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Early engagement and co-benefits strengthen cities' climate commitments

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Cities can lead the way in tackling climate change through robust climate actions (that is, measures taken to limit climate change or its impacts). However, escalating crises due to pandemics, conflict and climate change pose challenges to ambitious and sustained city climate action. Here we use global data on 793 cities from the Carbon Disclosure Project 2021 platform to assess how the COVID-19 crisis has affected cities' reported climate commitments and actions and the factors associated with these impacts. We find climate actions persist despite funding shortfalls; yet only 43% of cities have implemented green recovery interventions. Co-benefits of climate action (for example, health outcomes) and early engagement on sustainability issues (for example, via climate networks) are associated with sustained climate action and finance during COVID-19 and green recovery interventions. Cities should strengthen sustainability co-benefits and relationships with coalitions of actors to support durable climate commitments during crises.

Cities worldwide have emerged as critical actors in reducing greenhouse gases[1]. Since the 1990s, global networks of cities (for example, Local Governments for Sustainability [ICLEI], C40 Cities Climate Leadership Group [C40]) have taken the lead in addressing climate change with ambitious climate policies and actions[2]. Climate action broadly refers to measures taken to limit climate change (climate mitigation) and/or its impacts (climate adaptation) and can include direct actions (for example, development of renewable energy, flood risk mitigation) and indirect actions, such as monitoring efforts[1]. Given that over 70% of energy-related CO_2 emissions are estimated to come from cities and urban areas[3], their actions will be decisive for achieving global climate targets. However, recent years have witnessed a series of social and economic crises, brought on by the COVID-19 pandemic, Russia's invasion of Ukraine and increasing climate disasters[4,5], the impacts of which have been most notable in cities and large towns, where approximately 57% of people live[6] and where the large majority of economic activity is based[7]. Predictions of increasing economic pressures across the globe due to climate change[8] and conflict over scarce resources (for example, water)[9] raise an important question about whether cities will continue to lead the way in climate action[1].

Studies suggest that crises, particularly economic crises, have mostly negative effects on environmental commitments and policies[10–12], although they can also reconfigure relationships between the economy and the environment[13,14]. However, most of these studies focus on national-level policies[15] and the few city-level studies are either speculative[16,17] or limited to very specific climate actions and geographies (for example, solar panel adoption in Japan)[13,18,19]. Most research on city-level climate action addresses the initial adoption of targets and policies (Yeganeh et al.[20] includes a recent meta-analysis). While providing important insights, this literature does not shed light on how crises affect cities' climate policies and actions or the factors influencing whether cities respond with increased or decreased ambitions.

Understanding how crises affect the climate commitments of cities around the world—and the factors that moderate these effects—is essential to support efforts to enhance the durability of city climate policies and actions. We address these critical questions with a global

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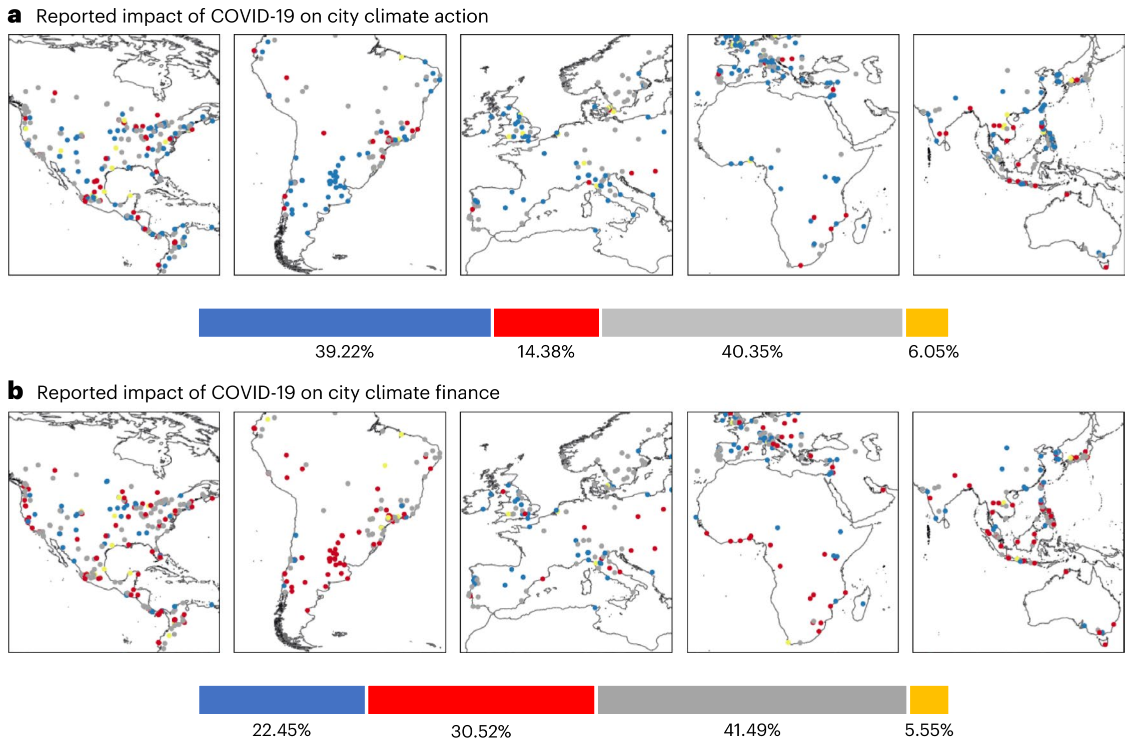

Fig. 1 | Impact of COVID-19 on cities' climate action and climate finance. **a**, Blue dots/bars indicate increased emphasis on climate action; red–decreased emphasis on climate action; grey–no change in emphasis on climate action; yellow–other. **b**, Blue dots/bars indicate increased emphasis on climate finance; red–reduced climate finance; grey–no change in climate finance; yellow–other. Sample of $n = 793$ cities. Regions shown from left to right are North and Central America, South America, Europe, Africa and Middle East, East and Southeast Asia and Oceania. The regions shown here do not coincide exactly with the CDP 'regions' (for reasons of space). Supplementary Information 8 includes global maps. Maps were produced using QGIS desktop 3.20.3 and basemap (coastline v4.1.0) from Natural Earth (https://www.naturalearthdata.com).

analysis of the impact of the COVID-19 crisis on cities' climate commitments. COVID-19 has had a truly global impact, causing the deaths of almost 7 million people[21] and contributing to a 3.1% decline in global gross domestic product (GDP)[22]. There are many insightful commentaries and articles about the potential effect of COVID-19 on climate actions[23–25] but no empirical analyses of how cities have responded to the compound health and economic crisis prompted by COVID-19 vis-à-vis their climate commitments.

