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Systemic assessment of urban climate policies worldwide: Decomposing effectiveness into 3 factors

Jeroen C.J.M. van den Bergh[a,b,c,*]

[a] Institute of Environmental Science and Technology, Universitat Autònoma de Barcelona, Spain
[b] ICREA, Barcelona, Spain
[c] School of Business and Economics & Institute for Environmental Studies, VU University Amsterdam, The Netherlands

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ABSTRACT

Optimism about the contribution of city policies worldwide to reduce greenhouse gas emissions is widespread. It is based, though, on partial and anecdotal studies rather than comprehensive system-wide estimates. Popular empirical indicators to support the importance of cities, such as consumption-based emissions within city borders, lack a policy connection. Here I undertake an initial assessment of the effectiveness of emissions reduction through urban climate policies. It employs a novel decomposition of effectiveness into reach, capability and stringency. This results in a qualitative estimation of current and maximum contributions of city climate policies – divided into four types – to global emissions reduction. I formalize the framework to numerically illustrate additional policy aspects. Based on the insights obtained, I suggest policy and political strategies to make better use of cities' competences to mitigate climate change.

1. Introduction

The idea that city authorities can do much to curb climate change is generally received with great enthusiasm. It gained momentum after repeated failures of international climate negotiations (Hale, 2016), raising the hope that ambitious urban policies might compensate for lack of strong climate policies at the national level (Watts, 2017). There are now several city networks for climate, such as the C40 Cities Climate Leadership Group, The EU Covenant of Mayors, and the UN's Compact of Mayors. The hype to put cities on the climate-change mitigation agenda is partly motivated by rapid urbanization worldwide and by cities being regarded as hubs for our economies.

Initial assessments of urban climate mitigation policies are, however, not very promising. Considering the role of city authorities, Chapter 12 in IPCC's AR5 noted that "Thousands of cities are undertaking climate action plans, but their aggregate impact on urban emissions is uncertain" (Seto and Dhakal, 2014a). According to one review, "… existing initiatives are fragmented … do not address many of the key drivers and determinants involved … local authorities tend to move towards rhetoric rather than meaningful responses." (Romero-Lankao, 2012). A mid-term evaluation of the Covenant of Mayors for the European Commission found that legal constraints limit the capacity of cities to implement own plans (Technopolis Group, 2013). Two specific assessment reports adopt a more positive viewpoint, but rather than testing the effectiveness of urban climate policies they aim to provide a knowledge base for practitioners (Rosenzweig et al., 2011, 2018).

In this study I examine the main arguments and evidence to assess the current and potential future contribution to climate mitigation of urban policies worldwide. This is guided by a novel decomposition of the *effectiveness* of a policy into three factors: *reach*, *capability* and *stringency*. This allows to get a clearer grip on how distinct policies employed by urban authorities work out in terms of effective emissions reduction. This provides a broader picture of the effectiveness of urban climate policies than one tends to find in the majority of studies. In fact, optimism about the role of cities in emissions reduction is mainly motivated by partial analyses and anecdotal evidence of promising developments – rather than by comprehensive and system-wide analyses. In fact, despite so many actions already undertaken by cities worldwide so far we see little effect of this in terms of global emissions. The outcomes of this study are intended to give a more balanced account of what policies have or can accomplish(ed).

A disclaimer is needed as the ambition of the task undertaken here is so enormous that it is – for the moment at least – virtually impossible to support it with credible empirical quantification. Instead, the framework is used to divide the literature in three parts and derive insights about the evidence for each of the three components of effectiveness. In addition, it is illustrated how the framework could be elaborated to

* Corresponding author at: ICTA, Edifici Z, UAB Campus, 08192 Bellaterra, Spain.
E-mail address: jeroen.bergh@uab.es.

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derive quantified results. It should be stressed that the numbers presented in that context are only indicative and lack a solid empirical basis. They merely illustrate how difficult it is to achieve high policy effectiveness of emissions reduction, and thus the huge challenge we face in putting a halt to climate change.

From previous interactions with experts on cities and climate change I have noticed discontent with, and even misinterpretation of, my conclusions. My experience is that a critical view as I elaborate here is not welcomed by everyone. I hope, nevertheless, that readers will accept that this study serves to stimulate healthy – and in my view urgently needed – debate about the role of cities and urban policies required, as well as the division of tasks between cities and higher political levels. My aim is certainly not to discard the relevance of cities in combatting climate change.

