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Developing a smart tool for integrated climate action planning (ICLAP 2050) in Asia-Pacific Cities

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Abstract

In light of the growing global environmental challenges, smart cities need to serve as testing workshops or labs to smartly tackle complex cross-sectional issues like jobs, seamless mobility, safety and security, sustained growth, while responding to the impending climate change too. This necessitates for developing a smart model or tool that integrates such varied but crucial climate concerns of a city into its direct decision-making and long-term planning. In this research, we conduct a literature review to have an overview of the state-of-the-affairs on urban climate planning in Asia-Pacific Cities covering China, Japan, India, Philippines, Singapore and Thailand. This is followed by an intensive theoretical understanding on the need of having a smart tool in urban climate action planning. This includes the study of recent urban climate metrics and tools, their different typologies based on key purpose, method, sectoral and geographical scope, and challenges and gaps in formulating smart urban climate tools. We then introduce the conceptual framework for integrated climate action planning (ICLAP) tool that transects spatial, statistical and bibliometric methods. We establish applicability of ICLAP in case of Indian cities by discerning climate vulnerabilities, GHG trends and relevant urban climate solutions. The paper eventually culminates with major scientific findings and policy recommendations, essentially underscoring more intensive and wider application of ICLAP like smart urban climate tools in local decision making and national urban policies duly supported by international scientific collaborations.

Keywords: Smart cities, Urban climate assessment tools, ICLAP- integrated climate action planning, Climate variability, Asia-Pacific, Indian cities

1 Introduction

Since the mid-2000s, smart cities are being considered as a new urban paradigm gaining popularity in policy and business circles, finding equal traction amongst government and private sector. The academia too is gradually focusing on smart cities as an emerging area of research and specialized courses (CIDOB, 2014). But how do existing cities become smart? It is seen that smartness is involved in data collection, often in real time conditions leading to efficient decision-making. Smart cities are those cities where investments in human and social capital and traditional (transport) and modern information and communication technologies (ICT) and its infrastructure fuel sustainable economic growth and a high quality of life, with a wise management of natural resources, through participatory governance (Caragliu et al., 2011). These highlight fundamental characteristics of sustainability including energy efficiency, responsible resource management and citizen engagement (Colldahl et al., 2013). For instance, California installed hundreds of thousands of smart meters at homes and commercial establishments that can modulate electricity-use with grid supply to prevent loading of infrastructure (Mittal & Sethi, 2018). Large cities like London and Singapore invested intensively in their public transportation

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systems and road pricing to implement highly contemporary, cost-effective and dependable network in the world.

The Japanese cities of Kawasaki, Yokohama and Kitakyushu mastered multi-purposed data-based solutions across multiple sectors like renewables (solar), e-mobility favoring light rapid transit and electronic vehicles, waste management solutions, energy load reductions using smart grid and demand management systems at the household level (IGES/YCU, 2011). European cities like Copenhagen, Berlin and Amsterdam are promoting digital technologies to facilitate mobility like using smart cards for continuous travel between different modes, 24 × 7 analysis of traffic data to inform users about expected travel time and parking space to users, thereby reducing traffic-jams, idle time and resulting air-pollution (Vembu & Sridhar, 2014). Evidence increasing suggests that smart is not the domain of the developed world only. According to the recent ranking by Sustainability Magazine, the top smart cities in Asia include (in bottom to top order) Bangkok, Kuala Lumpur, Beijing, Nagoya, Osaka, Hong Kong, Seoul, Singapore, Tokyo and Shanghai (Knowles, 2022). While identifying smart cities for an award for the period 2007–11 in the Asia region, three Indian cities namely Bangalore, Hyderabad and Jaipur figured in a list of 20 cities from the region (Ramachandran, 2014). A recent systematic review of 56 studies found that technology-enabled smart cities in developing countries can only be realised when governments step up their efforts to fulfil the basic infrastructure needs of citizens, develop human capital, ensure digital inclusivity and promote environmental sustainability. In light of the growing global environmental challenges, cities need to serve as testing workshops or labs to smartly tackle complex cross-sectional issues like jobs, seamless mobility, safety and security, sustained growth, while responding to the impending climate change too.

There are certain approaches that attempt to articulate smartness into urban planning, governance and decision-making, for instance the Sustainability, Metrics, Adaptiveness, Reporting, Technology for Inclusiveness (SMART) framework that can be crucial in addressing these multifaceted challenges (Mittal & Sethi, 2018). Smart cities are considered to have six features- smart economy, smart people, smart governance, smart mobility, smart environment and smart living (Giffinger et al., 2007). The concept is intricately related to intelligent, innovative or knowledge based settlements that mobilize ICT to deliver better services, reduce carbon footprint, create sustainable environments and improve living conditions. ISO 37120: 2014 is argued to be a standard indicator for smart cities, though the International Organization for Standardization regards it to be *Sustainable development of communities- Indicators for city services and quality of life*, essentially an outcome of the Global City Indicators Facility indicators (World Bank, 2008). Yet, how these cities respond to global climate change in a smart, objective and systematic manner remains an open question. So what would make the global climate concerns more 'integrated' into smart cities paradigm. Different institutions and organizations have a different perspective on 'integrated' approach with respect to climate planning. Some agencies regard integration as a mishmash of various sectors/ activities covering both adaptation and mitigation. Within adaptation, integrated essentially considers either vulnerability, impacts and adaptation, or ecological conservation, social development, and disaster-risk reduction (Gurung & Bhandari, 2009). Within mitigation, these consider combining reduction of greenhouse gas (GHG) emissions and controlling of local air-pollutants, or linking policies of transport, energy, air-pollution and climate (Creutzig et al., 2019, Sethi et al., 2020). But this provides an incomplete knowledge of 'integration', invariably regarding adaptation and mitigation as completely unrelated issues as well as missing out on evidence-based urban climate solutions gathered from case studies and best practices around the world.

Meanwhile, we already know that there is a high degree of fragmentation in urban climate planning raising some crucial knowledge gaps that impede and delay local action, notably non-availability of reliable empirical information on: (a) Short, mid & long-term climate vulnerability scenarios at sub-national level (b) How variedly do different societies contribute to climate change- their GHG structures, and (c) What useful climate actions are local governments taking, across the globe (Sethi et al., 2022). This necessitates for developing a smart model or tool that integrates such varied but crucial climate concerns of a city into its direct decision-making and long-term planning. In this paper, we conduct a literature review to have an overview of the state-of-the-affairs on urban climate planning in Asia-Pacific Cities (Section 2). This is followed by an intensive theoretical understanding on the need of having a smart tools in urban climate action planning (Section 3). We then introduce the conceptual framework for Integrated Climate Action Planning (ICLAP) tool (Section 4). We establish its applicability in case of India (in Section 5) discerning urban GHGs, climate vulnerabilities and identifying relevant urban solutions. The paper eventually culminates with major scientific findings (Section 6) and policy recommendations (section 7).

