Climate change and metabolic dynamics in Latin American major cities

G. Delgado-Ramos
Interdisciplinary Research Centre on Sciences and Humanities, National Autonomous University of Mexico, Mexico

Abstract

Climate and environmental problems have become increasing challenges for cities, especially for those experiencing rapid urban expansion and population growth. The dimension and likely implications of these challenges can be better assessed if metabolic analyses of inflows, outflows and stocks of energy and materials are carried out in addition to conventional means of evaluation. Urban metabolic analyses have been carried out for different cities and for diverse metabolic aspects or flows, but it has been largely absent in Latin America. This paper opens with a general introduction to the current state of Latin American cities. It introduces the main aspects of the urban metabolism analytic approach and offers an initial comprehensive comparative estimate of inflows and outflows of some Latin American major cities: Mexico City, Sao Paulo, Rio de Janeiro, Buenos Aires, Quito and Bogota. A rough estimate of Mexico City's stock of materials is then presented. The main characteristics of climate change plans are discussed in later pages with the purpose of offering a brief analysis of mitigation actions and existing metabolic dynamics. The paper concludes with some policy and governance considerations for the urban future and the forthcoming challenges and feasible opportunities at local or urban levels.
Keywords: urban metabolism, climate change, Latin America, low carbon cities.

1 Introduction

Latin America (LA) is the most urbanized developing region in the world, with about 78% of its population already living in cities and an average expansion rate of 1.8% annually [1].

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Main Latin American capitals expanded quickly during the second half of the 20th century, mainly as a result of rural migration and a high concentration of economic activities. Lack of proper land use planning, high rates of motorization, economic asymmetries within the population, among other aspects, generated and still deliver very disorganized, complex, unsustainable and uneven urban fabrics (27% of urban population in LA lives in irregular and marginalized settlements [1]).

Mexico City, for example, doubled its size and ten-folded its vehicle fleet from 1950 to 1970. By the year 2000 the city expanded again three times while the vehicle fleet did so by more than 500%. In the mid-1980s air quality was already so bad that it was described as the most polluted city in the world [2]. And yet, even if air quality has relatively improved by now, urban fabric is still expanding and socioeconomic relationships established with nearby mid-size cities are leading to an even more complex dynamics that indeed are giving shape to an urban corridor or urbanized region in central Mexico [3].

As an outcome of “planning-by-doing”, or of a lack of long term planning, but also as a result of limited economic resources and insufficient governance capacity, Latin American cities have been for the most part locked into an inefficient and/or not well integrated infrastructure; this inertia has lately complicated planning and implementing sustainable, low-carbon alternatives for development [4–6].

Below it is presented – from an urban metabolism approach – an estimate of the energy and materials demand of Mexico City, Sao Paulo, Rio de Janeiro, Buenos Aires, Quito and Bogota. As this paper seeks to offer an analysis of mitigation actions and existing metabolic dynamics, the selection of cities is based on two criteria: relevance by size and political power within the region, and the existence of a climate change action plan (with the exception of Bogota which doesn’t have one, yet because of its size is still included).

2 Urban metabolism flow patterns of selected Latin American cities

The more complex a society becomes, the more entropy is generated as more energy and materials are demanded to sustain the population biologically and to provide for intermediate biophysical structures with a role in social production and reproduction [7].

In the last century, human population increased fourfold worldwide while materials and energy use increased on average tenfold. Biomass use increased 3.5 times, energy use 12 times, metal ores 19 times, and construction minerals, mainly cement, about 34 times [8]. By 2000, the global level of resource extraction was 48.5 billion tons and per capita global materials consumption was 8.1 tons per person/year, however, per capita variations were of more than one order of magnitude [9]. By the end of the first decade of the 21st century, humanity used – unevenly – 500 thousand petajoules (Pj) of primary energy, about 50–60 billion tons of raw materials yearly [10], and generated more than 1.1 billion tons of municipal solid waste (depending on the definitions of waste streams, availability of data and management practices, the actual total amount may range from 2.5 to 4 billion tons when considering rural waste, irregular disposed residues, etcetera) [11].