The remainder of this article is organized as follows. Section 2 presents the decomposition framework. Section 3 and 4 review studies that provide information about reach and capability, respectively, of urban climate policies. Section 5 does the same for stringency and political feasibility of such policies. Section 6 then combines insights from these three sections into an overall qualitative assessment. Section 7 proposes a formal approach to elaborate such an assessment quantitatively, and offers some numerical calculations to illustrate the huge challenge that policies face in achieving highly effective emissions reduction. Section 7 discusses policy and political lessons.

2. The decomposition framework

The assessment in this study is guided by the framework depicted in Fig. 1. It represents a novel decomposition of the *effectiveness* of a policy into three factors: (i) the policy's *reach* or coverage of polluters and emissions, (ii) its inherent *capability* to alter behaviour that causes emissions, and (iii) its *stringency* in terms of the strength of the policy incentive, notably the explicit or implicit cost of environmentally harmful behaviour (OECD, 2016). If a policy mix shows broad reach, great capability and high stringency, it results in significant emissions reduction; but if it performs inferior on any of these criteria, it reduces emissions to a lesser extent. To complete the picture, systemic feedbacks affecting overall effectiveness (van den Bergh, 2012), such as carbon leakage and energy/carbon rebound, are considered as well.

Political feasibility also receives attention as it is crucial for understanding why certain policies are more popular than others. It directly determines which stringency of each policy instrument can be realistically achieved, and indirectly – through the policy mix choice – policy reach and capability.

Regarding the mix of policies, I consider a widely accepted division into four main modes of urban climate governance (Bulkeley and Kern, 2006a): (a) *self-governance* of urban public sector activities; (b) *provision* of public services, such as public transport; (c) *enabling* emissions reduction by firms and households, such as through information or adoption subsidies; and (d) *regulation* of firms and households, such as zoning or levies.

Accounting in addition for diversity – or uniqueness – of cities globally, in various respects, results in an overall picture of what to expect from urban climate policies. This diversity moderates in effect all other variables in the scheme, notably political feasibility and historical constraints, such as the current urban form. In turn, this moderating influence indirectly extends to the policy mix and the three effectiveness components.

The resulting framework provides a broad and more complete picture of the effectiveness of urban climate policies than what has been accomplished so far. It allows us to thoroughly assess the impact of distinct types of urban climate policies on emissions reduction.

3. Reach

Reach is defined here as the scope or range of control by climate policies. It can be measured as the number of polluters or as the quantity or proportion of global greenhouse gas (GHG) emissions that can be controlled. This notion has, surprisingly, not received explicit attention in the literature on climate policy. Several publications implicitly suggest that urban climate policies have a broad reach: "Cities are crucial to global mitigation efforts … urban areas are responsible for 71 % of global energy-related carbon emissions" (Rosenzweig et al., 2010); "Cities must address climate change … cities emit 75 % of all

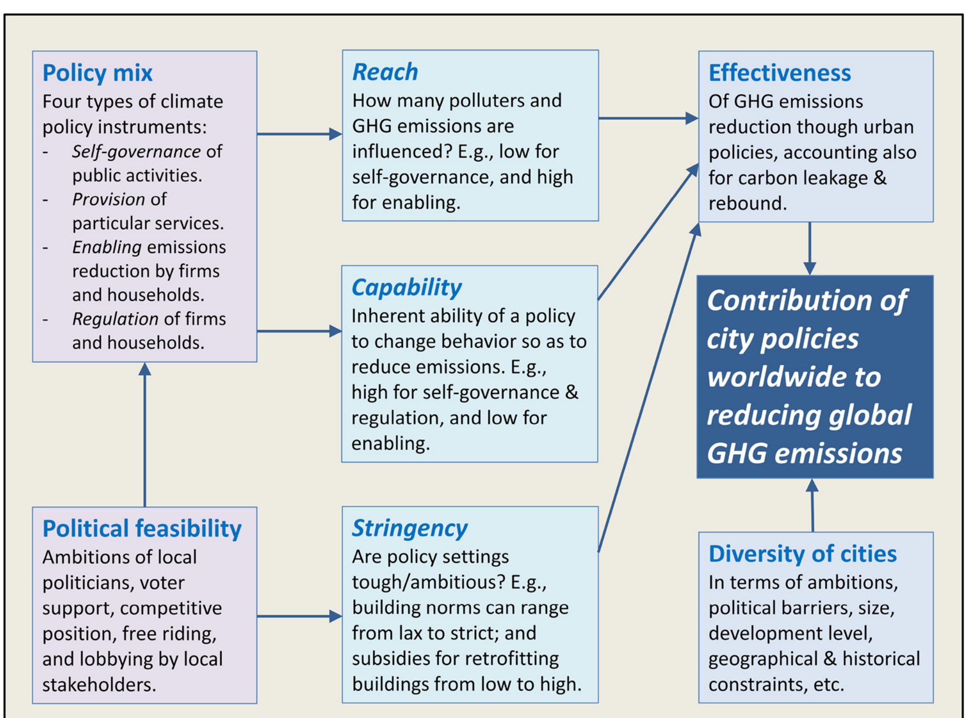

Fig. 1. Greenhouse gas emissions reduction expected from urban climate policies.