2 Review of climate planning in Asia-Pacific cities

The review of climate planning in Asia-Pacific cities essentially studies *climate action plans* (CAPs) of 16 major urban centres, covering China (5), Japan (2), India (6) and South-east Asian countries (3). In case of China, following their 13th Five-Year Plan on Climate Change (2016–2020), cities have a regular system of data inventorization for population, economy, urban, energy and emission indicators, covering adaptation and mitigation aspects of climate change. For instance, the national capital of Beijing methodically plans to reduce GHGs after 2020 by encouraging building energy efficiency and the use of renewable energy (PGBM-The People's Government of Beijing Municipality, 2016). Tianjin aims to promote carbon trading and modernization of industrial and energy systems to drastically reduce its emissions (PGTM-The People's Government of Tianjin Municipality, 2017). The megacity of Shanghai has developed both adaptation and mitigation measures into different sectors like industry, energy, construction and mobility (SMDRC-Shanghai Municipal Development and Reform Commission, 2020). Similarly, Guangzhou and Shenzhen focus on improving climate adaptation in water, cultivation and maintaining natural systems while also moving towards low-carbon technology (GDRC-Guangzhou Development and Reform Commission, 2017, SDRC-Shenzhen Development and Reform Commission, 2017).

In Japan, our review appraised the cities of Tokyo Metropolitan Government (TMG) and the Osaka Prefecture Government (OPG). The OPG has a long-term climate planning of 10 years, up till 2030 aiming to not just decrease its emission throughput by 40% over 2013 as the base year, but also formulating detailed projects that aim reduction of climate impacts (OPG, 2021). Similarly, TMG calls for limiting the rise in average global temperature to 1.5 °C through a robust Zero-Emission Tokyo strategy by 2050 that includes over 47 items and 82 actions for 17 targets. This strategy is built over TMG's earlier 'Carbon-Minus Tokyo' goal to decrease 25% GHG emissions by 2020 (base year- 2000) that thoroughly experimented with the prominent emission trading scheme known as Cap-and-Trade Program (TMG 2007), encouraging renewables, efficient fuel technologies and abatement of GHGs in plastic production.

The sample cities from India have high degree of variation in data availability for urban, energy, GHG indicators as well as climate planning at the city level. All the cities, even being major economic centres do not have any definite system of preparing CAP based on scientific inventorization of their GHG emissions. For instance, Bengaluru lacks its own climate plan and Chennai's strategy document merely tackles climate resilience. Similarly, though New Delhi has formulated climate plan with specific adaptation and mitigation measures (including water, energy, urban planning, health, transport, forest, landuse/ agriculture), the relation of its targets with current and future GHG scenarios is rather uncertain (GNCTD, 2017). It is also observed that most inventories and climate plans are formulated by non-government agencies like TERI in case of Navi Mumbai and Pricewaterhouse Coopers for Kolkata (PWC, 2016; TERI, 2013).

Southeast Asia hosts thriving urban centres including Singapore, Bangkok and Manila covered in this review. Singapore's National Climate Change Secretariat (NCCS) is responsible for the country's climate plan. It indicated that Singapore aims to reduce their Emissions Intensity by 36% from 2005 levels by reaching GHG emission peak around 2030. Their climate change mitigation and adaptation strategies comprise improving energy efficiency (in industry, transport, buildings, household, and water and waste management sectors), deploying low-carbon technology, and promoting awareness and action (NCCS, 2016). In addition, previously implemented flood-control projects and integration of green-blue spaces keeps Singapore well-prepared in terms of climate resilience.

Bangkok's climate concerns were finalized through the Bangkok Action Plan on Global Warming 2007–2012. It then elaborated into the Bangkok Master Plan on Climate Change which clarified the mitigation and adaptation measures. The plan focuses on five main sectors i.e. transport, energy, waste, urban green planning and adaptation. It states no specific disaster/climate government agency, but rather a collaboration between responsible government offices related to each sector and the Bangkok Metropolitan Administration (BMA). Regular monitoring and evaluation were initially planned, yet there seems to be no public report or announcement. Various mitigation and adaptation strategies were explored in detail and a 14% reduction of GHG levels were forecasted in the BAU scenario for 2020 (BMA, 2012).

The Philippines' Manila Bay Sustainable Development Master Plan supports the resiliency and sustainability of the Manila Bay area, covering the national capital region of Metro Manila. Its five focal themes embrace ecosystem protection, improvement in water quality, livelihood enhancement, inclusive growth, disaster risk reduction and climate adaptation. Meanwhile. the Philippines' Climate Change Commission (CCU) extensively covers Metro Manila's climate strategy under the national climate plan for 2028 (CCU, 2011). With base level of 2009, it forecasts five yearly emission targets for 2010 up till 2030 along with associated rise in 2020 & 2050 temperatures followed by formulating detailed adaptation and mitigation measures up till 2016, 2022 and 2028. The review of CAPs in Asia-Pacific cities indicates that the process of urban climate planning is highly inconsistent in the Asia-Pacific region, coupled by lack of determined mitigation targets and proper identification of climate strategies by the decision makers in several instances. The process gets further complicated by inconsistencies and untimeliness in the implementation and monitoring of climate actions. This makes the use of smart, systematic and integrated tools in urban climate assessment even more important.

3 Smart tools in climate action planning

Why do cities require smart metrics and tools for decision making in climate analysis and planning? Climate change in urban areas plays out in a highly complicated manner and requires systematic approach and tools to assess intersecting linkages. A scientifically informed policy on climate adaptation and mitigation depends on precise and credible evaluation of its environment and societal impacts, including both the costs and benefit perspectives. For example, the central method to measure impact is the alteration in the GHG emission of an activity, quantified in metric tons of gases involved, according to the intensity of involvement. Likewise, for projects and research studies dealing with climate adaptation, climate variability is assessed in terms of precipitation and temperature changes.

There are several tools and metrics being applied in assessment of urban climate change, contributions of cities to world emissions, and to ascertain urban policies and interventions being practiced globally to abate warming. Nevertheless, there is clear dearth of having consistent international standards in addressing all urban requirements. Certain tools are developed by international, regional or urban agencies, for e.g. UNISDR, UN-Habitat, European Union, World Bank, C40, etc. while others are formulated by academic and research bodies in different countries. Here, we acknowledge recent urban climate metrics and tools (section 3.1), their different typologies (section 3.2), and plausible challenges or gaps in formulating smart urban climate tools (section 3.3).