Our study addresses this question, first by identifying how cities have responded to COVID-19 with regards to their climate actions and climate finance and the extent of their engagement in green recovery; and second by examining which factors are associated with different responses to COVID-19. To do this, we use self-reported data provided by city officials from 793 cities worldwide, provided through the Carbon Disclosure Project's (CDP) disclosure system for cities[26]. Cities reported the effect of COVID-19 on their city's climate actions and available climate finance, providing valuable inside information about city officials' perceptions of how the pandemic has affected their climate commitments (Methods). Cities also reported their implementation of recovery interventions that are synergistic with climate action (which we term 'green recovery' interventions); such decisions to engage in green recovery may anchor longer-term commitments to climate action[27] hence providing important insights into longer-term effects of COVID-19.

To identify factors associated with durable climate actions and finance, and higher levels of engagement in green recovery in cities, we employ multilevel regressions to account for the fact that city responses to COVID-19 are likely to be influenced by national-level factors (Methods). We relied on the extensive literature on climate policy adoption to identify potential factors that might influence cities' response to COVID-19 (Methods include a review). From this literature we identified two broad categories of potential influence; the first is exposure to environmental stress[20,28–31], the expectation being that cities experiencing more climate-related impacts (for example, climate hazards, such as floods or droughts) are more motivated to engage in sustained climate action. The second broad category is early engagement with climate and sustainability; the underlying rationale is that the more that cities have engaged in addressing climate and sustainability issues (for example, by joining climate networks[32–35], by aligning economic development with sustainability[36–40]), the more likely these issues will become embedded in city policies, processes and interactions, which in turn will enhance their durability. We also control for COVID-19 impact, which is expected to affect a city's capacity to address climate change; and we include other controls (for example, population density) found to influence climate action in the literature. Factors included in the regressions are operationalized using data from CDP and from other sources. Extended Data Table 1 includes descriptions of the indicators; Supplementary Information 2 includes details about how they were operationalized.

In contrast to many large-*n* studies on city-level climate action, we emphasize the global character and scale of climate action and the COVID-19 crisis by considering cities from developed and developing countries (48% of cities in this study are from the Global South), allowing for a more generalizable understanding of city climate action and crises and lessons learned across geographies.

Impacts of COVID-19 on climate actions and finance

We find that more cities report increased climate action (39.2%) compared to decreased climate action (14.4%) due to COVID-19 (Fig. 1a; two-sample test of proportions $p < 0.001$), yet the opposite is true for climate finance, with more cities reporting reduced (30.5%) rather than

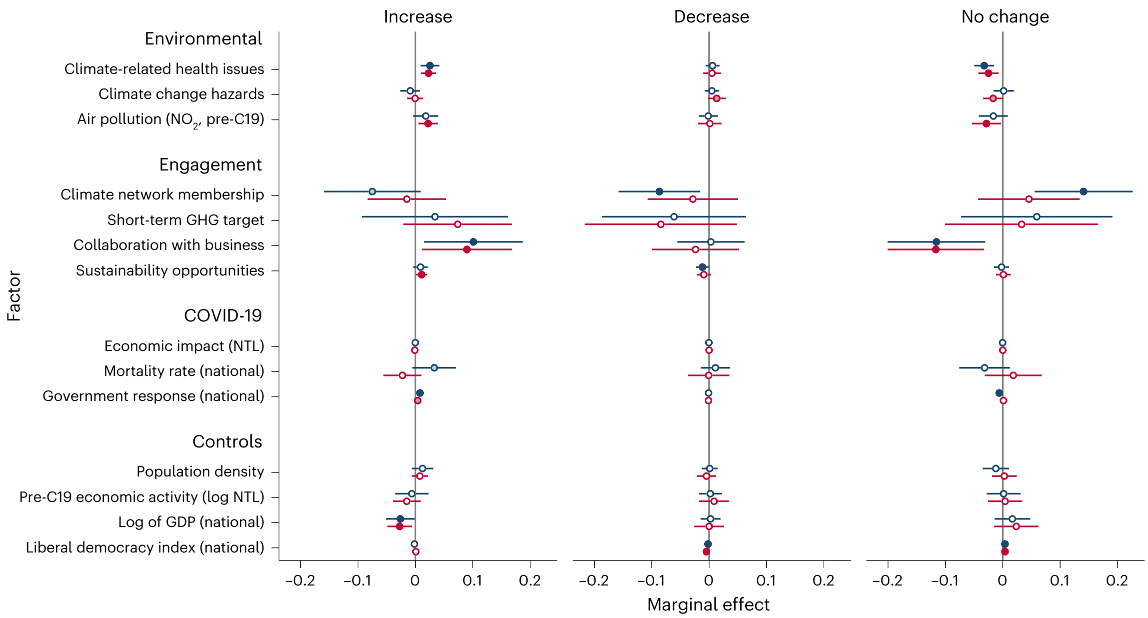

Fig. 2 | Factors associated with impacts of COVID-19 on city climate actions and finance. Results of multilevel generalized structural equation model (GSEM) regressions are displayed as marginal effects (gsem does not provide standardized outputs; Extended Data Table 1 provides interpretation of variable descriptions) ±95% confidence intervals. Regression results for the 'other' category are shown in Supplementary Tables 7 and 8. Blue circles: *emphasis on climate actions;* red circles: *finance available for climate action in your city*. Filled circles (dark blue) indicate that the association is significant at $p < 0.05$, light-blue filled circles indicate $p < 0.1$; empty circles indicate $p > 0.1$ (two-sided z-tests). Sample size of 689 cities for both climate action and finance models. Missing data due to non-response about climate-related health issues and/or collaboration with business (overall $n = 88$) and remaining $n = 16$ missing due to unavailable data on national GDP, liberal democracy rating and/or government response to COVID-19. Variable acronyms are GHG, greenhouse gas; C19, COVID-19; NTL, Nighttime Lights.

increased finance (22.4%) (Fig. 1b; $p < 0.001$). Similar proportions of cities report 'no change' in climate action (40.4%) and finance (41.5%).