The future business as usual (BAU) scenario is not encouraging: energy and material consumption may double by 2050. Yet total energy and material consumption would only grow 40% if developed countries reduced their consumption by a factor of two and developing countries registered only a moderate increase [12].

Since in the same period, population growth will be mostly urban, it is manifest that urban systems certainly will impose significant resource demands which in turn will increase, as they do now, multi-spatial interdependences on resource supply, often with stronger links across national boundaries than those found among urban systems and their own hinterlands or other subnational linkages. This is largely due to energy and material flows required to build, operate, maintain and expand urban infrastructure (urban stocks), which in turn support a certain level of quality of life by sustaining socioeconomic, cultural and other activities. Measuring such flows and stocks allows a policy-useful quantification of both direct and indirect greenhouse gases (GHGs) emissions as well as other environmental externalities (or sustainability patterns) of current and future scenarios.

Several metabolic assessments have been carried out, mainly for cities of developed or emerging economies and for different flows or metabolic aspects. It could be said that the call for studies on urban metabolism was already proposed in the writings of Geddes in 1915 [13] and later on by Mumford in 1961 [14]. It was Wolman, however, who in 1965 offered the first empirical approach for a hypothetical US city of one million inhabitants [15]. Wolman's main inflows were water, food and fuel, while main outflows were wastewater, solid waste and atmospheric pollutants [15]. Since then, besides the relevant contributions of Hanya and Ambe [16], Newcombe *et al.* [17], Boyden *et al.* [18], Baccini and Brunner [19] and more recently those of Kennedy *et al.* [20, 21] and Minx *et al.* [22], all published works have increased the scope of flows, using even more complex analytical frameworks and tools (a review of research methodologies is for example offered by Zhang [23]). Assessments for Miami, Taipei and Paris have been carried out from an energy approach [24–26]. Other studies have focused on urban metabolism of water [27–29], food and nutrients cycles [30–33], residues [34–39], transport and food [6, 40].

In following pages, this paper offers some rough data for energy, water and food inflows, and GHGs, wastewater and solid waste outflows of selected Latin American cities. More detailed information and analyses (for example, following time lines) don't seem to be available yet (apart from Bogota's case [41]). Table 1 summarizes metabolic patterns of such flows on a per capita consumption basis (for comparative purposes). This rough data mining and estimations of LA cities' flows are nevertheless useful for a first comparative glance, even when there is a clear lack of (reliable) data at city scale.

Table 1: Metabolic flow patterns of selected Latin American cities.

City	*Population (millions of inhabitants)*	*Population density (inhabitants per km^2)*	*Energy (Pj, total)*	*Water (litres capita/daily)*		*Food (capita/daily)*		*Sectorial direct emissions (kg of CO_2e capita/daily)*	*Waste water (litres capita /daily)*	*Solid Waste (kg capita/daily)*
				Total inflow	*Actually consumed*	*Weight (kg)*	*Meat, milk and eggs GHG (kg of CO_2e)*			
Mexico City	8.85 (22*)	6,020 (2,845*)	706*	327	220	2.01*	1.98*	6.8*	~390 ♠	1.4
Sao Paulo	11.31 (20*)	7,492 (2,492*)	~277.8 ♥	290	186.8 191	1.99	2.91	4.1	120	0.93
Rio de Janeiro	6.35 (11*)	5,250 (1,948*)	~161 ♥	472	237.8 226	1.99	2.91	1.9	170	0.98
Buenos Aires	3 (12*)	14,778 (3,130*)	337.8	535*	370*	2.06	4.31	9.04	500*	1.66
Quito	1.6 (2.2*)	4,545 (527*)	~50.1* ♥	271*	189*	1.41	1.76	~13 (25.7*)	---	0.73
Bogota D.C.	7.3 (9.85*)	21,276	228.7	428	171	1.82	1.99	5.17	192	0.76

* Metropolitan estimation

♥ Optimistic estimation.