carbon dioxide from energy use" (Bai et al., 2018); and "Cities are at the heart of the decarbonisation effort … cities account for about … 70 % of total energy-related carbon dioxide (CO_2) emissions." (IEA, 2016) But these numbers likely overestimate considerably the potential contribution of city authorities. As we will see, a large part of GHG emissions from industry, electricity generation, tourism, consumers and transport located within city boundaries is not, and cannot be, controlled by urban policies – for legal, technical or behavioural reasons (Satterthwaite, 2008). One study examined differences in emissions among ten large international cities (Kennedy et al., 2009). Several identified critical factors turn out to be not or hardly controllable by city authorities: geophysical factors are a clear case; or electricity generation and grids, and their GHG intensity, in most cases fall outside city jurisdictions (Bulkeley and Kern, 2006b).

Reach differs between policy types. Self-governance of the public sector often relates to municipal buildings and car fleet, which contribute only a small portion of all GHGs within city limits. For 66 of the largest metropolitan areas in the U.S.A. the majority of public transport emissions fall in the range of 3–7 % of total transport emissions, while the upper end of 10–15 % is probably more representative of less dispersed and car-oriented European cities (Glaeser and Kahn, 2010). Considering public buildings, shares of their emissions in total emissions from city buildings are expected to be lower than equivalent indicators for public transport, because public buildings do not substitute for private homes or offices in a way that public transport substitutes for private transport.

Provision of particular services has an equally limited reach. For example, in the absence of restraints on car use, improving public transport will have limited effectiveness in getting people out of their car as information about it is found to reach and affect a minority of those with a car-based lifestyle (Beirão and Cabral, 2007a). Enabling emissions reduction, through influencing firms and households with information provision can potentially count on a somewhat wider reach, but provision through subsidies, such as for adopting rooftop solar PV or investing in energy efficiency of buildings, has been found to have a disappointing reach (Ramaswami et al., 2012a).

There is no doubt that serious emissions reduction requires regulatory policies like emission standards for industry or a system-wide carbon tax on fossil fuels. But such policies belong predominantly to the domain of national governments. An important area is transport. Here, urban auto-restraint measures or parking tariffs have a limited reach in terms of transport-related emissions, even in urban precincts. Achieving major emissions reduction and encouraging a large-scale shift to low-carbon vehicles will depend to a greater extent on the mentioned national policies, also as most emissions from car use originate from long distance travel outside cities. Cities might entirely ban cars that generate carbon emissions in their confines or restrict car use using congestion charges. But neither of these have a great record in urban policy, for obvious reasons: a large number of local businesses, visitors and residents want to be able to reach their destinations through motorized transport. Despite decades of appeals for congestion pricing, very few cities in the world have implemented it, which should temper any expectations for the future. This all does not deny that car-free zones in the centre of cities are a common phenomenon. But it is something completely different to restrict or ban car use throughout the larger city. Moreover, car-free city centres can usually still be reached by car as they offer many parking lots in underground garages. In fact, the latter has contributed to a lock-in of car use to reach city centres.

Decisions made by people and businesses in cities cause considerable emissions outside city borders, which are largely outside the reach of city authorities. To illustrate, in Chinese mega-cities such as Beijing, Shanghai and Tianjin more than 70 % of CO_2 emissions related to urban consumption are outsourced to other regions in China (Feng et al., 2014). Even in Norway's Trondheim, considered a forerunner in terms of urban sustainability, 93 % of emissions of municipal services were found to be generated outside the city's borders (Larsen and Hertwich, 2009). Emissions in both cases are beyond the control of city authorities. Similarly, an important emitting sector like transport causes most emissions outside cities as this is where most kilometres tend to be driven. For instance, in the Netherlands, a very urbanized country, in 2018 20 % of all road kilometres driven were within urban borders, more than 30 % on rural roads and almost 50 % on highways (Compendium voor de Leefomgeving, 2017).