In terms of geography (using CDP's 'regions' breakdown; Extended Data Fig. 1), East Asia is the region with the highest proportion of cities reporting increased emphasis on climate action (63.8%, $n = 30$) and increased climate finance (48.9%, $n = 23$). Conversely, South and West Asia and Southeast Asia and Oceania are the regions with the highest proportion of cities (28.6% and 24.1%, respectively) reporting decreased emphasis on climate action, although this accounts for only four and 19 cities, respectively. The largest proportion of cities reporting decreased climate finance are in Africa (63.3%) and the Middle East (57.1%), although these only account for 19 and four cities respectively. Europe and North America have the largest proportion of cities reporting no change in climate action (49.7%, $n = 86$ and 47.4%, $n = 92$, respectively). European cities are more likely than North American cities to report no change in climate finance (52.6% versus 44.8%) and less likely to report reduced climate finance (12.47% versus 27.8%). Cities in East Asia are also less likely to report reduced climate finance (17%, $n = 8$).

For there to be climate action, there must be sufficient financial backing—hence, we expect climate finance and action to be correlated (Extended Data Fig. 2 includes a map showing action and finance responses combined). Statistical tests confirm that this is broadly true (χ^2 (test of independence) = 301.68, $p = 0 < 0.001$). However, a modest proportion of cities ($n = 90$, 11.3%) simultaneously report increased climate action and reduced climate finance (conversely ten cities (1.3%) report increased finance and decreased action). This response is most prevalent in Africa (30%, $n = 9$ out of 30 cities) and the Middle East (28.6%, $n = 2$ out of 7 cities), followed by Latin America (18.5%, $n = 46$ out of 249 cities). Simple hypothesis tests comparing these cities to all other cities in the dataset suggest they tend to be less economically productive (proxied by nighttime lights; Methods) and located in countries with lower national GDP and weaker measures of liberal democracy; they also are more likely to belong to international climate networks (Supplementary Information 3 and Supplementary Table 6). These results suggest that climate networks may play an important role in sustaining city climate action in less wealthy parts of the world. Whether reduced finance will persist over the longer term and negatively impact climate action remains uncertain.

Factors relating to COVID-19 impacts on climate actions and finance

Our regression analyses show that how cities respond to COVID-19 is mostly related to their exposure to environmental stressors ('Environmental' indicators) and to their pre-existing engagement in sustainability and climate action ('Engagement' indicators) (Fig. 2; regression results for the 'other' category are shown in Supplementary Information 5 and Supplementary Tables 7 and 8).

In terms of environmental stressors, we find that for each additional climate-related health issue affecting residents (as reported by city officials), cities are 2.5% more likely to increase their climate actions (0.025, $p = 0.003$) and 2.3% more likely to have increased finance for climate action (0.023; $p = 0.001$). They are also less likely to report 'no change' in climate action (−0.032, $p < 0.001$) and finance (−0.025, $p = 0.006$). We also find increased climate finance is more likely in cities experiencing higher levels of pre-COVID-19 air pollution (measured in terms of NO_2 concentrations) (0.022, $p = 0.010$). Interestingly, exposure to climate hazards (for example, floods, storms) is not associated with changes in climate actions or finance. These results suggest that the intersectionality between health and climate change may be a key driver for climate action (also noted in refs. 30,41).

Early engagement in sustainability and climate actions ('engagement') is also influential. We find that cities belonging to international climate networks are 8.7% less likely to report decreased emphasis on climate action (−0.087; $p = 0.017$) and 13.8% more likely to report 'no change' in emphasis on climate action (0.138, $p = 0.002$). Hence, climate networks may play a key role in enhancing the resilience of climate action during economic crises. Network membership, however, has no effect on climate finance, probably reflecting the fact that—in many countries—the financial basis for city policies is not determined at the city level[42].

Cities that collaborate with businesses on sustainability projects (measured as a binary response to a question asking whether they engage in such collaborations; Supplementary Information 2) are 10% more likely to report increased emphasis on climate action (0.101, $p = 0.021$) and 9% more likely to report increased finance for climate action (0.090, $p = 0.024$) as a result of COVID-19. Additionally, cities that have identified 'more opportunities as a result of addressing climate change' (for example, funding opportunities; creation of carbon markets) are less likely to report decreased climate action (−0.012, $p = 0.038$) and more likely to have increased climate finance (0.011, $p = 0.026$). Short-term greenhouse gas targets (indicated by whether a city had short-term (pre-2021) climate targets) have no significant influence on either climate action or finance. Taken together, these results suggest that identifying and leveraging the co-benefits of climate action can lead to greater sustainability efforts, even in crisis contexts such as COVID-19.

Our indicators of mortality and economic impact from COVID-19 have no relationship with the reported impacts of COVID-19 on climate actions or finance, suggesting that the magnitude of COVID-19 impacts has no bearing on city climate commitments (in Methods we discuss and assess alternative explanations for this lack of effect). On the other hand, how national governments respond to COVID-19 appears to influence climate action and finance—specifically, cities in countries scoring higher on the Government Response Index (a holistic measure of how a government responded to COVID-19; Extended Data Table 1) were more likely to report increased climate action (0.008, $p = 0.001$); there is also weak evidence they experienced increased climate finance (0.004, $p = 0.062$). This may reflect a greater availability of time and resources in countries and cities in which COVID-19 was addressed effectively. Countries with greater regulatory capacity to respond to COVID-19 may also have greater capacity to support increased or continued climate action.

