Kebede and Nicholls 2012).

Non-market impacts, too, are substantial and increasing. In 2000, heavy rains from typhoons caused a 15-meter slope in the dump to collapse near Manila in the Philippines, burying hundreds of homes in Quezon City, killing 288 people and displacing hundreds of families. In 2008, 152 of its 180 *barangays* (smallest administrative division) in the city of Iloilo, Philippines were affected by heavy rain and flooding, killing 500 people and affecting over 260,000. Many homes were washed away, along with personal documentation and belongings (IFRC 2010). Like their Asian counterparts, cities in Africa have also started feeling the brunt of climate change. Mozambique witnessed its worst flooding in 50 years, as a result of heavy rains and cyclones in February–March 2000. The capital city Maputo and neighbouring city Matola suffered widespread devastation and more than 1 million people were directly affected (Douglas *et al.* 2008). More than 70% of deaths in the floods of 2000 occurred in urban areas (Satterthwaite *et al.* 2007). Floods in October 2006 seriously affected 60,000 people in Mombasa, Kenya (Awuor *et al.* 2008). Floods are a major problem in Nigerian cities, beginning when the first flood hit Ibadan in 1948 and between 1963 and 2011, when a series of floods occurred in Ibadan and other parts of the country (Odufuwa *et al.* 2012).

Given the overall size of the economy and robust municipal tax base, cities in developed countries are better positioned to absorb rising climate change costs; cities in developing countries do not have this luxury. Unlike the cities of developed countries, cities in the developing world have a limited tax base to generate the revenue necessary for municipal operations, along with ever increasing service delivery obligations and climate change-induced losses to municipal assets and infrastructure. Given these issues, cities in developing countries will eventually be forced to compromise economic development and service delivery if they don't devise a plan to address growing urban climate change risks and impacts. Cities may ignore non-market impacts for now, but are not well positioned to ignore growing market impacts in the future, as these are linked to market transactions and directly affect GDP. In other words, inaction against rising impacts will have a negative impact on the ability of cities in developing countries to generate the revenue necessary for municipal facilities and services. Given the magnitude of the problem, these cities in developing countries will soon have to confront this hard reality and address rising urban climate change risks and impacts.

3. Identifying the "Win–win" interventions

Cities consume about 80% of energy production worldwide (Hoornweg *et al.* 2010) and account for over 67% of energy-related global GHG. This high percentage is projected to further increase to 74% by 2030 (IEA 2008). Rapid urbanisation and subsequent increases in urban resource demand and use results in rising urban emissions, including GHGs, in developing countries. Urban GHG emissions in developing countries range from 26% to 33% of total emissions and are projected to rapidly increase in coming years. It is estimated that 89% of the increase in CO_2 from energy use will be from developing countries (IEA 2008). These increases in urban emissions are concerning both from a global and local perspective. Given the high percentage of GHG emissions from cities, it will be difficult to slow down changes in climate without containing urban GHG emissions. Local impacts of urban GHG emissions will also be severe with increases in emissions. For instance, the negative impact of CO_2 on health and life expectancy is highest at its point of emission than in other areas (Jacobson 2008). Urban dwellers exposed to harmful GHGs are also exposed to climate change and climate-induced extreme weather events. This double exposure is alarming, given the socio-economic and socio-spatial changes concurrently happening in developing countries. For instance, urban income inequality in countries like the Philippines, Thailand, Sri Lanka, Nigeria, Kenya, Ethiopia, and Zimbabwe is high (UNHABITAT 2010a). High income inequality at a time when urban climate risks and impacts are also rising is disconcerting, because it will directly influence the capacity of poor urban households to adapt to changing climate. By negatively impacting longstanding practices of communal risk management that provides a bulwark for the poor against climate threats, (Adger 2002) income inequality, adversely affects both household and community-level adaptation to climate change (AfDB *et al.* 2003).

Cities determine and influence their urban environments, including the built environment, public transportation systems, infrastructure development and management, waste and water management systems, disaster risk reduction and management, and public services delivery. Hence, ongoing rapid urbanisation is not a bad thing in itself. It becomes problematic only if allowed to happen haphazardly. Ongoing rapid urbanisation provides creative opportunities to develop policy and programmatic solutions to deteriorating air, water, and waste systems. A wide variety of urban interventions can address these problems and also provide urban climate change mitigation and adaptation co-benefits, if used synergistically. Hence, there is an opportunity for "win–win" situations. In other words, effective and synergistic use of selective urban interventions could help solve both existing urban problems such as congestion and air pollution and help achieve climate change mitigation and adaptation objectives. The suggested urban interventions (see Figure 1) can help cities in developing countries shape mitigation and adaptation solutions to urban climate change.

3.1. Urban planning interventions

Urban planning acts as a key policy lever to reduce urban emissions and enhance climate change mitigation and adaptation benefits (Davoudi *et al.* 2010, Wilson and Piper 2010, Dulal and Akbar 2013). It can play an important role in the mitigation of rising urban emissions and adaptation of urban systems to adverse climate change effects. For example, through urban planning, Curitiba, Brazil, demonstrated that it is possible for population growth without congestion, pollution, and reduction of public space. From 1970 to 2008, despite a three-fold increase in the population density, the average green area per person increased from 1 km^2 to over 50 km^2. Compared to other Brazilian cities, like São Paulo and Rio de Janeiro, the cost of congestion is significantly low. In 2002, estimated fuel use from severe traffic congestion in Curitiba, which was estimated at a