3.1 Recent urban climate metrics and tools

During the last decade or so, there has been a marked advancement in preparation and usage of urban climate tools and models. For instance, in Europe, 300 million-plus strong urban population is represented by 10,774 participants in the Covenants of Mayors. Its cities are sharing climate initiatives through a Good Practices database that documents city profiles, their case studies, videos of accomplished projects, etc. These encompass different sectors- industry, electricity, residential, transport, municipal waste, buildings, lightings, agriculture and categorized for adaptation actions and mitigation targets spanning for 2020–50 (Covenants of Mayors, 2021). It is an easy to use tool for decision makers and policy planners disseminating a plethora of climate action information about other cities. Globally, Local Governments for Sustainability commonly known as ICLEI provides several smart tools for urban climate planning (ICLEI, 2021), like Clean Air and Climate Protection (CACP) software, Adaptation database and planning tool (ADAPT) and HEAT+. The former tool helps in preparation of urban energy baseline and corresponding emissions, estimating GHG reduction associated with different climate mitigation projects. The ADAPT tool assists in urban climate adaptation against five pre-defined milestones propagated by ICLEI USA. Meanwhile, the latter tool is simulation-purpose tool for assisting municipal agencies in estimating urban GHGs and local air pollution. It enables policy advice through inventorization of GHGs, their forecasting for preparation ofCAPs, phasing of vital projects, stocktaking and results reporting.

Recently, C40-Cities initiated a smart tool that supports cities to better comprehend interlinakges between climate adaptation and mitigation aspects in jointly moderating climate induced risks (C40-Cities, 2021a). On one hand, mitigation-side tool carries forward prevailing methods of GPC i.e. Global Protocol for Community-scale Greenhouse Gas Emission Inventories, the adaptation tool provides for cities to self-evaluate their climate risks with Climate Change Risk Assessment Guidance template (C40-Cities, 2021b). Topical evidence also indicates that though umpteen tools have been put into use for urban mitigation in the advanced countries, there remain challenges for adaptive urban climate planning in vastly dynamic settings. For e.g. studies from Indonesia and Vietnam show prospects but also limitations of prevailing tools to support adaptive urban governance (Birkmann et al., 2014), most crucial being unavailability of formal data indicators and methods to assess urban climate and consequent openings for result dissemination. In order to systemize and automate this process, a free and open source software based geo-processing portal has been developed that adheres to the Open Geospatial Consortium standards in analyzing over 60 urban variables (Bocher et al., 2018). It is imperative to reconsider current planning models and tools in light of exacerbating climate hazards, global change and socio-economic development, primarily focusing on developing countries in Asia.

3.2 Typologies of different urban climate assessment tools

Urban climate assessment tools can broadly be categorized on the basis of their: (a) Purpose, (b) Method, and (c) Sectoral and Geographic Relevance, as we elaborate below. We illustrate this by drawing of examples from multiple studies, though essentially building on theoretical classification propounded in Sethi (2018), a foremost investigation that reports on 44 urban climate metrics and tools, including 27 from mitigation and 17 adaptation side.

(a) Purpose: There is a definite intention while designing urban climate tools and metrics, either to provide database/ information, evaluation or simulation capabilities. *Database or Information* related tools aim to generate greater awareness or fundamental information through urban data or case studies. For instance, *Synergies in Multiscale Interlinkages of Eco-social Systems* is a tool for local agencies that assists in providing in-depth information and knowledge in sustainable urban transportation initiatives (EU, 2014). It covers over 150 best-practices pertaining to designing policies and guidelines for sustainable mobility and noise control. Meanwhile, evaluation-purposed tools enable experts and public to use their city data to appreciate the state of affairs, ascertain exact issues, assess the most appropriate policy initiative from numerous given alternatives. A case in point is the Practical Evaluation Tools for Urban Sustainability, a web-based model that evaluates infrastructure and building induced impacts on economy, environment and the society (PETUS, 2014). It contains material evidence useful to assess and develop urban infrastructure in a sustainable manner. Similarly, simulation centric tools provide innovative options for modeling to users in formulating futuristic or alternate situations, conceptualizations, forecasts, scenarios, etc. that assist in greater understanding of impacts for credible policy making. For instance, a tool called *Synthetic City* enables urban energy systems modelling that covers first-hand planning of a city, its principal activities, socio-economic configuration, energy and technology choices to meet their needs (SynCity, 2014). About half of urban climate tools are evaluation centric, followed by simulation tools, and only a few tools are purposed for database and information.

(b) Method: Urban climate tools can be categorized as per their primary scientific method; bibliometric, statistical, and spatial. Climate mitigation aspects in cities typically involve GHG estimation and thus their tools essentially harp on statistical methods. On the other hand, urban climate adaptation tools involve assessment of non-quantized indicators, basically formulating scenarios for policy making. Such tools focus on risk assessment of current or projected situations, climate vulnerability or hazards in cities, assessing policy choices, moderating appropriate resilience or adaptation strategies as well as project operationalization and their stocktaking. Thus, these broadly employ spatial or geographic analysis in projecting climate risk and vulnerability, while learning from similar peer cities through bibliometric or case study methodologies to guide plausible alternatives while framing their own climate policies and strategies.

(c) Sectoral and Geographic Relevance: Urban climate tools and metrics are extremely varied in geographical and sectoral applications. Some tools are dedicated in evaluation of impacts and benefits in certain mitigation sectors, namely buildings, mobility or energy. For e.g., there are several tools assessing supply and demand parameters of urban mobility. Similarly, many tools evaluate different spatial aspects of urban climate including landuse, form/ density, city-panning, etc. Likewise, different tools are purposed for specific geographical scale i.e. region or country. For instance, Urban CLIM enables decision support for urban climate action covering hazards resilience, water, transport, and health sectors in Asia-Pacific cities (APN, 2015). On the other hand, Green Clime Adapt and Urban Adaptation Support tool (EU & EEA, 2014) is customized for policy advice in European context only.

3.3 Challenges and gaps in formulating smart urban climate tools

The development of smart, practical and multi-faceted tools for urban climate assessment is a highly complex undertaking. As aforementioned, smart tools need to be super-specialized in terms of their intended purpose, focused sector and geographical coverage and find interconnections in grey areas. A case in point is to acknowledge linkages between adaptation and mitigation during target-setting for a city. Within mitigation, there is a scarcity of tools that cover sequestration of urban emissions. It is crucial to make a multipurpose tool over a variety of functional-scales, ranging from individual building or local area to sprawling urban-region, that entails management of varied and complex data variables.