Interestingly, cities located in countries with higher GDP are less likely to have increased their emphasis on climate action (−0.027, $p = 0.040$) and their climate finance (−0.027, $p = 0.012$), although there are no corresponding decreases in action and/or finance. Finally, cities located in countries with a higher liberal democracy rating are less likely to have decreased their emphasis on climate action (−0.002; $p = 0.029$) and less likely to report reduced finance (−0.005, $p < 0.001$). However, these cities are also more likely to report no change in climate action (0.004, $p = 0.001$) and finance (0.004, $p = 0.003$). Hence, liberal democracy may be potentially associated with more durable (unchanging) climate action.

Green recovery interventions

Although self-reported changes in climate action and finance in 2021 provide insights into the short-term impacts of COVID-19, the number of green recovery interventions implemented by cities could be indicative of longer-term commitments to low-carbon pathways (for example, EU Green Deal, ref. 28). Extended Data Fig. 3 shows the distribution of cities (by CDP 'region') implementing different green recovery interventions (for example, recovery interventions focused on 'employment opportunities in green sectors', 'public and sustainable transport options', 'increased access to urban green spaces'; full list in Supplementary Information 1).

We find that 42.6% ($n = 338$) of cities report no green recovery policies; the highest proportion of these cities are found in South and West Asia (64.3%, $n = 9$), North America (50.5%, $n = 98$) and Europe (46.8%, $n = 81$) (Extended Data Fig. 4). Conversely, the regions with proportionally the greatest number of cities implementing at least one green recovery intervention are Africa (73.3%, $n = 22$), the Middle East (71.4%, $n = 5$) and Southeast Asia and Oceania (64.6%, $n = 51$). Most implementing cities report one green recovery intervention (24.8%, $n = 197$). At the higher end of the scale, we find that 7.94% ($n = 93$) report more than five green recovery policies; proportionally, the greatest number of these cities are found in Southeast Asia and Oceania (13.9%, $n = 11$), followed by Europe (11.6%, $n = 20$) and East Asia (10.6%, $n = 5$).

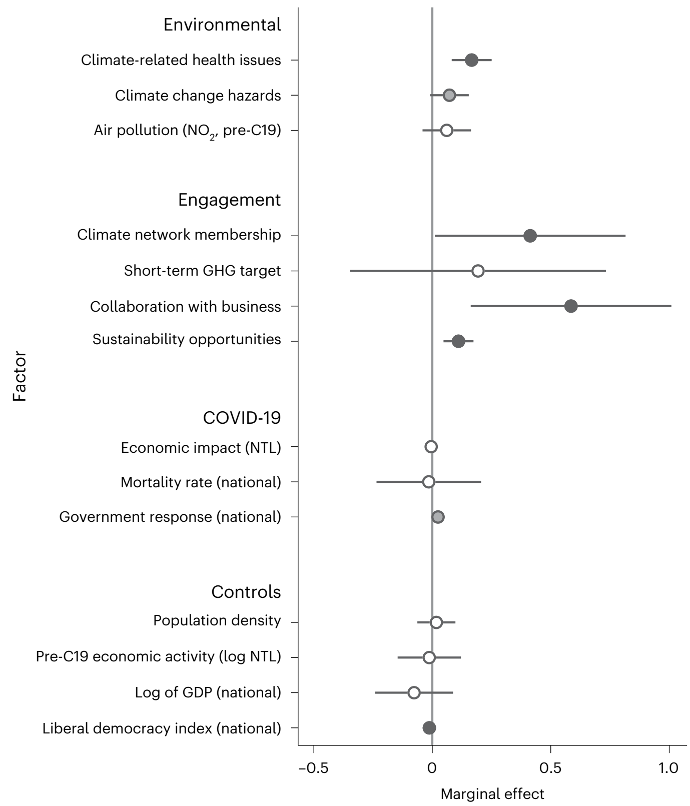

Fig. 3 | Factors associated with number of green recovery interventions. Results of multilevel GSEM regression with number of green recovery interventions (i.e. *total number of synergies between COVID-19 recovery interventions and climate action*) as the dependent variable are displayed as marginal effects (gsem does not provide standardized outputs; Extended Data Table 1 provides interpretation of variable descriptions) ±95% confidence intervals. Dark filled circles indicate that the association is significant at $p < 0.05$, light filled circles indicate $p < 0.1$; empty circles indicate $p > 0.1$ (two-sided z tests). Sample size of 689 cities. Missing data due to non-response about climate-related health issues and/or collaboration with business (overall $n = 88$) and remaining $n = 16$ missing due to unavailable data on national GDP, liberal democracy rating and/or government response to COVID-19.

We explore which factors are associated with numbers of green recovery interventions (Fig. 3) using the same explanatory variables as in our previous models. We find that cities with more climate-related health issues implement more green recovery interventions (0.166, $p < 0.001$), and there is weak evidence of a positive association between climate hazards and green recovery (0.072, $p = 0.082$). Early engagement is also important: network membership (0.413, $p = 0.044$), collaboration with business (0.586, $p = 0.007$) and identification of sustainability opportunities (0.111, $p = 0.001$) are positively related to green recovery. Government response to COVID-19 is weakly significant (0.024, $p = 0.094$); meanwhile there is a negative association between number of green recovery interventions and liberal democracies (−0.012, $p = 0.044$). All other explanatory variables and controls are not significant.

These results broadly align with our findings regarding the importance of exposure to environmental stressors and early engagement in sustainability and climate action for durable climate action and finance. As a final post hoc analysis, we use a one-way analysis of variance (ANOVA) to assess whether the number of green recovery interventions is associated with reported changes in climate action and climate finance due to COVID-19. Results are significant for both climate action (F(3df) = 24.55, $p < 0.001$) and climate finance (F(3df) = 35.38, $p < 0.001$) models, showing that investment in longer-term green recovery maps closely onto the shorter-term reported changes in climate action and finance due to COVID-19.