City authorities are often regarded as crucial for reducing building-related emissions. Not denying their role in this, it tends to overlook that in most countries building codes and energy-efficiency standards tend to be set by national governments (Young, 2014). Europe even has Eurocode, a set of pan-European standards for the design of buildings and other civil engineering works, which already guide technical specifications in public contracts. Various non-EU countries have already adopted the Eurocode, while many others are considering to do so, which contributes to a gradual shift from local to global building norms (Anon, 2020). If cities own the land on which new buildings appear they sometimes can negotiate contracts that include building conditions, such as a minimum capacity of solar PV on rooftops. This is, though, likely to reach a modest amount of urban emissions as most cities own little land and as most emissions come from existing buildings. Hence, also in this territory reach of city governments is limited.

4. Capability

Next I examine the inherent ability of policies to change behaviour that causes GHG emissions, which I refer to as 'capability'. Just like reach, it varies between the four types of climate policies. Self-governance can be very 'able' in reducing emissions. Provision of particular services has a weak pull force away from high-carbon alternatives, while its scope is limited mainly to transport and to a lesser extent waste management. An example is trying to achieve a significant reduction in car use by providing public transport with more capacity, frequency or speed, which has been shown to have limited capability (Beirão and Cabral, 2007b). Enabling emissions reduction by firms and households has a broader reach but has low capability to change behaviour and reduce emission. This is illustrated by a review of forty studies of behavioural intervention through information provision: it finds low average emissions reduction, namely of 3.2 % of total emissions from car use, 0.3 % of total emissions from food consumption, and 0.8 % of total emissions from household energy use (Wynes et al., 2018). Enabling can also have counterproductive behavioural effects, notably when it involves making a low-carbon alternative cheaper. For instance, free parking for electric vehicles may shift car ownership to these but also encourage some people to use their electric car for trips previously made with public transport. Regulation of households and firms is a very capable policy, especially if it involves making high-carbon alternatives more expensive. This is confirmed by both empirical evidence and model studies (Nadel, 2016; Mercure et al., 2014).

Four studies provide additional insight about capability as they evaluate the impact of urban policies on emissions for various samples of cities. Their unanimous conclusion is: few regulatory policies are used and there is no discernible effect on overall urban emissions. A first study assessed data from 478 cities in California for eight policy outputs: green building standards, residential solar photovoltaics, street lighting, waste programs, pedestrian/bicycle infrastructure, gasoline sales and commute vehicle share (Millard-Ball, 2012). It finds no evidence that emissions reduction is causally related to urban climate plans and policies. Instead, these are largely codifying outcomes that would have been achieved in any case, given national policies and environmental preferences of urban dwellers. A second study undertakes a time series analysis for the 50 most populous U.S. metropolitan regions, finding no significant effect of emissions control strategies (Stone et al., 2012). A third study reviews 55 U.S. cities, finding that less capable voluntary outreach programs with low participation prevail whereas more capable regulatory policies are scarce (Ramaswami et al., 2012b). For Denver it finds: that a combination of urban voluntary and regulatory actions to yield at best ~1% GHG mitigation annually in buildings and transportation; that only 2–4 % of households respond with emission-reducing actions to door-to-door campaigns, meaning low capability; and that less than 1% of households respond to loans offered for energy-efficiency investments in homes. The study refers to various other publications to confirm that these low participation rates are in line with other national-level reviews of outreach and loan programs. A fourth study analyses thirteen small and medium-sized cities in the Netherlands (Boehnke et al., 2019). It finds that good-practice climate policies mainly comprise low-capability policies of the enabling type, and observes no clear reduction in GHG emissions due to the policies in any of the cities. Altogether, these studies underpin that instruments with low capability, such as provision and enabling, tend to be more popular than ones with high capability, such as regulation.

Some suggest that city authorities might implement a capable emissions reduction instrument like carbon pricing (Carbon Washington, 2017). The scarce examples of city policies sold as carbon taxes, though, tend to concern general energy taxes that do not discriminate between distinct fuels on the basis of their carbon intensity. Equally important, none of these achieve a recommended (Baranzini et al., 2017) system-wide carbon price to capture all fossil fuel use by firms and households in the economy. One fundamental barrier here is that cities cannot control fundamental sources of carbon such as oil extraction and imports. Unsurprisingly, the academic literature on carbon pricing entirely disregards a particular role for cities. On the other hand, the literature on cities and climate pays scant attention to the role of carbon or fuel prices (Creutzig et al., 2015).