Software developers and urban practitioners have upscaled the development of smart urban climate tools in the last few years and their field-testing by decision makers on the ground becomes crucial. Similar to inconsistencies associated with estimation of urban GHGs, there are numerous gaps that limit the extensive use of smart urban climate tools, spanning conceptual, methodological, empirical and policy aspects (Sethi, 2018). Conceptual gaps arise out of insufficient scientific knowledge of current theories about climate associations with urban areas be it through emissions from contributing sectors or climate impacts arising out of variable hazards, vulnerabilities and risks. Methodological gaps are a consequence of improper assessment of climate vulnerability or city GHGs. There being a paucity of standard tools in evaluating climate mitigation and adaptation related to urbanization/urban centres. This leads to inconsistencies and incomparability in assessing their emissions, risks and vulnerabilities and climate co-benefits traversing multiple sectors, complicating necessary strategies to counter them. Empirical gaps result from insufficient scientific data or reasoning of urban climate impacts or carbon emissions in evidence of prevalent understanding. Policy-governance gaps arise from inadequate know-how amongst cities around their role and responsibility to effectually plan for climate action. Under these circumstances, a smart tool intended for the purpose of comprehensively guiding urban climate decision-making in a region has to be assimilating different functional sectors and scientific methods.

4 Materials and methods

Recent research elucidates how science based climate planning in urban areas is utterly complex and undefined, mainly augured by three particular approaches (Sethi et al., 2021): (1) *Spatial evaluation* approach that evaluates climate variability and its hazard propensity to guide mitigation of disasters, needs for climate adaptation and actions for long-term resilience, (2) *Statistical modelling* that relies on analysis of demographic & economic indicators, prediction of energy consumption & related GHGs to inform prepare policies for low-carbon development; and (3) *Case studying* that indulges in intense qualitative evaluation of best practices from city specific or peer-city experiences to apprise strategies in comparable conditions. Under such circumstances, reliable evaluation and modeling of multi-dimensional data and information for urban application becomes paramount. Here, we make use of ICLAP tool, a simulation based decision-making model that assimilates established methods in climate mitigation, adaptation and data science (Sethi et al., 2022, APN, 2021). The model constitutes an integrated approach to guide policy choices keeping in view tailored mitigation scenarios, projected climate variability (temperature and precipitation) for 2030, 2050 and beyond, and findings from post-factum urban solutions, in a highly organized, transparent and user-friendly tool interphase.

The ICLAP tool adopts an advanced methodology of synthesizing three different knowledge domains/ analytics, building on specific and accepted research methods (Fig. 1) in the respective domains of climate adaptation, mitigation and data science (Sethi et al., 2022), as summarized below:

1. Spatial- Downscaling climate scenarios & GIS mapping of variability: In order to forecast climate variabilities at urban-region scale, rainfall and temperature deviations from the normal would be downscaled from global/ regional MICROC6, with standard regional concentration pathways (RCP) 4.5 & 8.5 scenarios (Saraswat et al., 2016) and even up to 2080, eventually being crucial in guiding adaptation alternatives. Using ArcGIS (Version 10.3), we perform mapping of rainfall and temperature anomalies of all cities downscaled locally (50 km × 50 km grid) for both 2030, 2050. The results are reported in the form of shapefile (SHP) along with associated data structure.
2. Statistical- Trend analysis of urban indicators and GHG forecasts: Climate mitigation assessments

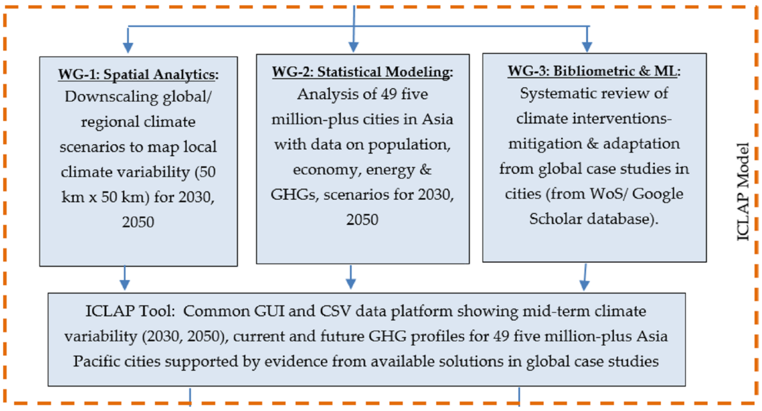

Fig. 1 The Integrated Climate Action Planning (ICLAP) model

would be supported by of urban data profiles, their forecasts covering population, economy, energy use in transport, buildings, agriculture/ landuse, waste and corresponding GHGs for 2030, 2050 (Fujimori et al., 2014). The details of relevant datasets used in this step, like World Urbanization Prospects, Global Human Settlement Layer Urban Centres Database (GHSL-UDC) and Emissions Database for Global Atmospheric Research (EDGAR v4.3.2) are discussed below. The trends and forecasts (for business-as-usual, with upper and low limits) in this step would be instrumental in reviewing current CAPs and identifying new climate mitigation actions.

3. Bibliometric- Meta-analysis of evidence from case studies: Data extraction and machine-learning are employed to systematically review 644 global case studies in local climate action. It employs Google Scholar and Web of Science database to undertake bibliometric analysis. This is followed by meta-analyzing key policy solutions (Lamb et al., 2018; Lamb et al., 2019; Sethi et al., 2020), the outputs of which are collated and analyzed in standard CSV file format. The results are coded for diverse GHG sectors (energy, industry, transport, landuse-landcover change, waste, etc.), their relative efficiency and governance modes for implementation (UN-Habitat, 2011) like regulations, enabling mechanisms, economic instruments and voluntary measures.