Discussion

Our study shows that cities worldwide remain committed to climate action in the short term; however, funding shortfalls and moderate engagement in green recovery in response to COVID-19 may limit their long-term commitment to climate action. In many cities in the Global South, for example, we find increased climate action is not matched with increased funding in the short term; however, many of these same cities are implementing green recovery interventions, suggesting that short-term impacts on climate finance may give way to longer-term climate-related investments. For example, the regions with proportionally the greatest number of cities implementing at least one green recovery intervention are Africa (73.3%, $n = 22$), the Middle East (71.4%, $n = 5$) and Southeast Asia and Oceania (64.6%, $n = 51$). Conversely, cities in higher-income countries with liberal democracies appear to be less ambitious in their response to COVID-19, such that reported climate actions and finance in the short term remain stable ('no change') in, for example, Europe and North America, but not more ambitious. Furthermore, cities in Europe and North America are among the least likely to engage in green recovery interventions, further suggesting low levels of ambition.

We find that cities that report actively engaging in sustainability and climate issues—either by joining climate networks, collaborating with business on sustainability issues or by identifying sustainability opportunities—are more likely to report stable (that is, non-declining) climate actions through COVID-19 and more green recovery interventions. Although we cannot make any claims about causality—indeed, cities that engage early on may also be more likely to sustain climate action through crises independent of their engagement levels—we consider it likely that these early efforts contribute towards mainstreaming climate and sustainability into cities' processes, operations and policies, which in turn may support more durable climate commitments.

An additional and related anchor point for resilient climate action through crises may be leveraged through sustainability co-benefits (for example, refs. 41,43). For example, we find that cities that experience more climate-related health issues are more likely to report increased climate action and finance during the pandemic and to have implemented more green recovery interventions. Linking climate and health risks and benefits may thus offer further support for increased climate action[41,43]; other sustainability co-benefits that may further enhance climate action include adaptation, ecosystem restoration and sustainable mobility (for example, refs. 44,45).

Overall, these results suggest that co-benefits and coalitions of actors that align on climate and sustainability goals can help stabilize and advance climate action through crises. This result supports research showing that climate policies are often successful when they find fitness with existing ideas, institutions and actors but also that crises provide openings for alternatives that diverge from the status quo[46].

In contrast to many previous studies, we emphasize the global character and scale of climate action, and of the COVID-19 crisis, by considering cities from around the world. Future research should aim to further understand how experiences of crises vary by country and region and how these experiences shape commitments to sustainability in the long term. By providing important global empirical insights into how cities' (self-reported) climate actions and finances were affected (in the short term) by COVID-19, and their extent of engagement in green recovery, we contribute to a growing evidence base that can support sustained climate action through crises. Our investigation provides a foundation for further research examining how to sustain climate action through crises; for example, studies could identify whether interventions that increase the alignment of economic interests with sustainability (for example, tax breaks, subsidies) lead to more durable climate policy or how to incentivize higher ambition among high-income countries and liberal democracies.

Although our results present important insights about how cities worldwide react to crises, the ability to draw firm conclusions from this analysis is moderated by the self-reported nature of our measures of climate action, finance and green recovery. Self-reported data rely on recall and perceptions and, as such, may not accurately represent what is being asked; on the other hand, perceptions of city officials may provide a deeper insight into changes on the ground for which there is no other source of data.

As a final note, we emphasize that in pursuing this research, we identified roadblocks towards a better comparative understanding of city-level climate action. Whereas important efforts have been made to standardize collection and reporting of cities' data (for example, through a unified reporting system since 2019 (https://www.cdp.net/en/articles/cities/cdp-and-iclei-introducing-streamlined-climate-reporting), important data challenges remain. Most notably, data availability—especially from developing countries—remains scarce and incomplete. Moreover, a lack of reliable and consistent longitudinal data puts considerable limits on identifying trends and understanding the development of city-level climate action. Further research on city-level climate action and crises requires the research and data communities to develop comprehensive, comparable and consistent datasets to enable a deeper understanding of how we can make climate action more ambitious and resilient in the context of escalating crises. Whereas cities can play an important role in climate action—in particular when responding to crises—understanding how needs to be informed by solid data and analysis.

Methods

Dependent variables

To identify the impacts of COVID-19 on climate policy in cities, we use data reported by city managers on the CDP platform in 2021[26]. These data are collected in partnership by CDP and ICLEI–Local Governments for Sustainability. Specifically, we use responses to three questions (from section 3 in the CDP survey). The climate action question asked: '*Please provide information on the overall impact of COVID-19 on climate action in your city.*' Response options were: 'increased emphasis on climate action', 'decreased emphasis on climate action', 'no change on emphasis on climate action' and 'other, please specify'. We note that the CDP survey does not provide a definition of climate action, hence responses reflect perceptions of what constitutes 'climate action' by city officials completing the surveys. Broadly, however, climate action refers to mitigation measures, monitoring and adaptation[1]. The implication of this non-prescriptive definition is that multiple actions can count as climate action as long as they serve to combat climate change and its impacts.

For the climate finance question, respondents were asked about '*the impact of the COVID-19 economic response on the city's budget for financing climate action in your city*'. Response options were: 'increased finance available for climate action', 'reduced finance available for climate action', 'no change on finance available for climate action' and 'other, please specify'. Responses to the 'other, please specify' category were analyzed to verify whether they should be correctly reclassified as increased/decreased/no change, which led to a small number of adjustments (Supplementary Information 1 provides details).

Respondents also provided information about '*COVID-19 recovery interventions and climate action synergies*' in their city (which we term 'green recovery'). They could make multiple selections from a list of

11 possible 'green recovery' options (Supplementary Information 1 provides list of 'green recovery' interventions, and Extended Data Fig. 3 provides a breakdown of responses), plus a 'don't know' and 'other, please specify' option.