There is widespread optimism that food production in cities, notably rooftop farming, is a way to advance sustainability and reduce carbon emissions, among others, as it may reduce transport distances between producers and consumers (Al-Kodmany, 2018). But rooftop farming has two serious shortcomings: it foregoes economies of scale with respect to energy and emissions, and as a result is also bound to remain a tiny part of global agriculture; and it involves frequent vertical movements of materials, products and people, relying on intensive use of elevators or moving belts, which causes considerable energy use. Altogether, it is doubtful that such ‘elevator agriculture’ can contribute much to GHG emissions reduction.

5. Stringency and political feasibility

To guarantee a significant contribution of cities to climate solutions, in addition to having capable policies with a broad reach, policy settings should be sufficiently stringent. The notion of stringency applies especially to self-governance and regulation. Regarding provision and enabling, it should best be read as “level of effort” which in turn depends on “amount of funding”, to pay for provision of public services, or for enabling emissions reduction by private actors through information provision or public subsidies. Currently, stringent policies of both kinds are rare as they tend to receive insufficient public and political support, or simply meet firm political barriers. Hence, I provide an integrated treatment of stringency and political feasibility in this section.

A fundamental barrier is that the climate is a global public good, inviting free-riding by countries and sub-national authorities. An effective solution requires a binding global climate agreement that commits countries to implement consistent and strict regulatory policies. A focus on sub-national agents does not make a solution to the global free rider problem that is characteristic of solving climate change easier – rather the opposite. Worldwide the number of cities is at least a factor 100 larger than the number of countries, and they are not negotiating coordinated action as countries do recurrently in UNFCCC COPs.

The ultimate effectiveness of emissions reduction by urban climate policies depends further on the extent of unintended systemic and cross-boundary effects, such as energy and carbon rebound. A study for Australia contrasting urban, suburban and rural households finds that rebound is relatively high for energy conservation in cities (Wiedenhofer et al., 2013). Moreover, significant rebound effects must be expected for reducing direct energy use through sector-specific standards rather than economy-wide regulation by national governments (Bourrelle, 2014). In addition, cross-boundary effects shifting “city emissions” to elsewhere – due to households or businesses opting for other municipalities, or city exports becoming less competitive – are likely if a city government implements very serious regulation on GHG emissions or limits the city’s economic growth.

Other political barriers have to do with policy choices being influenced by lobbying against effective regulation. Especially dominant firms in the city’s confines tend to have direct access to its authorities, knowing that the latter give much weight to local employment they create. This limits stringent urban regulation of GHG emissions by local industry. Barriers further include insufficient personnel or budget, or even a complete lack of agency, for climate protection by – especially small – cities (Pitt and Randolph, 2009). Local authorities proposing stringent regulation such as banning cars from the city should also expect political repercussions during elections, the fear for which already discourages any proposals in this direction. This also explains why in a highly urbanized country like the UK only two cities have implemented congestion schemes, namely London and Durham, and why in a much larger country like the U.S.A. or in a very densely populated nation like the Netherlands such schemes are entirely absent.

A basic factor underlying emissions is urban form. It covers building density and infrastructural patterns, which affect distances between residence, work, retail and leisure locations. Cities are characterized by idiosyncratic historical developments – known as path-dependency. In addition, there is institutional and behavioral lock-in (Ürge-Vorsatz et al., 2018). These, along with prevailing geographical conditions, severely limit the political/policy space for fundamental changes in urban form. Indeed, the spatial structure of fundamental building blocks such as streets, squares and buildings in cities is rather fixed. Predictably, urban climate action plans tend to focus on energy efficiency instead (Reckien et al., 2014). Self-reported data from cities indicate that such plans rarely discuss changes in urban form to achieve more integrated land use. At best one finds references to urban greenspace, but this is about CO_2 sequestration from, rather than controlling emissions to, the atmosphere (Kousky and Schneider, 2003; Rutland and Aylett, 2008; Kern and Bulkeley, 2009; Wang, 2013).

Urban form in rapidly growing small and medium-sized cities in developing countries is less locked-in. But according to the IPCC, “In rapidly urbanizing cities, limited capacities and the need to respond to everyday crises often occupy most of the available time in transportation and public utility departments, with little attention left to strategically plan for prevention of such crises in the first place” (Seto and Dhakal, 2014b). Cities in developing countries moreover face low consciousness of environmental challenges, insufficient coordination of local and national institutions, bureaucracy and corruption, and limited funds (Reyes, 2016; ICLEI and Climate, 2016) in view of ambitious investments-for-low-carbon (Gouldson et al., 2015; Sudmant et al., 2016) – altogether limiting long-term climate mitigation strategies. Hence, we face the paradox that in mature western cities policy ambition is relatively high but the system is locked into high-emission patterns, whereas in less mature cities in developing countries the system is more flexible but policy ambition and feasibility are modest.