♠ Includes water leaks, rainwater and other irregular sources.

Source: Author's compilation based on [40, 43–62].

2.1 Mexico City

The metropolitan area (Zona Metropolitana del Valle de México) covers 7,732 km^2. It embraces 59 municipalities of Estado de Mexico and 16 districts (*delegaciones*) of the Federal District (DF, according to its Spanish initials). DF or Mexico City covers 19% of total metropolitan area or 1,470 km^2 [43]. Total metropolitan population amounts to 22 million inhabitants, while DF's population is less than 9 million inhabitants. In 1990, metropolitan energy consumption, excluding electricity and jet fuel, was 443 Pj. It increased to 545 Pj in 2006, in addition to 14 million Mw/h (70% for industrial activities) [44]. By 2010 energy consumption reached 706 Pj, of which 527 Pj were generated by fossil fuels and 179 Pj of electricity produced outside the metropolitan area [43]. Gasoline was 34% of the total, 17% natural gas, 14% liquefied gas, and 10% diesel [43].

The city's water inflow amounted to 327 litres per capita daily in 2007 (35 litres less than in 1997), yet actual per capita water consumption was 220 litres daily since leakage losses accounted – and still do – for 30% of total water inflows [45, 46]. Metropolitan food demand has been estimated at about 16.16 million tons for 2009. Meat, milk and eggs consumption added up to 1.4 million tons, 2.5 million tons and 400 thousand tons respectively every year [40]. Direct and indirect emissions associated with those products are estimated to be about 16 million tons of CO_2e [40]. In addition, all sectorial metropolitan direct emissions contributed 51 million tons of CO_2e in 2008 and 54.7 million tons of

CO_2e in 2010 (22.94 million tons from the transport sector, 11.9 million tons from industry and 10.2 million from waste disposal) [43]. Data for 2007 indicates that wastewater is discharged at a rate of 40 m^3/s of which only $4m^3$ are treated [46]. City's municipal solid waste outflow was composed in 2010 of 12,589 tons daily and 7 thousand tons of construction debris daily [47]. Per capita solid waste stream has increased about four times since 1950.

2.2 Sao Paulo

The metropolitan area covers 7,943 km^2 and has a population of 19.8 million inhabitants. The city, of 1,522 km^2, has a population of 11.3 million inhabitants. City's electricity consumption was 35.5 million Mw/h or 127.8 Pj in 2010, while transport fuels accounted for about 150 Pj [based on 48]. Water supply was 71 m^3/s daily in 2008; consumption was 191 litres per capita daily and leakage losses of about 100 litres per capita daily (or 35% of the total) [49]. Metropolitan food demand has been estimated in 14.5 million tons for 2009. Consumption of meat, milk and eggs was 1.6 tons, 2.5 million tons and 150,000 tons, respectively [40]. Total direct and indirect emissions associated to those products are of about 21.25 million tons of CO_2e [40]. Sectorial direct emissions were 15.74 million tons of CO_2e in 2003, 54% attributable to transport and 23.5% to waste [48]. In 2006 wastewater flows were 15.4 m^3/s for the city and 25.4 m^3/s for the metropolitan area. Total municipal waste stream in 2011 totalized 3,829,799 tons or 10,493 tons daily [50].

2.3 Rio de Janeiro

About 11 million inhabitants live in Rio's metropolitan area, which covers 5,645 km^2. The city itself covers 1,200 km^2 and has a population of more than 6.3 million inhabitants. The city's electricity consumption was 14.5 million Mw/h or 52 Pj in 2010; natural gas consumption accounted for 58 Pj; and gasoline and diesel added another 51 Pj [based on 51]. Water supply in 2008 was 2,877,120 m^3 daily with a per capita consumption of 226 litres and about 32.8% of water leakage losses [49]. Metropolitan food demand has been estimated in 8 million tons for 2009 [40]. Consumption of meat, milk and eggs is in the order of 885,500 tons, 1.37 million tons and 82,500 tons, respectively. Total direct and indirect emissions associated with those products totalized 11.7 million tons of CO_2e [40]. Sectorial direct city emissions added up to 11.35 million tons of CO_2e in 2005, the energy sector being the greatest contributor with 64% of total emissions (transport sub-sector represented 41.3%), followed by waste with 31.5% of emissions (mainly methane) [51]. Metropolitan GHGs emissions were for that same year 19.74 million tons of CO_2, 41% from transport sector only [51]. Wastewater amounted to 378 million m^3 in 2008 while waste outflows were 2,277,346 tons in 2011 (or 6,239 tons daily) [50].