Taking the case study of Indian cities, ICLAP tool is used to test all distinctive features- *database* (in the form of urban solutions), *evaluation* (setting of standard features in downscaled climate variability, GHG scenarios) as well as their customizable *simulation*. In this research, we draw from *World Urbanization Prospects: The 2018 Revision*, a standard dataset on urban agglomerations (UNDESA, 2019) for city population. As relevant international conventions, namely Sendai Framework for Disaster Risk Reduction, Sustainable Development Goals, New Urban Agenda and the Paris Agreement (UN, 2015; UNDRR, 2015; UNFCCC, 2015; UN-Habitat, 2016) seek monitoring based on indicators; data of urban area, built-up area, green area, GDP, etc. are drawn from a reliable and uniform source, i.e. GHSL-UDC (Florczyk et al., 2019). In case of GHG emission data, we know that earlier urban energy/emission studies (Kennedy et al., 2015) performed macroscale correlations (volumetric) and microscale correlations (per-capita) for energy-use while Lombardi et al. (2017) used similar approach of discerning urban GHGs as "spatial" or "direct", and "economic" or "life cycle based" emissions. Thus to have credible, consistent and comparable GHG dataset for sampled cities, we draw from European Commission's in-house EDGAR v4.3.2, which estimates anthropogenic GHGs from 1970 to 2012 (Crippa et al., 2018). It includes CO_2, NO_x, SO_2 from all production-based activities following standard sector definitions/codes, bottom-up approach of data computation and hence offering consistency and comparability (IPCC, 1996).

5 Results discussion: the case of Indian cities

5.1 Climate variability

The temperature and precipitation scenarios for 2030s, 2050s and 2080s under RCP 4.5 and 8.5 have been analyzed using the scatterplots generated for the analysis, as given in Figs. 2 and 3. The top left quadrant in these figures has cities that will experience lower levels of temperature rise as compared to the ones in the top right quadrant. However, all cities in the top half of the graph will experience higher levels precipitation (in % terms) and those in the lower half which will experience reduced levels of precipitation. In the scatterplots for RCP 4.5

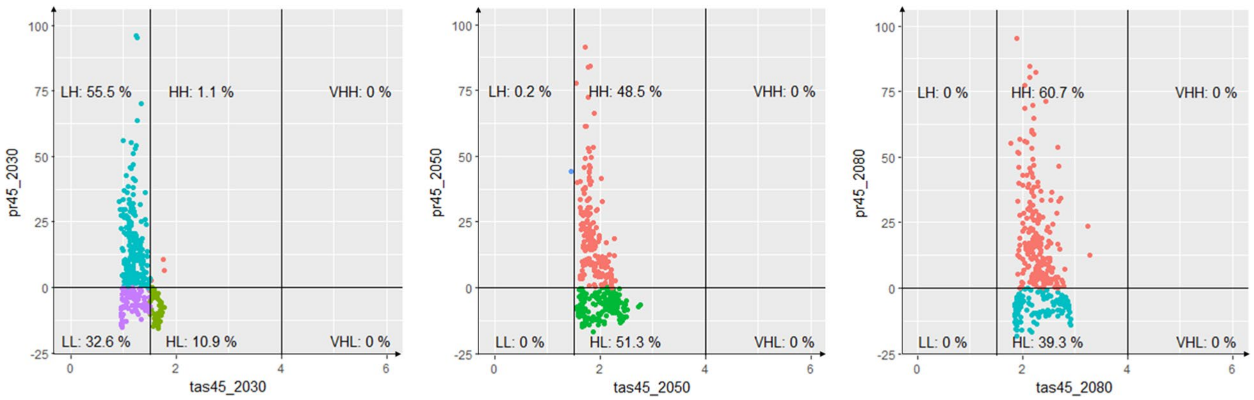

Fig. 2 Combined variability of temperature in DegC (X-axis) and rainfall in mm/day (Y-axis) under RCP 4.5 (left to right: 2030, 2050, 2080). LH: Low temperature High precipitation, HH: High temperature High precipitation, VHH: Very High temperature High precipitation, LL: Low temperature Low precipitation, HL: High temperature Low precipitation, VHL: Very High temperature Low precipitation

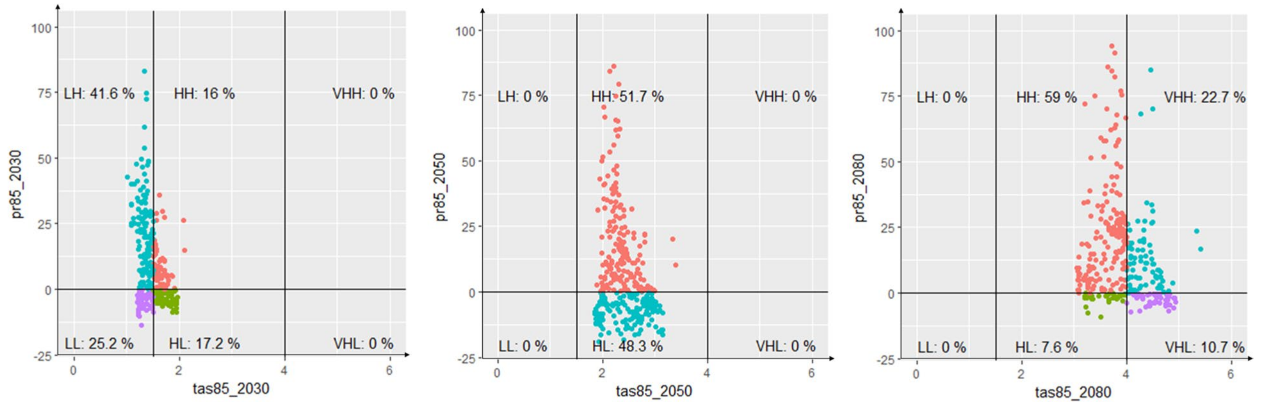

Fig. 3 Combined variability of temperature in DegC (X-axis) and rainfall in mm/day (Y-axis) under RCP 8.5 (left to right: 2030, 2050, 2080). LH: Low temperature High precipitation, HH: High temperature High precipitation, VHH: Very High temperature High precipitation, LL: Low temperature Low precipitation, HL: High temperature Low precipitation, VHL: Very High temperature Low precipitation

and 8.5, two vertical lines have been drawn for temperature. The first vertical line represents a temperature rise of 1.5 °C and the second 3.0 °C. This was necessitated as temperatures are showing only an increasing trend and by 2080s the temperature rise will be well above 2 °C and also going beyond 3 °C. Therefore, two vertical lines were required for temperature. An analysis of future temperature and precipitation scenarios (indicate that under RCP 4.5 scenario most cities will experience a rise in temperature up to 1.5 °C and about 57% of cities will experience an increase in precipitation in 2030s. By 2050s all the cities will experience a rise in temperature from 1.5 to 2.5 °C and about 50 % cities will experience reduced precipitation. By 2080s three-fifths of the cities will experience an increase in temperature of about 2–2.5 °C and also an increase in precipitation (Fig. 2).