Expected influences on climate actions, finance, green recovery

To identify potential factors that might help explain city responses to COVID-19 vis-à-vis their climate actions, finance and green recovery interventions, we drew on the extensive literature examining determinants of climate policy adoption. This includes a meta-analysis of studies based in the United States[20] and individual studies of city-level climate policy adoption from around the world (for example, refs. 15,47–49). Although this literature does not specifically examine the factors influencing how cities' climate policies and actions are affected by economic crises, it provides useful insights for our analysis. We also considered findings from Krause et al.[17] on the determinants of climate policy abandonment and drew on the limited literature examining the impact of disasters on climate actions[13,18,19], noting their limited applicability to our question given their focus on solar panel adoption in Japan or the United States.

On the basis of these studies, we identified exposure to environmental stress[15,20,30,31] as one major broad category of influence on climate action and/or policy adoption. We include number of climate hazards as one indicator in this category; the expectation is that cities experiencing more climatic hazards (for example, climatic disasters) may be more motivated to engage in climate action (for example, ref. 15). We also include an indicator of health impacts from climate change—in the context of a pandemic, this variable is expected to positively influence climate actions and commitments. Additionally, cities experiencing worse air pollution may be more likely to adopt climate actions due to (perceived) co-benefits from tackling sources of air pollution (which also often cause climate change)[30,31,47]. For this reason, we also include air pollution (specifically, NO_2 concentrations) in our models. Extended Data Table 1 provides descriptions of selected indicators, and Supplementary Information 3 provides details about how they were operationalized.

We also identified another set of influences on city climate action, which we have categorized broadly as early engagement in sustainability and climate. This category includes climate network membership, with most studies finding a positive correlation between network membership and climate action or policy adoption[33–35,50] and a key constraint on climate policy termination[17]. Notably, earlier literature used network membership as an indicator of climate policy adoption (for example, refs. 50,51); however, it has been recognized that network membership may not be a suitable indicator of actual policy adoption but rather a precursor to policy adoption[15,37,50]. Other factors include: whether the city collaborates with business on sustainability issues (a proxy for business group support (found to be a key influence in ref. 20), which can be crucial for general community support[52]; government interest in sustainability and climate action[20], which we operationalize using the number of sustainability opportunities identified by city departments; and whether a city has been engaged in climate action from early on (proxied by pre-2021 climate targets). The underlying rationale here is that the more that cities engage in addressing sustainability and climate concerns, the more likely these will become embedded in city operations, established practices and in their interactions with other entities locally, nationally and internationally—hence, the more entrenched and durable their climate and sustainability commitments[46].

We also expect that the greater the negative impact of COVID-19, the less able a city is to address climate change. Thus, we include three indicators of COVID-19 impact in our analyses: change in economic activity over the COVID-19 period (measured as the change in nighttime lights; Supplementary Information 3); mortality rate (measured at the national level) and government response to COVID-19 (national level). We expect that the greater the economic impact due to COVID-19 (proxied by change in nighttime lights between 2019 and 2021), the less-available budget a city has for continued or increased climate action. Likewise, the greater the mortality rate, the greater the impact on the economy through labor force impacts and expenditures on health care. Finally, we expect that the 'greater' the government response to COVID-19 at the national level, the more likely cities are able to cope with the impact of COVID-19 and hence dedicate continued or increased resources to climate action.

Additional expected influences on our dependent variables include city population density, which has been shown to be positively associated with climate action adoption[20,31,33,37,47]. Government fiscal capacity is also expected to be a major influence (for example, refs. 31,47), here proxied by national-level GDP and city-level nighttime lights. Type of government (for example, democracies and authoritarianism) has also been found to influence the adoption and strength of environmental and sustainability policies (refs. 53,54), with more democratic regimes often associated with greater responsiveness to citizens, particularly in delivering public goods and addressing sustainable development. Hence, we include liberal democracy as a proxy for 'type of government' at the national level, as this may influence cities' responses vis-à-vis the strengthening or weakening of their climate efforts.

Finally, climate action and policy adoption have also been found to be influenced by city government capacity[20,47] and public support[20,55]. However, we could not identify any data that could be used as indicators for these factors across all cities in our sample; hence, our models do not explicitly account for these broad influences on city climate action. Nevertheless, we expect that the explanatory variables included in the models partly capture some of the effects of these key influences; for example, city capacity may be partly captured by the change in economic activity (nighttime lights) and by the government response to COVID-19. As for public support, we expect this will be partly captured by our variable representing city collaboration with business on sustainability issues[52] and also by our indicator of the health impacts from climate change. In both cases, we expect public support for continued or increased climate action to be higher if there is business support for climate action and if there are clear links between health and climate action.

Given the dearth of existing evidence regarding the factors associated with climate policy responses of cities to crises, the analysis here is exploratory. Extended Data Table 1 provides descriptions of all the selected indicators described above, and Supplementary Information 2 provides details about how they were operationalized.

Data collection and preparation

Data on our dependent variables and data on indicators of exposure to environmental stress (climate-related health issues, climate hazards) and early engagement in addressing climate sustainability (pre-2021 climate targets, collaboration with business, sustainability opportunities) (independent variables), were obtained from the CDP platform for the year 2021 (Extended Data Table 1). CDP data are collected through the CDP-ICLEI Unified Reporting System available publicly from the CDP website and targeted at cities. We note that entities reporting to CDP comprise a variety of administrative boundaries (for example, municipality, city state, federal district); we use data from all entities ('cities') regardless of their self-reported administrative boundary (Supplementary Information 1 for a discussion).