6. Overall assessment

To synthesize the previous insights, Table 1 qualitatively assesses current and maximum performances of the four policies on each of the considered performance criteria underlying effectiveness, i.e. reach, capability and stringency. Assessments in the table reflect the evidence and arguments discussed in previous sections for each combination of

Table 1
Estimation of current and maximum performance of urban climate policies.

POLICY PERFORMANCE (Current / Maximum)	URBAN GOVERNANCE MODES			
	Self-governance	Provision of services	Enabling	Regulation
(1) Reach	Low / Low	Low / Moderate	Low / Moderate	Low / High
(2) Capability	High / High	Low / Low	Low / Low	High / High
(3) Stringency	Moderate / High	Moderate / High	Moderate / Moderate	Low / Low
(4) CURRENT EFFECTIVENESS OF EMISSIONS REDUCTION (combines blue values in rows 1 to 3)	MODERATE	LOW	LOW	LOW
(5) Political feasibility of 'maximum' governance mode implemented	High	Moderate	High	Moderate
(6) MAXIMUM EFFECTIVENESS OF EMISSIONS REDUCTION (combines green values in rows 1-3 & 5)	MODERATE	MODERATE	MODERATE	MODERATE

Note: Performance sub-criteria in rows 1, 2, 3 and 5 can take on three values: 'low', 'moderate' and 'high'. The aggregation of rows 1–3 (blue assessments) into 4 (BLUE), and of 1–3 and 5 (green assessments) into 6 (GREEN), is open to debate; here I opted for the following transparent aggregation scheme: 2x values 'low' for the sub-criteria aggregate to 'LOW' effectiveness; only if all sub-criteria have values 'high' is effectiveness 'HIGH'; all other combinations of sub-criteria values aggregate to 'MODERATE' effectiveness.

instrument and criterion.

Of course, this is a complex issue, and the resulting assessment is tentative in nature, not meant to represent a final and absolute statement but serving as a starting point for further study and debate about what to realistically expect from cities regarding overall GHG emissions reduction. This, in turn, could contribute to more urgency for designing and implementing effective climate policies at the national level.

Particular shortcomings are that the empirical basis is limited, biased towards developed countries and large cities, while – given limited space – it has been impossible to discuss all possible urban policies that have been or could be implemented. In addition, negative or positive synergetic effects might occur between policies, even though the size of these seems to be limited (Wiese et al., 2018a). Hence, further study and review is worthwhile to confirm the main findings presented hereafter.

Nevertheless, a fairly clear picture emerges. A first finding is that the profiles of the four policy instruments – in terms of scores on the criteria – are very different, especially for the maximum attainable results. This means the instruments are rather complementary. An exception is the current performance of provision and enabling, which have a similar performance on criteria in rows 1–3. A second finding is that the current joint contribution of the instruments is small, as reflect by the sum of the values in row 4. This is consistent with the finding of all ex-post evaluations, namely that GHG emissions have virtually not been reduced by urban policies. A third finding is that the maximum overall contribution in row 6 indicates there is room for improvement in all four governance domains. However, the overall contribution is unlikely to get easily beyond "moderate". This means a major part of emissions generated within city borders will remain outside the control of local policies, instead depending on policies set by higher-level governments. That is, unless stringent regulation is implemented, which has low political feasibility in comparison with the other governance modes (row 5).

It is tempting to compare the assessment of maximum performance with what one would expect for national climate policies. Some notable differences are a higher reach and possibly also a higher stringency of national regulation, and a higher stringency (i.e. funding) for enabling through adoption subsidies at a national level. In addition, on should expect less carbon leakage and rebound due to an economy-wide reach. For self-governance, provision and enabling, one would anticipate smaller differences. Obviously, systematic comparison with national-level policies is worth a separate study.

In the next section we go one step further by formalizing the framework, to illustrate the huge challenge of achieving a considerable share of emissions reduction.

7. Formalizing the framework to illustrate the huge policy challenge

So far, no study has provided an estimate of the potential overall contribution of cities to global GHG emissions reduction. Instead, there is a lot of work on "GHG emissions accounting for human settlements" (see IPCC, Box 12.2) (Seto and Dhakal, 2014c), following three approaches: (i) production emissions (territorial based), (ii) including also non-territorial supply chain emissions, and (iii) consumption based (including all direct and indirect emissions). Two assessments find that the share of urban activities in global GHG emissions is 53–87 % and 37-49 % (Grubler et al., 2012; Marcotullio et al., 2013). None of these accounting approaches, though, bear a logical link to the limited reach of urban climate policies.