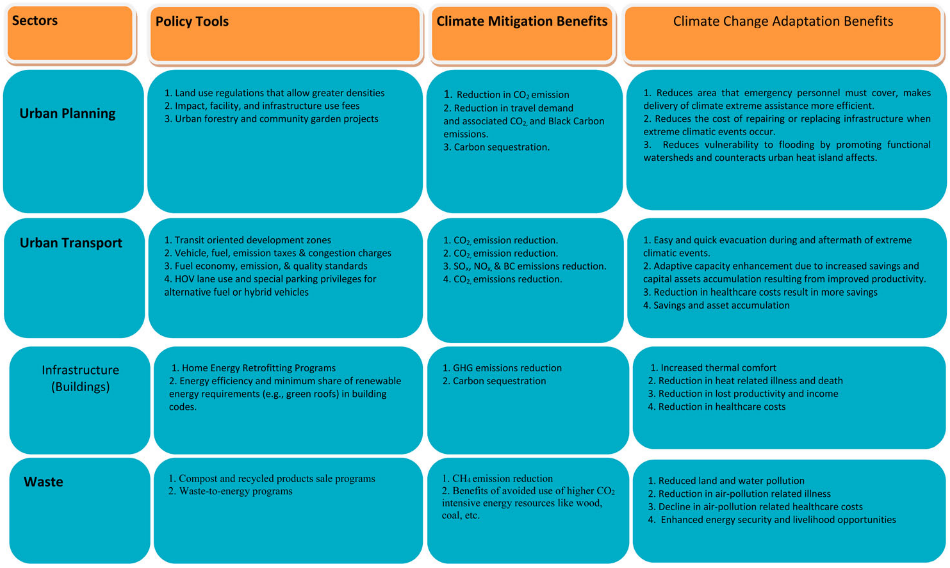

Figure 1. Climate change adaptation benefits of urban interventions.

value of US$1, was approximately 13 and 4 times less per capita than in Rio de Janeiro and São Paul, respectively. Likewise, the congestion cost and per capita productivity loss from time spent in severe congestion in Curitiba was approximately 7 and 11 times than in Rio de Janeiro and São Paul, respectively (UNEP 2011). Compact cities are better when it comes to mitigating urban emissions, including GHGs. Lyons *et al.* (2003) show direct air pollution reduction benefits when the outward growth of cities is minimised. A comparative study of two neighbourhoods in Nashville, Tennessee (United States) reveals that the more dense neighbourhood produced 25% fewer vehicle kilometres travelled and 7% less toxic emissions per capita per day from vehicles than the 68% less dense neighbourhood (NRDC 2003).

Urban planning could serve as an important instrument to adapt to climate change and climate-induced extreme weather events. Administratively, simple urban planning interventions, such as land use regulations that allow high-density development, not only enhance mobility and reduce transport sector emissions, but also provide urban climate change adaptation benefits.

The high-density development allows for more opportunities to guide development away from sensitive and hazard-prone urban areas (Cruce and Yurkovich 2011). In the event of extreme weather events and other crisis situations, high-density development reduces the area that emergency personnel must cover, making the delivery of emergency assistance more efficient and effective. Free urban road networks is also crucial during extreme climatic events, such as floods and heat waves, when vulnerable populations need to evacuated or transported to healthcare centres. High-density development leads to more compact cities, which lessen impacts from extreme heat events (EHEs); EHEs are increasingly responsible for a greater number of climate-related fatalities per year. Stone *et al.* (2010) examined the association between sprawling and compact metropolitan regions and the frequency of EHEs between 1956 and 2005. Findings suggest the annual number of EHEs between 1956 and 2005 in sprawling metropolitan regions is double the rate observed in compact metropolitan regions. Even though urban climate impacts can be addressed in multiple ways, cities still enact traditional responses, such as increasing the capacity of sewage systems or drainage canals for storm water management and installing air-conditioning for heat-stress management (Mees *et al.* 2012), which are often not enough to combat these impacts.

City planners and policy-makers in developing countries have yet to explore alternate solutions to urban climate impacts. Green infrastructure is a viable alternative, and its potential to regulate water quantities and moderate temperature is well documented and acknowledged, as seen in Riverside, California (US). Local authorities there invested in the rehabilitation of a natural wetland in lieu of building a conventional denitrification facility at a water treatment plant. This wetland system will remove atmospheric nitrogen and save the city an estimated $18 million. For $2 million – 90% less than a conventional facility – the city constructed 28 hectare of wetlands. Non-native vegetation near the treatment plant was cleared of invasive species and rehabilitated for optimal nitrogen removal. In a similar example, Emerton *et al.* (2009) demonstrate that natural ecosystem maintenance in the Ulaanbaatar Watershed in Mongolia protects the city's water supplies and prevents urban development from expanding into the reserve. In the next 25 years, daily water supplies in Ulaanbaatar are expected to reduce by 32,000–52,000 cubic meters. In the face of projected water shortages, the city will need to make strategic decisions to prevent impending water stress. The city will need to decide between sustained water supplies to Ulaanbaatar and reduced land values in the upper watershed because of conservation in the Upper Tuul. The conservation scenario yields a net present value of $560 million over 25 years, which is higher than values generated from a continuation of the status quo or a rapid ecosystem degradation scenario. Given resource constraints of cities in the developing countries, savings accrued through ecosystem-based approaches could be substantial and therefore desirable. Savings could contribute to enhanced economic development, improved service delivery, and expanded social welfare programmes, including those intended to reduce urban poverty.