A series of steps were taken to prepare the CDP data for statistical analysis. CDP data for each year is organized in long format, where each row in the dataset contains a single response to a question—in addition to city identification information and question information. This format is designed for an Application Programming Interface (API). To prepare the data in a format to facilitate analysis, Stata was used to reshape the data from a long, question–answer level to a wide city-level structure. We note that the 2021 CDP data for this study was collected in tandem with data from other years (2015–2020) for use in another study; for this reason, we also renamed the variables due to variations from year to year in terms of which questions were included, their location in the questionnaire and the question number. Hence, to append CDP data from different years, we had to rename the variables for consistency across survey years. The last stage in data preparation of the CDP data involved additional actions to make the data usable for statistical analysis, including: (1) converting strings into numerical codes where possible (all data were stored as strings) and (2) condensing the variables for analysis. All coding was conducted in Stata 17.0 (Code availability provides details).

As for the non-CDP data, these were obtained from different sources (Extended Data Table 1 provides details). Climate network membership data was obtained from ClimActor[56], a global dataset of 10,000+ cities and regions. It includes location coordinates (obtained from Wikipedia using the MediaWiki API) and membership in multiple climate networks (for example, Global Covenant of Mayors for Climate and Energy, C40 Cities for Climate Leadership). The list of cities reporting to CDP was run through the ClimActor R package (we did this for all cities reporting to CDP between 2015 and 2021, as part of the larger research project mentioned above). It first matches cities by name from the source to the ClimActor dataset, then appends to the source dataset, the location (coordinates) and climate network variables (ref. 56).

For the geospatial data (air pollution (NO_2), nighttime lights, population density), we used city coordinates provided in the ClimActor dataset[56], which we submitted to a series of checks for validation and corresponding corrections where needed (detailed in Supplementary Information 3). Using these corrected coordinates, geospatial data were captured using raster data with varying resolutions: 15 arcsecond (~500 m) for radiance data, 30 arcsecond (~1 km) for population density and 0.1° (~11 km) for NO_2. We obtained the nighttime radiance data from annual global Visible and Infrared Imaging Suite (VIIRS) nighttime lights (derived from monthly averages with background masked) from 2019 to 2021 from the Earth Observation Group platform (Annual VIIRS Nighttime Lights (VNL) V2)[57] (in units of nW cm^{-2} sr^{-1}). NO_2 data were obtained from NASA/Goddard Space Flight Center[58] as a monthly tropospheric NO_2 column (units of molecules per cm^2). Population density data (in persons per km^2) was obtained from Socioeconomic Data and Applications Center (SEDAC)[59], hosted by Center for International Earth Science Information Network (CIESIN) at Columbia University (Supplementary Information 2 provides details about data collection and operationalization of indicators).

Given that we did not have administrative boundary data for all cities in the dataset (we only had data for 449 of our study cities, based on the 2015 World Urban Areas, by Esri Data and Maps)[60], we used centroid buffer zones of approximately 25 and 50 km around the city's coordinates (0.25 and 0.50° radius, respectively). The zonal statistics tool was used to capture the minimum, maximum, median and mean of the raster values within the parameters of the buffer zones around the coordinates of the city locations and within the city boundaries where available. We selected various statistics so that we could choose the statistic that most closely correlates with the corresponding statistic for the city boundary for those cities with administrative boundary data. Supplementary Information 3 provides details of these correlations, and Extended Data Table 1 shows final selected measures.

Mortality data, used here as an indicator of COVID-19 impact, were obtained from Our World in Data (https://ourworldindata.org/COVID-deaths). It is provided on a daily basis in rolling sums from 24 February 2020 through 22 December 2021. We use the final cumulative number of deaths per million reported on 22 December 2021 as our main indicator, scaled to units of deaths per hundred thousand for better interpretation of coefficients.

The 'Government response index' variable from the Oxford COVID-19 Government Response Tracker[61] is used as an indicator of how well national governments responded to COVID-19. For this index, which ranges from 0 to 100, there is a raw calculated index value and a 'display' version which smooths over gaps in the previous seven days. We use the display version in our analysis. The data are available on a daily basis from 1 January 2020 through 10 August 2021; we aggregated by averaging over the year.

National GDP data were obtained from the World Bank national accounts data and Organisation for Economic Co-operation and Development (OECD) National Accounts Data Files[22]. We use the natural logarithm of country GDP to control for impacts of COVID-19 on GDP. The liberal democracy variable was collected from the University of Gothenberg Varieties of Democracy (V-Dem) Project dataset, for the year 2021 (version)[62]. Data are available only at the country level. The variable itself addresses the question '*To what extent is the idea of liberal democracy achieved?*'—and is based on the extent to which limits are placed on the government. Each country is assigned a value between 0 (low) and 1 (high). We changed this to be expressed in percentage points from 0 to 100.

Supplementary Information 2 provides more detailed descriptions about how the various indicators used in this study were sourced and operationalized.

Regression analyses

Because both the climate action and climate finance dependent variables are nominal categorical variables, our analysis uses multinomial logit regressions, which are suitable for analyzing this type of datum. Additionally, cities are clustered in countries, and therefore can be similar in terms of their policies, social qualities and economies; indeed, national policies are likely to affect the types of policy implemented at the city level[48]. To account for this clustering, we used a generalized structural equation model (GSEM) with a multilevel structure for multinomial logit. This model can handle multilevel data (in our case, data on cities and countries), which have a nominal structure[63]. Studies indicate that multilevel models are more efficient than those with clustered standard errors[64,65], and they are also preferable when data have an unbalanced structure (that is, different numbers of cities per country)[66,67]. For comparative purposes, we also ran clustered and unclustered multinomial logit models (Supplementary Tables 7 and 8); results are similar across model specifications.

To implement multilevel multinomial logistic models, we used the *gsem* command in Stata 17.0 combined with the *mlogit* specification[63]. To determine if the impact of the level-2 (country-specific) characteristics was sufficient to warrant use of multilevel models, we observed the variance in the country-level groupings of cities and conducted likelihood-ratio tests to determine if models with a random intercept were different than those without. The likelihood-ratio test for our climate finance model was highly significant (χ^2 value = 9.18, p = 0.0024), and the test for the climate action model was weakly significant (χ^2 value = 2.84, p = 0.0917), indicating that the multilevel model fits the models better than one without a random intercept (Supplementary Information 4 provides details). Aside from the likelihood-ratio test, most of our assumptions and model fit testing were conducted for the *mlogit* (with and without clustering) models because these tests are not available for GSEM models at this time. Overall, our models contain no major issues with misspecification or fit (Supplementary Information 4).