Using the framework in Fig. 1, I propose a formalized conceptual approach to quantify current and maximal emissions reduction by cities, expressed as a share of global emissions. A decomposition into four factors provides a rough estimate of the contribution of global cities to emissions reduction:

$$P = c{\cdot}e = c{\cdot}r{\cdot}a{\cdot}s$$

Here P denotes the proportional contribution of cities to global emissions reduction, c is the global share of cities with climate policy, and e the average effectiveness of the climate policy mix in such cities. The latter is multiplicatively decomposed into r, a and s, which denote, respectively, the average reach, capability and stringency of the policy mix. All variables are in percentage values. In the case of the performance criteria this denotes the level relative to the maximum attainable performance. To illustrate, assume that 20 % of all cities in the world implement some climate policy with an average reach of 15 % (namely 30 % of emissions due to electricity, heat production and transport, which make up about 50 % of all global emissions (IPCC, 2014), average capability of 20 %, and average stringency of 10 %. All these values are rather generous in view of the reviewed empirical studies in previous sections. Then the abatement by all cities in the world is

0.2·0.15·0.2·0.1 = 0.0006 or 0.06 % of total global emissions. This is consistent with city policies so far having had no observable effect in terms of global emissions reduction. Note that even if all four variables would take on half of their maximum value (i.e. 50 %), which is very optimistic, then this would produce an overall contribution of urban climate policies of only $0.5^4 = 6.25$ %. This illustrates how difficult it will be to arrive at a significant contribution of cities.

Next, consider a more disaggregate formalization of the decomposition to arrive at a more reliable estimate:

$$P = \sum_{\substack{i=cities \\ globally}} \sum_{\substack{j=policy \\ instruments}} r_{i,j} \cdot a_{i,j} \cdot s_{i,j}$$

Here $r_{i,j}$ denotes the reach, $a_{i,j}$ the capability and $s_{i,j}$ the stringency of policy instrument j in city i. The latter three variables take percentage values again. Reach $r_{i,j}$ is a function of city i's relative contribution to global emissions, depending largely on population size and affluence level, but also on specific industries and technologies, and the policy instrument j (e.g. self-governance has a low reach and enabling a higher reach). Capability $a_{i,j}$ is mainly a function of the policy instrument i (e.g. high for self-governance and regulation but low for provision and enabling) while it also depends on features of city j. Finally, stringency $s_{i,j}$ depends on political feasibility, notably if city i's political barriers against tough policies are strong or can be overcome.

To illustrate how difficult it is to achieve a significant share of emissions reduction, I apply the above model to calculate a tentative maximum contribution of cities. This assumes – in line with the qualitative assessment in Table 1 – maximum magnitudes for reach, capability and stringency for each of the four policy types, as shown in Table 2. This results in an overall proportional emissions reduction of 19.5 % as the relative emissions reduction of an ambitious city (row v of the table). Multiplying this by the percentage of cities expected to implement this policy gives the final result. If we assume that one third of all cities worldwide will be ambitious in the future and the remainder half as ambitious, then the joint contribution of policies by cities worldwide to emissions reduction would be 13 % (row vi of the table).

Note that the relative contribution of regulation can be calculated from rows iv and v as 0.125/0.195 = 64.1 %. This illustrates that a serious contribution of cities to climate mitigation will ultimately depend on whether cities are willing and capable of implementing strict urban regulations of emissions and to a lesser extent on the other three policy modes. Note further that whereas the illustrative numbers in row i sum up to 0.86 or 86 %, one can also imagine values that add up to something larger than 100 %. This would reflect that distinct instruments partly overlap in terms of emissions reached. Alternatively, instruments might reinforce or weaken one another. To address this, one could extend the model by accounting for negative and positive synergetic effects of instruments. Unfortunately, empirical evidence for significant synergy is patchy (Wiese et al., 2018b; Viguié and Hallegatte, 2012).