Urban forestry and community gardens can act as mitigation measures as they retain and enhance carbon stocks and help adapt to climatic extremes, such as heat waves by counteracting urban heat island effects. Vegetation abundance is an influential factor in controlling land surface temperature (LST) (Weng *et al.* 2004). Using the greater Manchester, UK as an example, Gill *et al.* (2007) explored the potential of green infrastructure to help cities adapt to climate change. Output from energy exchange and hydrological models suggest that urban green space offers significant potential to moderate increases in summer temperatures expected with climate change. Findings suggest that the addition of 10% green space in high-density residential areas and town centres keep maximum surface temperatures at or below 1961–1990 baseline levels. Results also indicate the possible danger associated with reductions in green space: a 10% reduction in high-density residential areas and town centres will increase surface temperatures by 7–8.2°C by 2080. Taking the urban area of Aksu, China as an example, Maimaitiyiming *et al.* (2014) quantitatively examined the effects of spatial composition and configuration of green space on LST. Findings suggest that both the composition and configuration of green space elicits urban heat island effects. The combination of edge density (ED) and patch density (PD) are the most deterministic factor of LST; thus, optimising green space configuration to increase PD and ED should be prioritised in sustainable urban planning and development to mitigate urban heat island effects. Despite clear benefits, the expansion of green space is not a priority in the developing world, mainly because heat stress is not considered an urgent problem. Municipalities are responsible for water supply and rain and sewage water, leading the local government to overlook problems arising from urban heat islands. Given that cities, especially those in the dry land, will be increasingly confronted with heat waves, green space maintenance will have to become a priority or else the magnitude of non-market impacts will increase significantly as climate-induced temperature increase.

3.2. Urban transport interventions

Urban expansion in cities of most developing countries happens because of lack of development control. Lack of spatially focused efforts and explicit zoning and protection laws and regulations have skewed the balance between employment and housing that determine the use of transport and associated emissions in cities. As cities expand, more and more people live farther from employment centres. Given the unreliability and poor condition of public transport, people have no choice but to own private vehicle. Increase in private vehicle ownership and use is causing traffic gridlock and increase in emissions in many cities. The situation has gotten so bad that average vehicle speed in megacities of developing countries is 14.19 miles per hour (see Table 2).

Reduced mobility is a serious concern because it adversely affects municipal fiscal conditions. In 1996, the cost of traffic congestion in Bangkok, Kuala Lumpur, Jakarta, and Manila accounted for 2.1%, 1.8%, 0.9%, and 0.7% of GDP (ESCAP 2007). Societal costs are even higher. It accounted for 0.6% and 3.4% of GDP in Mexico City and Buenos Aires (UNEP 2011). Creutzig and He (2008) analysed externalities of car transportation in Beijing and show that social costs induced by motorised transportation are equivalent to about 7.5–15.0% of Beijing's GDP. Air pollution-related health costs are above 5% of GDP in Dakar, Senegal (UNEP 2011).

Given the lower urban mobility and higher congestion costs incurred by developing countries, targeted policy intervention and integration is not only desired, but is becoming increasingly necessary. For example, transit-oriented development (TOD), which is designed to maximise access to public transport, could discourage auto-dependency and promote transit ridership if complemented with fiscal policy instruments such as congestion charge. Adverse impacts of fiscal policy instruments such as congestion charge on poor households can be ameliorated through revenue recycling. TOD allows for easy and quick evacuation during and after extreme climatic events.

Proper enforcement of regulatory policy instruments, such as fuel economy, emission, and quality standards, could indirectly boost climate change adaptation through increased household savings, as healthcare costs tend to decrease with urban environmental quality improvements. Reduction in healthcare costs, because of reduced emissions, also means a reduction in productivity loss and increase in savings and investment in capital assets. Household savings and capital assets play a crucial role for the expansion of livelihood options for vulnerable households. Vehicle taxes could be another potent instrument when it comes to discouraging private vehicle ownership and associated emissions in cities of developing countries. Its successful use in Singapore discouraged private transportation demand and growth. By limiting private ownership, vehicle tax in Singapore played an important role in containing air pollution and congestion (Willoughby 2000). Vehicle taxes are effective in containing emissions, not only in Singapore, but elsewhere as well. Using data from 68 large cities, 49 Organisation for Economic Co-operation and Development (OECD) countries, and 19 non-OECD Asian countries, Hirota *et al.* (2003) demonstrated that for every 1% increase in acquisition and ownership taxes there is a 0.19% decrease in CO_2 emissions. Like vehicle tax, fuel tax is another important instrument that can contain rapidly increasing energy demand and associated emissions in the transport sector. Indicative evidence suggests that a 1% increase in fuel tax would reduce vehicle-miles travelled by 0.042%. Lower vehicle mileage in most cases reduces vehicular emissions (Eltony 1993). The introduction of stronger fuel economy standards can reduce transport-based emissions. DeCicco (1995) demonstrated that fuel economy improvement at the annual rate of 6% would result in savings of 2.9 million barrels of gasoline per day and 147 million metric tons of carbon emissions per year.

Table 2. Road travel speed in selected cities, 2000.

Megacities	Average road speed miles per hour
Mexico City	14
São Paulo	15
Mumbai	13.8
Shanghai	12.4
Buenos Aires	18.6
Delhi	14.4
Jakarta	11.6
Beijing	11.1
Rio de Janeiro	18.6
Cairo	12.4

Adapted from Gurjar *et al.* (2008) and Parry and Timilsina (2009).

The adoption of high occupancy vehicle (HOV) lanes and parking charges could discourage private vehicle ownership and use, which is a major source of urban emissions in many developing countries. The introduction of HOV lanes primarily results in emission reduction through congestion easing (Rosenfield *et al.* 2015). Boriboonsomsin and Barth (2015) examined the operational differences in traffic dynamics between HOV lanes and mixed-flow (MF) lanes in southern California (US) and evaluated their impacts on vehicle emissions. Findings showed that HOV lanes produce lower emission rates per vehicle per mile in most cases, except when they are underutilised. HOV lanes produced much lower emission rates for the same amount of travel, on the order of 10–70%. Introduction of parking charges could reduce emissions by reducing private vehicle use. Dasgupta *et al.* (1994) used simulation studies to show that doubling parking charges reduces the share of central area car trips by 13%.