The scenario under RCP 8.5 though follows a trend similar to RCP 4.5, the temperature and precipitation projections in 2050s are similar to the projections for 2080s under RCP 4.5. However, under RCP 8.5, the temperature and precipitation scenarios in 2080s shows an increase in temperature of between 2.5 and 3.5 °C and an increase in precipitation in four-fifths of the cities. Nearly 10 % of the cities will experience higher temperatures and reduced precipitation (Fig. 3).

The analysis of Indian cities indicates that Mumbai shows the *most variability,* with high temperature increase in future climate scenarios. A minimum rise of 1.27 °C (in 2030s for RCP 4.5) is expected for average maximum near surface air temperature, while the upper value could be as high as 4 °C in the worst case (in 2080s for RCP 8.5). The impacts of temperature rise are expected to worsen when cumulated with high increase in the precipitation rates that could range from 2.3 mm/day (RCP 4.5, 2030s) to 3.74 mm/day (RCP 8.5, 2080s). Such massive increase in precipitation rates could have implications for extreme rainfall events in the city, indicating an increase in frequency of floods like that experienced in July 2005 or August 2017. Cities along the Indo-Gangetic Plains in the states of Punjab, Haryana, Uttar Pradesh, Bihar, Jharkhand, West Bengal (and Odisha) fall in the *more variability* to *highly variability*. Cities in south India demonstrate *least to less variability*, except for Chennai, Hyderabad and Bangalore, which show *more variability*. These cities are expected to experience a rise in maximum temperature between 1.14–3.74 °C under projected climate scenario. Bangalore is predicted to have an increase in precipitation rates between 0.55 mm/day (RCP 4.52030s) and 1.3 mm/day (RCP 8.52080s). In Hyderabad, the situation could worsen in future when the precipitation is expected to increase by 0.5 mm/day in 2030s under RCP 4.5 and up to 0.96 mm/day in 2080s under RCP 8.5. Chennai might face higher risks of flooding in future due to expected increase in precipitation rates by at least 0.37 mm/day (RCP 4.52030s). In effect, cities in the Indo-Gangetic plains and Mumbai in the western region are in general found to be more climate prone and hence need to put in efforts to prepare for the hazardsin future.

5.2 GHG trends

There is a strong association between India's urbanization trends with its economic development, energy consumption and GHG emissions. A comparison of these indicators (Fig. 4) indicates that a unit rise in urban population is concomitant with GHG emissions rise by a factor of 2.0. Though India has been urbanizing at a consistent and relatively slower rate of 1.16% during 1971–2011, overall GHG emissions have escalated at a *compound annual growth rate* of 4.01% from 1994 to 2007. The future

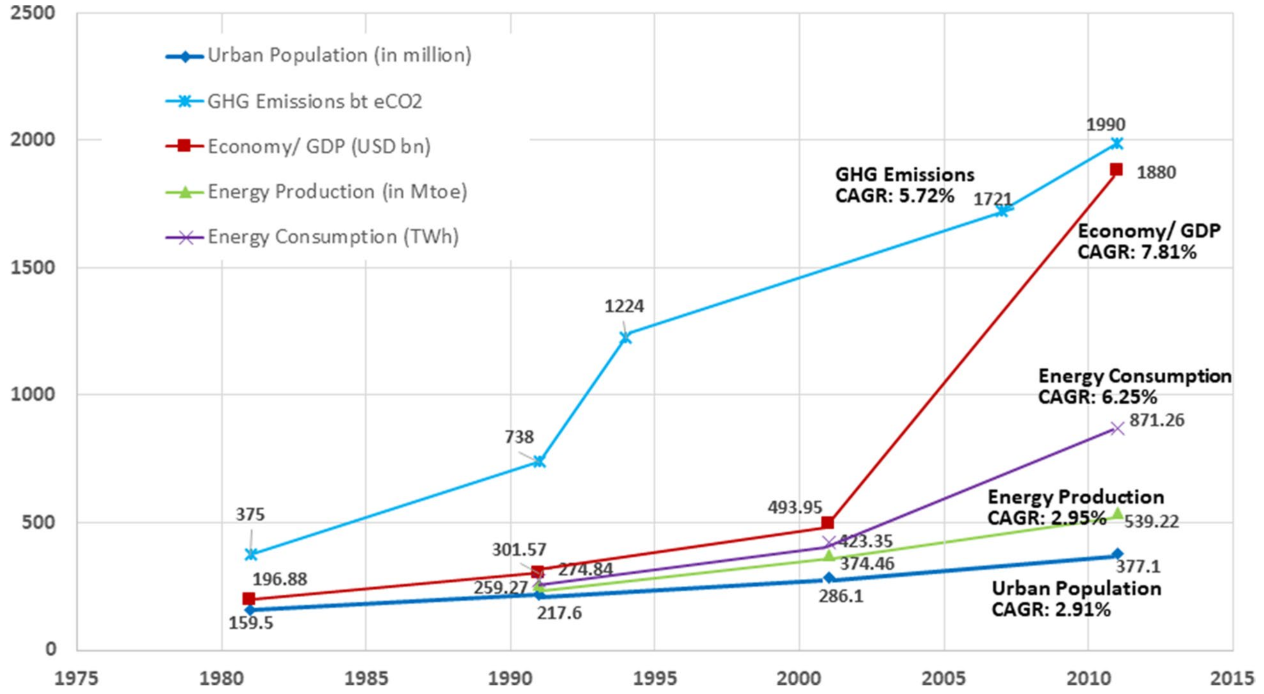

Fig. 4 Urbanization, economy, energy (production and consumption) and GHG trends in India

Source: The time series analysis is generated based on the following point data sources: 1. Urban Population data from TCPO (2012), 'Data Highlights (Urban) based on Census of India', Town & Country Planning Organisation, Government of India, New Delhi. 2. Energy Consumption and Production figures for 1991, 2001 and 2011 from IEA database available at http://www.iea.org/statistics/statisticssearch/report/?country=INDIA&product=indicators&year=1991 3. GHG emissions data (1994 & 2007) from MoEF (2010): 'India: Greenhouse Gas Emissions 2007', Indian Network for Climate Change Assessment, MoEF, India. Figures for 1981, 1991 are from World Bank indicators, see point 4 below. 4. Economic baseline in current USD from World Bank indicators available on http://data.worldbank.org/indicator

urbanization is projected to be doubly rapid (at 2.83% annual growth) till 2039, when most estimates consider India's population to be about 50% urbanized. It is apparent that this steady urban growth phenomenon is concurrent with economic progress, rising affluence, energy surge for living, commerce and other production related activities along with increasing GHG emissions.