2.4 Buenos Aires

The metropolitan area covers 3,833km^2 and contains 12 million inhabitants. The city, or *Ciudad Autónoma*, had about 3 million inhabitants in 203 km^2. The city's energy consumption has been estimated for 2008 at 370 Pj (27.1% energy production, 36% transport, 23% dwellings, 10.6% commerce and the rest industry). Gasoline and diesel accounted for 133 Pj and electricity for 137.4 Pj or 38.17 million Mwh [52]. Fresh water inflow was 535 litres per capita daily drawn from the La Plata River and in small amounts from local aquifers. Water system's efficiency is low since average consumption has been estimated in 370 litres per capita daily with peak consumptions in wealthy neighbourhoods of 454-431 litres per capita daily [53]. Metropolitan food demand has been estimated at 9 million tons for 2009 [40]. As expected, Argentinian diet is carbon intensive, mainly because of high consumption of meat and dairy products that make up 43.7% of total food intake in terms of weight [40]. Direct and indirect emissions related only to meat, milk, and eggs, are 19 million tons of CO_2e yearly [40]. In addition, other direct sectorial GHGs emissions in 2010 added up to 9.91 million tons of CO_2e of which 3.3 million corresponded only to transport [54]. Wastewater outflow is 500 litres per capita daily but the actual capacity for water treatment is only enough for 1.7 million inhabitants [53]. Total waste emitted by the city in 2008 was 5,055 tons daily or 1.85 million tons a year [55].

2.5 Quito

The metropolitan area covers 4,230 km^2 with a population of 2.23 million inhabitants. The main urbanized area of 352 km^2 contains 1.6 million inhabitants according to 2010 census. Electricity demand in 2011 was 3.5 million MWh or 12.9 Pj, of which 2.2 Pj was hydroelectricity [56]. Gasoline and diesel accounted for about 37.2 Pj [based on 57]. Total crude water inflow in 2011 was 7.73 m^3/s (89.4% superficial and the rest from aquifers and springs) while drinking water actually distributed was 7.18 m^3/s [58]. Metropolitan food demand has been estimated at 1.15 million tons for 2009 (based on national consumption intake average [59]). Consumption of meat, milk and eggs was 125,772 tons, 208,059 million tons and 12,711 tons, respectively. Total direct and indirect emissions associated with those products added up to about 1.43 million tons of CO_2e [based on 40]. Sectorial direct city emissions added up, at the metropolitan level, to 20.93 million tons of CO_2e in 2007; 38% were attributable to agriculture, 32% to waste and 15% to the energy sector, which includes transport [57]. Wastewater service coverage reaches 96% in the most urbanized areas and 90% in the less urbanized areas [58]. Waste stream for 2011 reach 598,708 tons, 6% more than in the previous year [60].