Congestion charges implemented in developed countries in North America, Europe, and Asia are largely successful. The introduction of Ecopass in Milan led to a 14–23% reduction in urban emissions (Rotaris *et al.* 2010) overall welfare gains (Gibson and Carnovale 2015). It reduced PM_{10} by 23%, NOx by 17%, and CO_2 by 14% inside the implementation area. Congestion charge resulted in respective 16%, 13%, and 16%, reductions in PM_{10}, NOx, and CO_2 in London (Transport for London 2007). The total environmental benefit generated by the congestion charge in London is estimated at €4.9 million per year (Prud'homme and Bocarejo 2005). Similar results were achieved in Stockholm: congestion charges resulted in respective 10–14%, 8.5%, and 14%, reductions in PM_{10}, NOx, and CO_2 (Eliasson *et al.* 2009). A modal shift triggered by congestion charge would improve air quality through reduced emissions, including GHGs, and yield adaptation co-benefits. Decongested roadways facilitate faster transport of vulnerable populations and their moveable assets from at risk areas during and after climate-induced extreme weather events. As largely poor populations live in climate-exposed areas of cities, it is important to safeguard their limited savings and assets because failure to do so may negatively impact their resilience to climate change.

3.3. Infrastructure interventions

The infrastructure sector produces much of a city's urban emissions, including GHGs, and heightens its vulnerability to climate change. In the Asia and Pacific region alone, $8 trillion in infrastructure investment will be needed to bridge the existing infrastructure gap by 2020; about two-thirds of the $8 trillion will be in new infrastructure (Bhattacharya *et al.* 2012). The existing infrastructure gap provides an opportunity to build low-carbon, climate-resilient cities with efficient infrastructure. Infrastructure investment that considers rising urban emissions and future climate change impacts will save cities money, avoid costly future renovations, and reduce urban pollution-related losses. Public transport infrastructure investments, such as bus rapid transit (BRT) and railways (metro, surface, and elevated rails), could help contain urban externalities like congestion and emissions. In Mexico City, the BRT system is expected reduce CO_2 emissions by 0.28 metric tons and produce US$3 million in health benefits each year from reduced local air pollutants (Vergara and Haeussling 2007). Likewise, in Bogota, Colombia, the TransMilenio BRT project is estimated to reduce CO_2 emissions by 14.6 million metric tons during the first 30 years of its operation (Lee 2003).

Current sustainable urban infrastructure investments need to scale up. Many cities in developing countries are reluctant to implement suggested urban infrastructure investments, because of the fear of increased costs and negative impact on economic growth. In doing so, they fail to see that these costs are smaller than those in the future. Present investments could bring down future costs resulting from increased urban emissions and climate-induced extreme weather events, both of which are projected to rise. For example, higher temperatures and subsequent EHEs will increase both energy use and costs in the coming decades. Increased energy use is observed not only in cities from drier parts of the world, but also in cities in cooler climates like North America and Europe. For example, in Toronto, an average increase of 3°C was associated with a 7% increase in mean peak electric demand (Colombo *et al.* 1999). By 2030, the average number of days in July that require air-conditioning in

Boston, Massachusetts (US) could increase by over 24%, with a corresponding rise in energy use. In Boston, climate change will be responsible for 25–40% increases in energy demand (Kirshen *et al.* 2004). By 2050, the typical air conditioned office building in London is estimated to increase its energy use for cooling by 10%, and by 2080, the increase is expected to be around 20% (LCCP 2002). Given the available resources, cities in the developed world might be able to afford increased energy costs, but even a relatively small increase in energy costs could force cities in developing countries to cut back on service delivery, development, and welfare budgets – crucial for cities to avoid further environmental deterioration and provide residents with a reasonable quality of life.

Cities in developing countries need to avail of opportunities that both reduce urban emissions and maintain economic growth; less they get locked into carbon-intensive growth pathways. Using back-casting scenarios in Tokyo, Japan, Gomi *et al.* (2010) found opportunities to reduce the city's CO_2 emissions by 50% by 2030 when compared to 1990 and maintaining 1.3% annual economic growth rates. Energy efficiency improvements in the household and commercial sectors are relatively large among the countermeasure categories. In developing countries, energy efficiency is low-hanging fruit: easy to reach and ripe for the taking. Cities in developing countries could start off with energy efficiency programmes that have substantial GHG mitigation and cost savings potentials. The South African city of Durban, for example, reduced energy costs by administering simple changes such as minimising the use of air conditioners and fans, changing lighting technology, and modifying building management systems. Energy audits of municipal buildings found that administering these changes reduced building energy consumption by over 15% at little or no extra cost (eThekwini Municipality 2004).

Table 3 illustrates some administratively simple interventions that can reduce energy costs and GHG emissions. Implementation of energy efficiency programmes in Brattleboro, Vermont (US) led to an 18% decline in the city's carbon emissions between 2000 and 2010 (Town of Brattleboro 2014). With a modest payback time and implementation cost, some programmes hold a great replication potential. Programme such as building retrofits – especially in poor developing countries with larger informal settlements – could provide dual benefits. In addition to enhancing energy efficiency and reducing GHG emissions (UNEP 2011), they would also reduce urban vulnerability to climate change and climate-induced extreme weather events. Likewise, building retrofits are important to reduce emissions and can be achieved through institutional and financial innovation. For instance, a large proportion of cities in India have building stock that is aged, dilapidated, and not up to

Table 3. Selected energy efficiency measures.

Measure	Status	Estimated annual CO_2 reduction (Tons)	Estimated annual cost savings	Estimated implementation cost	Payback (years)
LED traffic signals	Existing	Negligible	$1500	$1785	1.2
Convert remaining signals to LED	Proposed	Negligible	$3773	$4480	1.2
10% Energy efficiency programme – residential	Proposed	3793 tons	$819,392	$5000	0
10% Energy efficiency programme – commercial	Proposed	780 tons	$44,423	$2000	0
Efficiency upgrades to town buildings	Proposed	136 tons	$64,901	$0	0
Efficiency upgrades to school buildings	Proposed	55 tons	$14,489	$0	0
Wood-Chip heating system at Brattleboro Union High School	Planned	378 tons	$55,000	$300,000	5.5
Conversion of town fleet vehicles to biodiesel	Proposed	72 tons	$0	$5545	0
Use of compact fluorescents in residences	Proposed	Negligible	$146,678	$77,632	0
Total	Proposed	5214 tons	$1,150,156	$396,442	

Source: Adapted from Town of Brattleboro (2003).

contemporary building safety standards. City-scale retrofitting of these buildings is possible if institutional and financial innovation accompany incentives and regulatory mechanisms (Satterthwaite *et al.* 2007). Like in these Indian cities, retrofitting older buildings would reduce the vulnerability of cities in developing countries to climate change and climate-induced extreme events, as large portion of vulnerable populations live in climate-exposed areas.