As per the key scenario within World Energy Outlook (IEA, 2011), India's carbon emissions will increase at 3.2% per annum to 3535 $MtCO_2$ in 2035, responsible for 8% of global emission i.e. 43,320 $MtCO_2$. Emissions from coal combustion would be 2227 $MtCO_2$ or 63% of India's total emissions. It assumes that by then, India is projected to be the world's most populous nation with 1.511 billion people, India's per-capita carbon emissions could reach 2.34 tCO_2/capita, which is higher than 1.7 tCO_2/capita at present but will be still substantially lower than the World average of 4.25 tCO_2/capita, with China's emissions at 7.39 tCO_2/capita and the United States' at 12.03 tCO_2/capita in 2035 (IEA, 2012). Such projections of a massive increase of carbon emissions in India raise concerns about their impact on global climate change. Another study supported by the Government of Indian (MoEF, 2009) considers multiple models to forecast future emission pathway. An average of results from five models suggests that GHG emissions in the next two decades are bound to become threefold, from 1727 (2007) to 5220 $MtCO_2e$ (2030–2031), while per capita emissions will also become almost four times, from 1.5 (2007) to 5.6 tCO_2e (2030–2031). Meanwhile the LCS Report pegs India's emissions at 3537 to 3071 $MtCO_2e$ in determined and aggressive low-carbon growth scenarios respectively (PC- Planning Commission, 2014). The urban share of India's emissions, which was estimated to 70.3% or 1213.9 $MtCO_2$ of national GHGs in 2007 (MoEF, 2010) is expected to expand to 2696 $MtCO_2$ by 2039 (Sethi, 2017), assuming that the economy grows at constant rate.

5.3 Global urban climate solutions

Based on bibliometric analysis, the systematic review of case study literature leads to identification of the following major urban climate solutions being practiced worldwide: Building information system, Green building, Smart meters/ intelligent controls/ thermostats, Urban form, design, planning, Passive solar design, monitoring, Biomass, biomass gasification, Energy efficiency measures, Intelligent transportation system (ITS), biodiesel/ ethanol, Awnings or window glazing, Cogeneration or tri-generation (winters only), Fuel or technology shift, car free city, PV Solar, roof garden (higher latitudes), Energy storage- battery or from breaking energy, Afforestation & greening expansion, Smart grid, Cool roof/façade, District heating/cooling. Their mitigation potential is limited up to 26.25% emission reductions.

The next set of solutions are Wind energy, Public transport expansion, Buildings, energy& transport combined solutions (B + E + T), Cogeneration or tri-generation (city or urban district), Waste heat recovery, Geothermal heat pumps, Thermal comfort & insulation, Transit oriented development, Composting and biological treatment of waste, Retrofitting old buildings, Cool roof/facade, roof garden (lower latitudes), Combined walls/ roofs, Life cycle assessment, DSM- optimization, peak shifting/ shaving, Travel demand management optimizing mobility. These are found to have a mitigation potential ranging from 26.25% to 52.5%. There are some more effective case studies too; Solar tri-generation CPVT, EE + PV, PV thermal, Private and public transport, Integrated waste management, EE + RE + EV. Their mitigation potential is known to vary from 52.5% to 78.75%/. The most superior urban climate solutions include Electric mobility- electric vehicles (EV) & hybrid electric vehicles (HEV)- in public & private vehicles, Net zero emission building (NZEB), Energy from waste (WtE/EfW) or Waste to energy. These solutions are found to have a mitigation potential ranging from 78.75% to 105%.

6 Conclusions

By sheer mass of urban population and its economic propensity, high water and energy dependency and local air-pollution, cities bear a strong role and responsibility as agents to mitigate and adapt to climate change in comparison to their rural counterparts. In its submission to UNFCCC at CoP 21 Paris, India declared that it aspires to achieve the ambitious target of reducing the emissions intensity of its GDP by 33%–35% by 2030 from 2005 level (MoEF, 2015), mainly by augmenting renewable energy capacity to 175 GW by 2022 and 500 GW by 2030. By July 2022, India's installed capacity in renewables is at 161.28 GW out of which 114.43GW is from small hydro, wind, solar, bio-power, including WTE (CEA, 2022). Based on future climate projections ranging from 2030 to 2050, it is apparent that there would be significant yet variable impacts in most of the regions. For instance, higher winter temperatures can lead to decreased heating use, while increased summer temperatures can lead to increased need for cooling. It is now known that greater use of air conditioning due to rising temperatures can worsen the urban heat-island effect and further increase the cooling demand in urban areas (Hunt & Watkiss, 2007). On the other hand, with rising temperatures, more frequent extreme heat events and population growth in future, water demand in cities is expected to increase (Ruth & Gasper, 2008). This would definitely increase the energy consumed in pumping to draw natural water, transmit, purify and distribute it to the urban population.

The review of global case studies through bibliometric analysis under ICLAP (section 5.3) suggests that urban climate solutions need to respond to a city's future GHG trajectory and climate variability (Table 1). Based on different GHG, temperature and precipitation deviations, four possible pan-India situations emerge for influencing urban climate impacts. Out of these, Situation 3 (decrease in projected temperature, decrease in projected precipitation) and Situation 4 (decrease in projected temperature, increase in projected precipitation) have not been observed. The projections indicate that cities have to take adaptation measures that will help them manage flood and drought situations. Cities with increased rainfall in summer may also face prolonged periods of high humidity days, which will result into a spike in energy consumption to meet air-conditioning loads. Cities that face higher temperatures and drought like situation like Hyderabad, Kolkata will have to invest significantly in water supply infrastructure, including augmentation and efficient management of the water supply system, demand management and consumer education. The indirect consequences of water scarcity will be social tensions due to altercations over water. There will be over withdrawal of ground water leading to consequences such as land subsidence over long term. Therefore, these cities will need to do rainwater harvesting, recycling of wastewater, recharging of aquifers, regulate ground water withdrawal and rejuvenate water bodies. Cities will therefore have to plan adaptation measures in the immediate future to address emerging climate change scenarios in the near and distant future.