2.6 Bogota

Bogota D.C. covers an area of 384 km^2 with 7.3 million inhabitants. In 2010, the city's energy consumption was 10,236 GWh or 34% of national electricity consumption [41]. In addition to those 132.7 Pj of electricity, other 96 Pj of fuels were used for transport [41]. Water infrastructure capacity is of 36.5 m^3/s. In 2009 the system delivered 14.6 m^3/s, though paid consumption was only of 8.6 m^3/s due to illegal water use and leakage [41]. Water consumption is expected to increase by 2025 to 19.5 m^3/s [41]. Metropolitan consumption of food has been estimated at 4.86 million tons for 2009 (based on national consumption intake average [59]). Consumption of meat, milk and eggs was 339,450 tons, 992,070 tons and 78,840 tons, respectively. Total direct and indirect emissions associated with those products added up to 5.31 million tons of CO_2e [based on 40]. Sectorial direct city emissions added up to, in 2008, 13.49 million tons of CO_2e, 51% attributable to energy sector which includes transport [61]. City's wastewater outflows in 2010 were 16.3 m^3/s while municipal solid waste was, in 2009, of about 3.6 thousand tons daily [62] + 70 thousand tons annually of hazardous waste [63].

2.7 Urban stock analysis: the case of Mexico City

Traditionally urban metabolism has quantified flows; however, the great relevance of stocks accounting has recently been recognized [19]. Today most materials (and energy embedded) are to be found in urban stocks of mature cities, which accordingly have the greatest potential for reusing and recycling such materials. New cities are, on the contrary, demanding increasing flows in order to magnify their own stock as a consequence of their expansion. The BAU resource demands from both old and newer settlements certainly imply major environmental and climate consequences.

Stock material calculation is absent in LA; however, the case of Mexico City is being analysed as part of a research project currently under way at the National Autonomous University of Mexico (UNAM) [64]. Preliminary rough data, to be merely taken as an argument of stock's relevance more than an empirical validation, suggests that Mexico City's stock is essentially comprised by at least: 352.4 million tons of steel; 395.4 million tons of concrete; 90.7 million tons of cement; 276,563 tons of aluminium; and 48.7 million tons of asphalt. Transport infrastructure (including vehicle fleet), buildings and network-type infrastructure such as electricity, water and wastewater disposal represent the main share as presented in Table 2. Carbon embedded emissions of such infrastructure crudely and overoptimistically added up to 930.56 million tons of CO_2e. If 1% of infrastructure renovation indeed takes place annually, carbon embedded or GHGs associated to replace it – with no material production efficiency change – would be equivalent to 17% of the city's total direct GHGs emissions of 2010; and this doesn't consider urban expansion at all. (Following the lowest percentage of infrastructure renovation in urban settlements estimated by Davis *et al.* [66].)

3 Metabolic dynamics and climate change action plans

The analysis of urban flows and stocks and their interactions enables current and future policy design to keep pace with reasonable future metabolic scenarios (more efficient and sustainable), while considering eventual uncertainties and challenges such as resource availability/depletion, environmental pollution, climate change, among other issues, in and out of city limits.

Metabolic planning is however limited. In order to be more useful it needs to be integrated to land use planning with infrastructure design, operation and renewal, and material recycling and urban mining (or planned material recovery through time from expected urban stock decommissioning) [6, 19, 38, 39, 65].

Table 2: Rough estimation of Mexico City (not metro) stocks and its carbon content by sector and main materials.

Sector	*Sub-sector*	*Material Stock*	*Energy/carbon embedded emissions*
Transport (reliable estimations)	Roads*	48.7 million tons of asphaltic mix	15.9 million tons
	Vehicle fleet	2.4 million tons of steel	4.6 million tons
		275,000 tons of aluminium	2.2 million tons
	Metro infrastructure**	2.28 million tons of concrete	679,000 tons
		3.1 million tons of steel	6.5 million tons
Water infrastructure (medium reliability estimations)	Water supply & waste pipeline network***	172,750 tons of fibrocement	137,854 tons
		85,385 tons of PVC	213,462 tons
		105,470 tons of HDPE	210,940 tons
		145,644 tons of steel	305,852 tons
Electricity (medium to low reliability estimations)	Distribution network****	1,563 tons of aluminium	13,051 tons
		18,528 tons of copper	70,035 tons
Buildings***** (unreliable estimations)	90.72 million tons of cement		72.39 million tons
	393.12 million tons of concrete		50.65 million tons
	346.76 million tons of steel		727.56 million tons
	169.34 million tons of bricks		49.14 million tons
TOTAL CARBON EMBEDDED EMISSIONS			930.56 million tons

*It includes primary, secondary and tertiary roads (based on Delgado [6]).