3.4. Waste sector interventions

With higher urban populations in developing countries come higher resource consumption and associated waste and emissions. For instance, in China, the total municipal solid waste (MSW) amount increased from 31.3 million tons in 1980–212 million tons in 2006. The waste generation rate increased from 0.50 kg/capita/day in 1980 to 0.98 kg/capita/year in 2006 (Zhang *et al.* 2010). This high growth rate is projected to continue in the same trajectory in the coming years. In Bangladesh, waste generated in urban areas is expected to increase from 0.49 kg/person/day in 1995 to 0.6 kg by 2025 (Ray 2008). The problem with observed and projected increases in MSW is both its adverse impacts on global climate, local pollution, and aesthetics, but also the overall municipal budget. Cities already spend 20–40% of municipal budgets on waste management (Thomas-Hope 1998, Bartone 2000). For the fiscal year 2007–2008, Asansol, Agra, Patna, and Varanasi – second-tier cities in India – allocated 44.7%, 30.39%, 29.36%, and 27.8% of their revenue for waste management, respectively (FICCI 2007). Despite spending a significant portion of their budgets on waste management, cities at best collect 30–80% of generated waste. Urban waste collection is only about 40% in Yangon, 33% in Karachi, and 50% in Cairo (Cointreau 2008). Waste collection is less efficient in and around informal settlements. For instance, in Monrovia, Liberia where illegal slums hold thousands of new inhabitants each year, authorities collect a meagre 15% of generated waste (SFIAST 2008).

Poor waste management in the cities of developing countries leads to more urban GHG emissions, particularly methane (CH_4). Higher CH_4 emissions from wastewater are a major threat to public health and well-being. The waste sector poses many opportunities to implement measures that produce significant socioeconomic and climate co-benefits measures. Cities can adopt codes and standards that divert construction waste and encourage recycling, green waste programmes, and composting to contain rising urban methane emissions. In developing countries, composting, recovering landfill gas, and exploiting energy from waste (e.g. landfill gas, incineration, and anaerobic digester biogas) can provide substantial public health, environmental, sustainable development, and climate co-benefits, in addition to reductions in waste volume (see Figure 2).

Cities in developing countries are often financially limited; however, the adoption of these suggested measures can add funds to their operating budget and create jobs in their municipalities. For instance, the promotion of composting can provide financial benefits for municipalities. Composting is a biological decomposition of organic matter in aerobic conditions and generates little or no methane. Compost can then be sold in the market for use in landscaping, horticulture, and agriculture. In southern Bali, Indonesia, for example, 50 pig farms generated enough demand for organic waste to employ hundreds of scavengers (Medina 2009). Organic materials account for the largest share of waste in developing countries – usually three times higher than developed countries – but energy from these materials is not recovered cost-effectively because of high moisture levels. Emerging economies can take waste to energy route, as the organic material in waste is significantly lower. Capturing energy from waste can help contain rising emissions, especially methane, and generate much-needed revenue (see Table 4).

Replicating successful waste management measures mentioned in Table 4 would simultaneously reduce emissions and generate revenues that could fund much-needed local programmes, including social protection and healthcare for vulnerable population. Increased employment opportunities and reduced healthcare costs can boost both household and community-level adaptation to climate change through increased savings and accumulated capital assets.

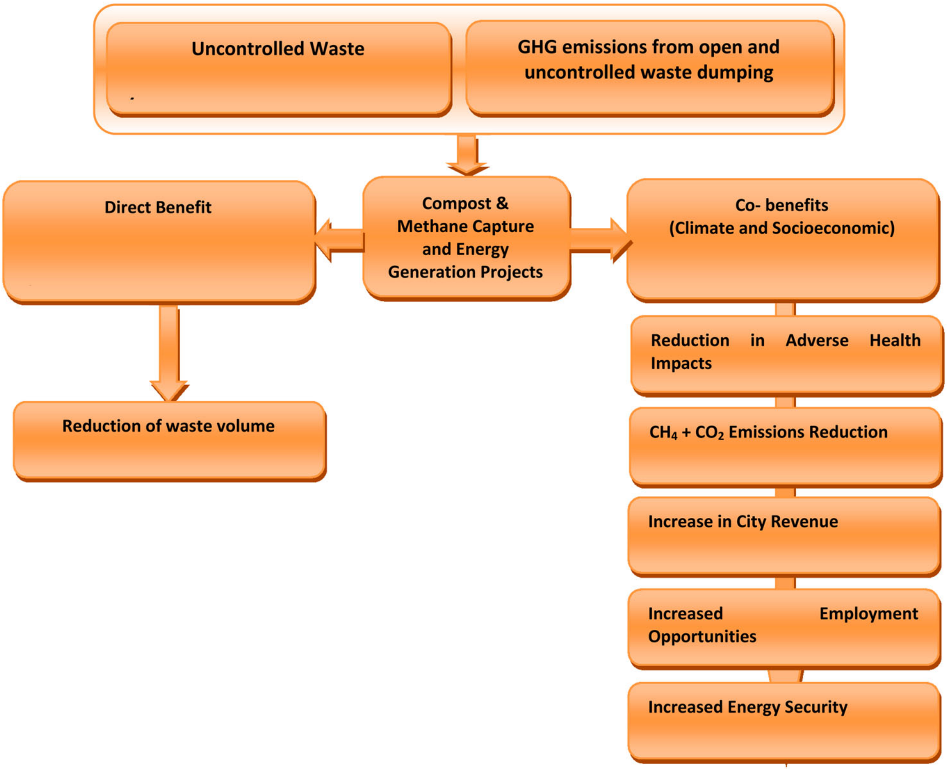

Figure 2. Benefits of waste sector interventions.