With the increasing occurrence of climate induced extreme events, substantial damage to buildings, transport and energy system- cable networks, poles and installations, switch boards/ panels, etc. in residential and commercial areas is expected. Coastal cities are particularly prone to sea/ salt water intrusion that could damage the foundation and support structures of civil infrastructure. In plain areas, flash floods with sudden downpours in are likely to increase in many dense, compact towns and metropolitan regions as precipitation intensity increases. The repeat occurrence of intense and rapid urban flooding in Mumbai, Srinagar, Chennai, Bengaluru, etc. in the last one decade have revealed what mayhem

Table 1 Description of impacts and plausible solutions for sample of Indian cities experiencing different GHG, temperature and precipitation in future

Case	GHGs	Projected temperature	Projected precipitation	Sample Cities	Description of Impacts	Plausible solutions
1	Increase	Increase	Increase	New Delhi, Mumbai, Bangalore, Chennai, Ahmedabad, Surat, Pune	Increase in thermal loads (air-conditioning) particularly during monsoons, energy consumption, urban flooding, rising pumping energy and costs in drainage, submergence of power systems during floods, preventive power-cuts	Green building, Smart meters, DSM- peak shaving devices, rainwater harvesting, recharging of ground water aquifers, rejuvenating surface water bodies, creating roof gardens and soft landscapes for greater percolation
2	Increase	Increase	Decrease	Kolkata, Hyderabad	Ground water depletion, heat waves, urban heat island, drought like conditions, Increase in air-conditioning particularly during summers, rising pumping energy and costs in water supply, melting and deformation of power cables/ installations, short-circuits in electric and metro systems, load-shedding, etc.	Afforestation & greening, green building, smart-grids, installation of rooftop solar PV, recycling water and rainwater harvesting in buildings, demand management systems or building information systems, smart meters, geothermal heat pumps
3	Increase	Decrease	Decrease	–	–	–
4	Increase	Decrease	Increase	–	–	–

and misery climate hazards could unfold in large settlements (Sethi et al., 2021). Damage to pumping devices, especially if electronics are damaged, can take weeks to fix and can cost as much to repair as their initial construction costs, as evident from several case studies around the world (Wilbanks et al., 2007, World Bank, 2000). The aversion of such a situation requires diligent and widespread integration of green-blue infrastructure at regional, city and community levels with solutions including afforestation and recharging of ground water aquifers, rejuvenating surface water bodies, creating roof gardens and soft landscapes allowing for greater percolation in residential localities and city arteries.

The highly variable impacts in cities located across different geo-climatic regions offer a multitude of plausible solutions for cities to choose from. Certain high-impact climate mitigation and adaptation solutions (like net-zero emission buildings, electric mobility, waste to energy, transit oriented development, afforestation, cool roofs and rainwater harvesting) may be commonly beneficial in most situations. Nevertheless, exact application has to be extremely specific to the city context, contingent upon several locally determined economic, environmental, social and governance factors like (a) availability of technology, (b) actual demand, project cost and feasibility (c) ecological or environmental impacts (d) social acceptance/ inhibitions, (e) implementation and management as an urban strategy, so as to ensure its seamless and coordinated integration with other sectoral policies at the city level.

7 Recommendations for incorporating ICLAP in smart cities

Contemporary research shows that urban climate issues are particularly fraught with complexity due to intersection of large number of distinct variables in *climate geoscience* (precipitation and temperature anomalies at different locations, RCPs, timeline), *adaptation alternatives* (approach, priority, intervention level) and *urban governance* (functional mandate, institutional capacity, and plans & policies) and require systematic 'negotiation' process to situate, ground and operationalize climate action in cities (Sethi et al., 2021). This necessitates transition to be multi-dimensional, systems interactive, for e.g. interaction of multiple technologies or governance sectors and also be context dependent, breaking through the burdens of path dependency (Sethi, 2022). It is meant to overcome the short-termism currently dominating urban planning, and instead embrace long-term, integrated, global perspectives. To implement it through climate governance, the mixture of adaptive, precautionary and reactive policies becomes imperative. Precautionary policies are necessary to limit harmful surprises, but due to the current trends of change it is inevitable to prepare for system changes. Therefore, policies based on scientific tools like ICLAP become necessary to increase the adaptive capacities in the environment and that of the urban societies.

The study of CAPs in the Asia-Pacific cities (section 2) demonstrates how urban climate planning is fraught with and lack of ambitious targets, inconsistencies and untimeliness in their implementation. Monitoring and evaluating is a critical step to ensure that a city's climate planning process is both effective and sustainable over time. This includes developing an approach (monitoring and evaluation plan or strategy) to track progress on the implementation of climate actions and assess whether the city's stated objectives are being achieved. Measurable indicators can provide quantifiable information on the baseline conditions and tracking progress. There are many existing resources e.g. C40, Covenant of Mayors, ICLEI that provide indicators or examples of indicators have served as a reference point or inspiration for cities, yet integrated and smart tools are indispensable. Beyond setting up an effective indicator-based monitoring framework, a city should then use smart monitoring tools to revise and readjust their urban strategy or action plan to best meet their climate objectives. This provides for an iterative process where local authorities can reflect on the outcomes of the selected and implemented actions and make adjustments moving forward.

At the same time, developing smart metrics and evaluation tools for climate action is an intense process of scientific collaboration, data collection, knowledge sharing, identification of tools and methods, to implementation and policy review. It requires comprehensive knowledge of multiple disciplines, existing methodologies and tools to effectively integrate these ensuring greater filed application. Integrated models provide an opportunity for partnership between inter-disciplinary experts, city managers to facilitate platform for exchanging knowledge that can ultimately build capacities for technical and local governance processes. In the long-term, ICLAP like metrics and tools act as an instrument of science based policy application in local urban and sub-national development, cooperating with the private sector and encouraging public-participation. Given the practical relevance, ICLAP should be incorporated within national urban sustainability initiatives in India like the Smart Cities Mission and Atal Mission for Rejuvenation and Urban Transformation and their associated funding mechanism with state governments, guiding stakeholders in sensible target setting, prioritizing projects and tracking progress. Since the phenomenon has global causations and consequences, using such urban climate tools will also promote comparisons with other cities, interactions with intercontinental city forums, scientist community, non-governmental organizations, businesses and general public. In addition, the resulting multi-sectoral strategies would foster inter-departmental coordination, enhance public awareness on climate science and promote private and civic action in urban systems. In this regard, national governments, regional and international scientific bodies should mobilize greater support to integrated and collaborative scientific tools showing significant practical applicability on the ground to combat global climate challenge.

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Authors' contributions

All authors contributed to the conceptualization, methodology, formal analysis and investigation. The first draft of the manuscript was written by Mahendra Sethi and all authors were involved in reviewing and editing. All authors read and approved the final manuscript.

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Availability of data and materials

All data that support the findings of this study are included within the article.

Declarations

Ethics approval

Not applicable. Upon detailed review of the project, the Ethics Committee of ISARD finds that the study does not involve any humans or animals.

Consent for publication

Not applicable.

Competing interests

The authors have no financial interest or non-financial interest to declare that are relevant to the content of this article.

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