**Based on average material input analysis of L12 [6]. Total system length: 225.9 km.

***Network material composition is assumed as follows: 30% for fibrocement, 30% PVC, 30% HDPE and 10% steel. Primary and secondary pipelines are both taken into account. Considering city infrastructure norms, primary supply pipelines are assumed to be on average 50cm of diameter, and secondary pipes of 22–25cm. Primary waste water pipelines are assumed to be on average 60cm of diameter, and secondary pipelines 22–25cm. Fibrocement emissions are assumed to be equal as those of cement. Emission factors have been taken from Calkins [42].

****Distribution network length has been estimated based on national system's length official data and the percentage of users and energy consumed in Distrito Federal. It includes all types of electric voltage lines (mostly 34.5–13.2 kV). Recent changes from copper to aluminium cable make it difficult to allocate real amounts to one or other material. A mix of 80% copper and 20% aluminium has been assumed. Weight factors are assumed to be 400 kg/km for copper and 135 kg/km for aluminium. Emission factors have been taken from Calkins [42].

*****Amounts of materials are based on an optimistic average of 2.5-floor buildings for the entire city (of 504 km^2 of urbanized surface; area excludes conservation land and green areas). Amount of materials per constructed square meter has been established unilaterally as follows: 780 kg of concrete/m^2 of construction (only first floor); 120 kg of cement per m^2 (except first floor); 224 kg/m^2 of bricks; 275 kg of steel per m^2 (except first floor).

Source: Author's compilation based on national construction norms and [6, 42].

Such a broad approach to urban metabolic analyses should be then understood as part of an integral urban planning approach that also demands taking into account specific aspects of each city, such as geographical location, urban form, economic structure, demography, income, social demands and organization, behavioural and cultural issues, as well as governance capacity and policy drivers.

The previous items are certainly relevant from an adaptation and mitigation of climate change perspective. Planning material and energy dynamics of settlements is not a minor issue, mostly because minimizing biophysical metabolism and thus direct and indirect emissions will be crucial, especially in relation to newer infrastructure. Already, existing infrastructure, much of which consumes or promotes the use of fossil fuels, has a lock-in effect as future emissions are expected to be 496 Giga-tons of CO_2 by 2060 [66]. Therefore, infrastructure will have to be chosen and designed for liveable and social inclusive low-carbon settlements; this means considering, among other aspects, climate conditions, weather resilience, energy embedded and GHGs emissions. Infrastructure replacement will require major attention –largely energy utilities, buildings and transport – in emerging economies and developed countries where infrastructure will need soon to be substituted [66]. Developing countries on the other hand will need to avoid as much as possible high-carbon infrastructure alternatives and at the same time increase infrastructure coverage as an outcome of policy design for future low-carbon settlements. In other words, “planning-by-doing” is not an option any more if climate change is to be indeed mitigated.

An analysis of selected Latin American cities’ climate change action plans, which are in some degree or another moving the climate change agenda forward, reveal an insufficient and asymmetric implementation of climate change mitigation and adaptation measures (the latter lagging behind the former). And moreover, climate change action plans are not sufficiently taking into account within their concrete mitigating measures, actions for reducing current indirect emissions related to material and energy flows (beyond those related to somehow shaping human behavioural issues such as diet), neither are they developing policies for eventually reducing future metabolic patterns. See Table 3 for main mitigation actions of climate change action plans of selected Latin American cities.

In addition to the above, a low or still limited integration among government agencies and policies, lack of governance capacity in terms of implementation and monitoring of concrete actions, as well as limited economic resources, are clearly noticeable. Brazilian cities are probably the less disarticulated but still face major challenges, similar to the rest of the cities here analysed. In the meantime, GHG reductions steps are being quickly surpassed by urban metabolism growth.

Table 3: Climate change mitigation actions as presented in official climate change programmes.