4. Urban interventions implementation barriers

As of now, there is no interest in stand-alone urban mitigation and adaptation programmes in the cities in developing countries. Mitigation and adaptation objectives will have to be, thus, achieved through the effective and synergistic use of interventions primarily aimed at solving urban economic development, environmental, and service delivery problems. Cities will have to reframe, localise, and bundle local urban issues in order to mobilise local action on urban climate change (Lasco *et al.* 2004, de Oliveira 2009). Even though cities may be implementing some of the suggested interventions, they lack effective and synergistic use of the interventions on a larger scale. Despite of obvious benefits many cities are still not implementing these interventions, because there exist several barriers that hinder deployment of these interventions. Barriers include but are not limited to: lack of information and knowledge, low human and institutional capacity and flexibility, political unwillingness and minimal funding, and poor inter-agency communication. They hinder wide-scale implementation of the suggested interventions. These barriers need to be addressed for the suggested urban interventions to be synergistically implemented at a scale necessary to curb rising urban emissions and cause noticeable improvement in urban climate resilience.

4.1. Lack of information and knowledge

Constitutional mandates dictate cities in developing countries to provide basic services (e.g. roads, water, sanitation, and waste management). Many cities do not go beyond the mandates and do things that changing urban forms need or demand with changing urban, social, and climatic context. For instance, many city plans have no target for GHG emissions; plans for Beijing, Delhi, and Amman do not even provide data regarding overall emissions reduction (Jabareen 2015). Not

Table 4. Waste emissions mitigation projects and their emissions reduction and revenue generating potential.

City	Project type	Project start date	Annual CO_2 reduction	Annual financial savings
Copenhagen, Denmark	Landfill- – less waste, more separation (only 3% of waste into landfill).	1990	40,000 tons CO_2 is reduced by recycling paper, cardboard, plastic, glass.	$670,856 USD
Dhaka, Bangladesh	Composting-waste is composted and sold as bio-rich fertiliser – reducing emissions, generating jobs, and cleaning up the city.	1995	1270 Tonnes	$7218 USD for a 3 tons/day capacity plant (both from plants and carbon credits)
Gothenburg, Sweden	Integrated waste system – waste to energy cuts 200,000 tCO_2 annually.	1972	205,060 tons (2006)	$33.6M USD (Annual financial savings = sales of energy from incineration 2006)
Sao Paulo, Brazil	Energy and waste-thermoelectric power plants to burn biogases emitted by decaying waste from the landfills in order to produce clean energy and prevent GHG to be thrown into the atmosphere.	The Bandeirantes Powerplant started operating in January 2004, and the Sao Joao, in January 2008.	Total reduction of 11 million tons by 2012	€ 26,786,490.00 from public auctions of Carbon Credits (CERs)
Sydney, Australia	Recycling programme – cuts 210,000t CO_2 and generates $11.6M USD annually.	2004	210,000 tons per annum, processing around 11% of Sydney's municipal waste.	$11.6M USD ($14M AUS), based on CO_2 abatement savings.
Emfuleni, South Africa	Efficiency – a water efficiency system known as advanced pressure management reduces pressure in the city's water network, thus reducing the amount of water leaking through small undetected holes.	Conceptualised: 2004 Implemented: 2005	12,000 tons	$3.5 million

Source: Adapted from C40 best practices.

only mitigation of GHGs, which is often considered to be causing global problems, but also mitigation of rising urban climate impacts are considered a priority. Sharma and Tomar (2010) cite a lack of understanding of climate change impacts at the local government level as one of the biggest impediments towards urban climate change adaptation governance in India. The situation is not very different in other developing countries or emerging economies. In Lima, Peru and Santiago, Chile, representatives from different administrative levels attribute inadequate knowledge and poor incentives to their lack of willingness to take responsibility for climate risk reduction and management (Lehmann *et al.* 2015). In the absence of required information, cities are not fully aware of cumulative impacts that frequent weather events have. Loss incurred as a result of small climate-induced extreme events can add up over the course of time. Small hazards, when added up in terms of their impact and damage potential, could very well be more devastating than low-frequency large-scale disasters (Bull-Kamanga *et al.* 2003). This lack of understanding at a local level leads to apathy toward preparedness and management to reduce current and future urban climatic risks and threats.

Lack of reliable data and information to inform policy decisions hinders the widespread effective and synergistic use of the suggested interventions. Many cities do not have useful, credible, and relevant data and information on urban emissions, climate risk and impacts, and suggested adaptation measures and incurred costs. The lack of local-level information makes it hard for planners to effectively use these interventions. Without data on the total market and non-market costs incurred as result of emissions and climate-induced extreme weather, the total loss incurred cannot be calculated; without this information, local governments will not recognise the gravity of these risks and threats or the need for action.

The existing information and knowledge void hinders local actions against rising urban GHG emissions and climate-induced extreme weather events; it can and should be bridged. The science community in developing countries can play an important role in filling this void. Often, they have access to the best available science, which can be applied to generate locally relevant estimates of potential impacts and losses. Alternatively, planners and policy-makers can reach out to the in-country science community to seek "concrete" information such as urban area most exposed to urban emissions and extreme weather events. Gaining such information is crucial, as it will allow planners and policy-makers to better understand the nature of impacts and the population and assets exposed. They can also identify and sequence appropriate urban interventions to reduce and manage both current and future impacts.