The previous estimates are merely illustrative of the formalized conceptual approach. To arrive at more reliable ones, further disaggregation is desirable. This could involve an assessment of emissions per city sector – transport, built environment, public sector, etc. – and then derive the part of these controlled by specific urban policies. One might also consider a more detailed categorization of mitigation policies for each sector, such as land use (vegetation, urban agriculture), transport, buildings, electricity and heat production, local industry, waste management, and urban form and infrastructure. In addition, one would need to weight estimates for very different cities around the world in upscaling to a global level. This represents a huge challenge, as we do not even know how many cities there are, let alone their distribution in terms of emissions. What we know is that there are approximately 1700 cities worldwide with over 300,000 inhabitants, and some 430 cities with over a million inhabitants (UN, 2016). In upscaling one might use insights from empirical studies about variation in climate policies among cities, within and between countries, depending on local socio-cultural, environmental, internal-political and institutional characteristics (Vasi, 2006; Zahran et al., 2008; Pitt, 2010). Cities in developing countries, where most emissions growth is expected in coming decades, show much diversity already, as is illustrated by very distinct average features of cities between African, Asian and Latin American continents (Nagendra et al., 2018).

It should be clear that quantifying the contribution of urban climate policy to global emissions reduction represents an enormous, possibly unattainable, challenge. The above conceptual approach formalizing the framework in Fig. 1 serves as a starting point for further thinking about this.

8. Political and policy lessons

How can we maximize the contribution of city policies to fighting climate change? Here are some recommendations motivated by the assessment framework and findings.

First, city governments should not be satisfied with mere emission targets but complement these with policies that score well in terms of all three dimensions of reach, capability and stringency. This will then assure high effectiveness in terms of emissions reduction. The finding of the empirical evidence, and the illustration in the previous section, both suggest that a serious contribution of cities to climate mitigation will ultimately depend on whether cities are able to implement strict emissions regulation, and to a lesser extent on the other three policy modes.

Second, instead of developing a large number of ad hoc and often rather ineffective urban policies for distinct sectors, or suggesting we need to experiment with many new policies – as currently characterizes climate action plans of many cities (Castan Broto and Bulkeley, 2013) – it is recommendable to focus on fewer instruments that encompass multiple sectors and are known to consistently and effectively reduce emissions with minimum emission leakage. This will not only control costs of, and facilitate, monitoring and control but also contribute to a broader reach, thus limiting rebound.

Table 2
Illustrative calculation of share in global emissions reduction of climate policies in ambitious cities.

Policy performance	Urban governance modes			
	Self-governance	Provision of particular services	Enabling	Regulation
(i) Reach	0.01	0.3	0.3	0.25
(ii) Capability	1	0.1	0.1	1
(iii) Stringency	1	1	1	0.5
(iv) Product of i-iii	0.01	0.03	0.03	0.125
(v) Maximum proportional contribution to emissions reduction by an ambitious city (= sum of elements in iv):	0.01 + 0.03 + 0.03 + 0.125 = 0.195 (= 19.5 %)			
(vi) Assuming one third of cities worldwide is ambitious and the remainder half as ambitious, gives an overall contribution:	(1/3)*0.195 + (2/3)*(0.195/2) = 0.13 (= 13 %)			

Third, more coordination among national and local policies is desired as this will improve their complementary roles, notably in terms of reach. For instance, national carbon pricing will control emissions resulting from using vehicles, while limited urban parking space will discourage car ownership and thus embodied emissions (i.e. associated with the production of cars).

Fourth, to achieve quick and significant progress, national or even supranational (as the EU) governments might adopt a clearer guidance role to assure harmonization of basic climate policies across cities, especially with regard to regulatory instruments. This would reduce competitiveness and relocation effects, thus allowing for more stringent policies in all cities simultaneously. At the same time, it would minimize undesirable systemic effects, such as carbon leakage. Harmonization of urban policies would also encourage smaller cities – with less experience, capacity or funds – to implement effective climate policies.

Fifth, if national governments would join forces, harmonization could be extended internationally, far beyond current city networks, which tend to comprise a very small number of all cities globally. The contribution of such networks to the effectiveness of emissions reduction is limited anyway given that they depend on the voluntariness of participating city governments (Giest and Howlett, 2013). In this respect, politicians might consider negotiating a section in the Paris Agreement that explicitly focuses on harmonization of effective, notably regulatory, city policies worldwide. To meet the final two recommendations, city mayors concerned about climate change would do well to lobby with their national political parties for trans-municipal harmonization of local climate policies.

Declaration of Competing Interest

The author certifies that he has no affiliations with or involvement in any organization or entity with any financial interest (such as honoraria; educational grants; participation in speakers' bureaus; membership, employment, consultancies, stock ownership, or other equity interest; and expert testimony or patent-licensing arrangements), or non-financial interest (such as personal or professional relationships, affiliations, knowledge or beliefs) in the subject matter or materials discussed in this manuscript.

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