City	Base Line	Period	Reduction Goals	Mitigation actions																								Plan year
				Transport							Buildings					Energy				Waste			Waste water	Water supply	Land planning	Green spaces	Education, Consumption awareness and others	
				Public	Non-motorized	Hybrid / Electric / Efficient vehiles / Biofuels	Car pooling / car sharing / High Occupancy	Parking charges, road pricing, public transport subsides and other economic measures	Vehicle verification / Limits of emissions / filter requirement	Others	Energy efficiency	Building codes / Buildings renovation	Retrofiting	Financial measures (subsides, incentives)	Others	Efficiency	Alternative Energies	Financial measures	Other	Integrated waste management (avoiding waste, separation, reuse, composting, recycling)	Plastic management /reduction	Energy production	Water treatment		Mixed use land			
Buenos Aires	2008	2010-2030	30% below 2008 emissions (-5.13 Mtm CO_2e per year)	X	X	X				X	X	X	X			X	X			X			X					2009
Mexico City	2008	2008 2012*	7 million ton CO_2e	X	X			X	X	X	X	X	X			X	X			X		X	X	X				2008
Rio de Janeiro	2005	2005-2025	8% -2005, 16% -2016, 20%-2020.	X	X	X				X	X		X			X	X			X		X	X		X	X		2009
Sao Paulo				X	X	X					X	X	X			X	X			X		X	X		X	X		2011
Quito	2007	2012-2016	15% according to projected growth	X	X						X					X	X			X			X	X	X	X	X	2009
Bogota	2008			X	X	X	X					X	X			X	X			X	X	X				X		

4 Concluding remarks

Climate change is a global phenomenon, but the local/regional scale is where people, governments and economic actors jointly, but unevenly, release GHGs. It is also at the local scale where actually climate and environmental implications are faced and where opportunities are to be found.

Since implications and opportunities don't arise homogenously, local governments' role is critical. They can better identify grassroots trends; measure, monitor, and evaluate joint actions; and induce an absolute (not merely relative) reduction of biophysical metabolism of settlements, among other actions. Besides regulating and influencing the behaviour of inhabitants, businesses and industries, local governments can improve the way they provide municipal services by adopting better practices and promoting more efficient, integrated, and climate-ready infrastructure. Likewise, local governments can raise awareness, improve the level of knowledge and synchronize sustainable actions with climate change.

Considering that governance in a broader sense isn't constrained to governmental endeavour, active and long-lasting participation and engagement of all social actors is fundamental as well, particularly of lay citizens whose everyday practices are at the vary base of urban transitions to low carbon.

As the challenge is to identify the best appropriate and possible responses to climate change, mitigation and adaptation, local responses are perceived as more robust if designed jointly, for the long term, and with a socio-ecological vision. Potential synergies seem to be increasingly important, as the timeframe for effective action is indeed shrinking. One key deduction of the latter issue is the need to coordinate climate change and environmental agendas, along with the disaster preparedness agenda at both local and national levels. Such a broad, multi-scale and multi-dimensional perspective for climate change action, positively allows taking into account other socio-ecological (co)benefits other than those directly associated only to climate.

Accordingly, when planning, setting the agenda and taking decisions, political leaders at all levels, but mainly at the local one, should get into action always by looking beyond their own political elected timeframe. This is certainly not happening in most of the cases here analysed, even when some provisions have been taken to compel subsequent government administrations to implement some types of climate change measures (as in the case of Mexico City).

Although most of local climate actions remain voluntary, local steps forward have been taken. Cities have been at the frontline and on occasion have even encouraged national climate change initiatives after approving their own law and action plans (as, again, in the case of Mexico). Nevertheless, responses still don't seem to embrace all the dimensions and complexities of the challenge. As such, there is still much to be done. Further experiences are and will be important for determining lessons (positive and negative), but also for detecting novel paths of action, identifying potential replication and promoting aggregated outcomes. Urban metabolic analyses as part of integral urban planning may definitely be helpful for such purposes.

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