4.2. Lack of human and institutional capacity and flexibility

City-level public authorities have the governmental control, legislative mandate, and institutional mandate to contain rising urban emissions and address climatic risks and impacts through the synergetic use of suggested interventions; lack of required human and institutional capacity often undermines these efforts. Human and institutional capacity and flexibility are important if the implemented interventions are to achieve their fullest potential. The risk of failure increases if the capacity level is low; for instance, even though many countries have emission inspection programmes for automobiles (CONCAWE 2006), the lack of institutional capacity has led to poor implementation of emission standards like vehicle inspection and maintenance (I/M) programmes . More than 15% of drivers do not take I/M tests in India; those who do, pass without truly controlling their emissions (USAID 2004). In many cases, cities may not be aware of how much of the population is affected by rising emissions and extreme weather events. For instance, institutions like the Kampala City Council in Uganda lack capacity in climate change vulnerability assessment, climate change adaptation, and climate change mitigation. Key departments in the council, such as urban planning, public health, environment, public transport, and energy, do not prioritise climate change on their agendas, meaning capacity must be built before they can address adaptation and mitigation to climate change (UNHABITAT 2010b). The situation is similar in neighbouring Kenya. Mombasa, the second-largest city in Kenya, is a growing, vulnerable urban centre with low adaptive capacity, as limited institutional capacity is unable to contain withering resilience and enhance climate change adaptation (Awuor *et al.* 2008). The lack of human and institutional capacity is a severe constraint to containing rising urban emissions and improving urban climate resilience, even in cities that recognise urban climate change risks and impacts. For example, because Estelí, Nicaragua is frequently affected by climate events like urban flooding, it developed an Urban Development Plan for 2005–2015; however, it does not have the human capacity or financial resources to implement it. Institutional capacity for public education about risk prevention and preparedness is also very limited (ICF 2012).

Enhancing human and institutional capacity is crucial, because climate change mitigation and adaptation requires strong human capital and institutional systems, among other things (Adger *et al.* 2003, Dulal and Akbar 2013). It plays a pivotal role in changing the individual attitudes of local planners and decision-makers and creating champions for urban climate change mitigation and adaptation. The latter is a factor behind successful urban adaptation initiatives (Moser and Ekstrom 2012). The political and administrative structure provided by institutions can either enable or restrict adaptation to climate change (Dulal *et al.* 2010, Amaru and Chhetri 2013, Pasquini *et al.* 2015, Smucker *et al.* 2015). The congruence of personal perspectives and beliefs of key actors involved in urban planning is a major determining factor in the promotion of adaptation activities in Berlin, Germany (Lehmann *et al.* 2015). Building institutional capacity is equally important, because Governance arrangements can offset damage and enhance opportunities linked to urban GHG emissions and climate change hazards. Institutions influence adaptation and climate vulnerability in three critical ways: (1) they structure impacts and vulnerability, (2) they mediate between individual and collective responses to climate impacts and shape adaptation outcomes, and (3) they deliver external resources to facilitate adaptation, and thus govern access to such resources (Agrawal 2008). Institutions can offset both market and non-market impacts by developing, communicating, and implementing proactive adaptation strategies and creating networks between various stakeholders (Carter *et al.* 2015). However, building human and institutional capacity should not be treated as an end in itself; rather, a means to support flexible systems and approaches. Local institutions in developing countries are not very flexible, as a result of fragmented governance arrangements, asymmetrical access to information, and top-down decision making. Through greater institutional flexibility, changes in the existing institutional rules, regulations, and laws can attain meaningful reduction in urban emissions and climate risks and impacts. Currently, cities lack the required human and institutional capital to accurately assess the highest potential emissions and vulnerability reductions that can be achieved through the synergistic use of available urban planning and policy instruments.

4.3. Lack of political will and funding

At the city-level, all decisions are influenced by political interests and competing interests vying for support. Short-term political and budget cycles do not allow politicians to look beyond immediate problems. Key decision-makers, like elected officials, lack the political will and funding to implement the suggested urban interventions. Urban emissions and climate impacts are considered a "future problem". For instance, most municipal authorities in India consistently grapple with large infrastructure deficits and service delivery problems; they do not see climate change adaptation as a priority or responsibility (Sharma and Tomar 2010). The lack of political will can be addressed if urban planners and senior city officials are well informed about the nature of urban emissions and impacts, and subsequent losses incurred. Indicative evidence reveals that city planners can take up urban climate adaptation, to varying degrees (Measham *et al.* 2011). City planners could advise elected officials on how to synergistically use interventions to tackle urban problems and achieve climate change co-benefits.

A general lack of resources also stymies the political motivation to solve urban air pollution and climate change-related problems. Funding plays a crucial role in local implementation of the suggested interventions. Evidence suggests cities are more likely to adopt urban interventions when funding is available, whether or not they are specifically designed to mitigate climate change and its impacts. In Sweden, between 1998 and 2002, local actors could apply for funds from the Local Investment Program (LIP) focusing on sustainable development. Evaluations show that only 55% of the Swedish municipalities obtained grants from the LIP. In most cases, municipalities that did not receive grants did not focus on environmental efforts (Granberg and Elander 2007). In cities in developing countries, a wider use of the suggested urban interventions is unlikely without a dedicated stream of funding available.

Funding could come from various sources, such as the central government, multilateral and bilateral donors, and international non-governmental organisations. Central governments could provide funding for the implementation of urban interventions with the potential to reduce urban emissions and climatic risks and impacts. They could also mediate among municipalities within megacities and help them collectively pool funding and experiences for the synergistic use and wide application of these instruments. The distribution of central funds to adopt interventions could trigger "demonstration effects" in other cities. Together, these proactive cities could work together to develop and exchange information about the use of specific interventions and share experiences to broaden and replicate successful initiatives.

4.4. Lack of inter-agency communication and coordination

Many cities in developing countries use one or more of the suggested interventions, but do not fully benefit from using such interventions. Sporadic and uncoordinated implementation of these interventions limits the maximum accrual of benefits. Institutional fragmentation results in unnecessary duplication of management efforts and emissions and disaster risk reduction. Horizontal coordination among agencies is further impeded by compartmentalisation, resulting from strong sectoral structure. As responsible agencies operate in "silos", assistance does not often reach communities at risk or affected by emissions and climate-induced extreme weather events. Even when it does, publicly transmitted information is largely for educational purposes. For instance, institutional barriers to urban climate change adaptation in Lima, Peru are the lack of a coordinating organisation and low inter-organisational cooperation. This lack of coordination also hampered the effective flow of information needed for the development of a general adaptation strategy (Lehmann *et al.* 2015). Communication and coordination among agencies involved in urban emissions and disaster risk reduction is crucial if urban emissions and climate risks and impacts are to be reduced to acceptable levels. For example, Cuba has an outstanding record of successful risk reduction and disaster mitigation. Cooperation among local institutions is the reason for the low number of casualties from strong hurricanes that hit the island every year (Rodriguez and Perez 2004). Several institutions in Cuba constitute a well-coordinated network of organisations capable of developing both preventive and reactive measures at the local and municipal levels (Lizarralde *et al.* 2015).

Institutional fragmentation in many cities in developing countries leads to coordination failures, which is especially evident during and after urban flooding and heat island effects. Concerned agencies fear encroachment of authority and institutional power, and therefore do not join forces and use these suggested interventions. Existing communication and coordination failures can be largely corrected if urban emissions and disaster risk reduction and management are consolidated into one governing body. Such a body could bring together formal, semi-formal, and informal sectors together to design and implement the suggested urban interventions. This newly formed agency can enable relevant departments within the city to integrate datasets, jointly prioritise the use of suggested interventions, share new knowledge and best practices, and secure higher level government support to enact transformational changes in how these interventions are implemented and sequenced. The design and implementation of the suggested urban interventions would become more effective when a single government agency takes coordinating lead to oversee urban interventions. The need for this agency becomes more important when diverse federal, state, and local tiers of government manage the city. In such cases, cities function as a complex system, where various urban activities are linked by socioeconomic interchanges and transportation activities.

5. Conclusion

Cities in developing countries are both culprits and victims of climate change. Rising urban emissions resulting from urban-centric economic growth has made them more exposed to rising emissions, including GHGs. They are also becoming increasingly vulnerable to climate-induced extreme weather events, as with increase in urban-centric migration and growing income inequality, poor urban dwellers with low paying jobs increasingly inhabit in hazard-prone areas. High urban land prices limit the ability of emigrants to live in safe and secure areas. As a result, they often live in more polluted and climate-exposed areas. It is not that cities in developing countries are not doing anything to address these problems. Many cities in developing countries are proactively dealing with rapidly increasing urban problems, such as congestion, pollution, and vulnerability to climate-induced extreme weather events. China, India, Mexico, Colombia, and Brazil are the frontrunners in urban sustainability and climate change experiments and innovations, with proactive implementation of many suggested urban interventions.

However, ongoing implementation of the suggested interventions is not well distributed and synergistic use of these interventions is yet to happen. Furthermore, there is a clear preference given to certain type of interventions. For instance, in Asia and Africa, infrastructure interventions are widely used; however, in South and Central America, urban transport interventions are preferred (Bulkeley and Castán Broto 2013). Selective use of urban policy interventions is not the right thing to do if cities are to achieve low-carbon and climate-resilient urban development pathways. Doing so will not help cities solve complex urban problems, such as traffic congestion, local air pollution, and climate risk reduction and management.

The synergistic use of multiple instruments across multiple sectors is needed if cities in developing countries are to bring rapidly increasing emissions, including GHGs and climate change vulnerability down to acceptable levels. However, before this happens, these cities must address existing implementation barriers: lack of information and understanding of rising GHG emissions and urban climatic risks and threats, human and institutional capacity and flexibility, political willingness and funding, and inter-agency communication and coordination. Local planners and policy-makers in cities in developing countries need to recognise the costs imposed by rising air pollution and climate-induced extreme weather events. They also need to know how rising emissions and climate change vulnerability can be reduced through synergistic use of various sectoral interventions. They may be more motivated to implement the suggested interventions if they know the positive welfare impacts of these interventions. Evidence suggests that instruments – like congestion charge – have the potential to generate revenue if used judiciously and recycled properly in the economy.

In order for the cities of developing countries to effectively implement and benefit from the suggested interventions, the existing human and capacity gaps needs to be bridged. Closer coordination between the sectoral agencies is necessary to ensure that interventions aimed at addressing existing urban problems such as traffic congestion and air pollution control yield greater climate change mitigation and adaptation co-benefits. Local agencies need to move away from current siloed efforts to a more accommodating, flexible approach to solve existing, cross-sectoral urban problems. The adoption of a special coordinating agency would ensure proper communication and coordination in urban issues, including emissions and climate vulnerability reduction and adaptation. Planners have a greater role to play in order to foster political willingness. They need to explain critical sectoral linkages and why the synergistic use of sectoral instruments is more cost-effective to tackle urban problems, including rising GHG emissions and vulnerability to climate change. As funding is always an issue, planners also need to explain as and how local elected leaders can convince national governments to establish special grants for cities interested in advancing urban sustainability and climate change agendas.

Both emissions and vulnerability to climate change are increasing in the cities of developing countries. These cities are not in position to tackle the problem on their own. They need help to establish information and knowledge databases, build human and institutional capacity, secure necessary funding, and improve inter-agency communication and coordination. Instead of funnelling more funds on stand-alone urban climate change mitigation and climate change programmes, donor communities would most benefit cities through policy support and multi-sectoral emissions reduction programmes. Financing these initiatives would reduce urban GHG emissions and contain ongoing deterioration of urban resilience. Greater cumulative emissions reductions and climate co-benefits can be achieved through the synergistic use of suggested urban interventions than through stand-alone sectoral projects.

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