With respect to the analysis of green recovery interventions, given that our main indicator was a count (specifically of 'synergies between COVID-19 recovery interventions and climate action', which we term 'green recovery' interventions), we used a negative binomial model with a multilevel structure to account for country-specific impacts (details in Supplementary Information 5). For comparative purposes, we also ran clustered and unclustered negative binomial models (Supplementary Table 10); results are similar across model specifications.

Sensitivity analyses

We examine the sensitivity of our results to our modeling approach and to how we chose to operationalize some of the indicators. First, as noted above, for comparative purposes we ran different models on the climate action and finance variables, with results indicating (Supplementary Information 4) that our selected model was appropriate for our data. We also tested different operationalizations of some of our independent variables to assess the robustness of our findings to assumptions and choices made when generating these variables. We specifically examined those variables which had quality issues for some values (for example, NO_2; Supplementary Information 2) or those which could have been feasibly operationalized differently. Network membership, for example, could have been modeled using separate indicators for the key networks as opposed to a single indicator of membership of *at least one* network. Model results (Supplementary Tables 11–13) show that operationalizing this variable differently has no effect on the overall model or other coefficients, although we do find that some networks have different effects on climate actions and green recovery (Supplementary Information 6). Similarly, the short-term greenhouse gas target indicator was operationalized using a 2020 threshold to indicate 'early' target-setting; changing this for a 2030 threshold had no effect on regression outputs (Supplementary Tables 20–22).

We also tested whether modeling NO_2 as a categorical variable (rather than as a continuous variable, as in the main regression) affected model outputs; separately, we also assessed whether including a dummy variable where 1 = low-confidence NO_2 values (Supplementary information 2 provides details), affected results. We found that operationalizing NO_2 differently (Supplementary Tables 14–16) has no meaningful effect on model results.

Economic impact (change in nighttime light) was modeled as a single continuous variable ranging from negative to positive values; this assumes that there is linearity in how economic impact is related to the dependent variables. An alternative is to disaggregate economic impact into several categorical (binary) variables representing (different levels of) negative and positive economic impacts. Results from this alternative operationalization (Supplementary Tables 17–19) suggest some nonlinearities (Supplementary Information 6), although the findings are broadly aligned with the main model results.

An additional consideration was whether the change in nighttime lights (proxy for impacts on economic activity) fully or correctly captures the magnitude of COVID-19 impacts on cities around the world. These data (particularly the VIIRS dataset) have been found to track the economic impacts of COVID-19 quite well for cities in China[68,69], Morocco[70] and India[71]. We make the assumption that these findings apply to all countries and cities in our dataset. Any between-country variation would be controlled for in the regressions, which account for the multilevel nature of our dataset whereby cities are clustered within countries.

As a final exploratory analysis, we examine whether national-level climate action ambition influences how cities respond to COVID-19 (Supplementary Information 7). Using ratings for a subset of countries available from the Climate Action Tracker (https://climateactiontracker.org) (https://hub.arcgis.com/datasets/esri::world-urban-areas/explore), we find national-level ambition has little to no effect on how COVID-19 has affected reported city climate actions, finance or green recovery.

Reporting summary

Further information on research design is available in the Nature Portfolio Reporting Summary linked to this article.

Data availability

All the data used in this study are publicly available. The full (raw) CDP 2021 dataset can be downloaded from the CDP website at https://data.cdp.net/. All other data sources are listed in Extended Data Table 1. Additional data sources used to identify city coordinates and boundaries (where available) include the World Cities Database (https://simplemaps.com/data/world-cities) (Version: Mar-2022) and Esri Data and Maps (Version 10.3, Nov-2015) (https://hub.arcgis.com/datasets/esri::world-urban-areas/explore). The final clean dataset used for analysis in this paper can be found at https://github.com/climateactiondata/climatecitiesproject/.

Code availability

The do files used for cleaning, organizing and analyzing the data are available at https://github.com/climateactiondata/climatecitiesproject/.

References

1. Rosenzweig, C., Solecki, W., Hammer, S. A. & Mehrotra, S. Cities lead the way in climate-change action. *Nature* **467**, 909–911 (2010).
2. Betsill, M. & Bulkeley, H. *Cities And Climate Change* vol. 4 (Routledge, 2003).
3. *Empowering Cities for a Net Zero Future: Unlocking Resilient, Smart, Sustainable Urban Energy Systems* (IEA, 2021); https://www.iea.org/reports/empowering-cities-for-a-net-zero-future
4. Klomp, J. & Valckx, K. Natural disasters and economic growth: a meta-analysis. *Glob. Environ. Change* **26**, 183–195 (2014).
5. Botzen, W. J. W., Deschenes, O. & Sanders, M. The economic impacts of natural disasters: a review of models and empirical studies. *Rev. Environ. Econ. Policy* https://doi.org/10.1093/reep/rez004 (2019).
6. *World Urbanization Prospects: The 2018 Revision* (UNDESA, 2019); https://doi.org/10.18356/b9e995fe-en
7. Dobbs, R. et al. *Urban World: Mapping The Economic Power Of Cities* (McKinsey, 2011).
8. *The Economics Of Climate Change: No Action Not An Option* (Swiss Re Institute, 2021).
9. Heinrichs, D. et al. in *Cities and Climate Change* (eds Hoornweg et al.) 193–224 (World Bank, 2011).
10. Gravey, V. & Jordan, A. J. Policy dismantling at EU level: reaching the limits of 'an ever-closer ecological union'? *Public Adm.* **98**, 349–362 (2020).
11. Burns, C. & Tobin, P. The impact of the economic crisis on European Union environmental policy. *J. Common Mark. Stud.* **54**, 1485–1494 (2016).
12. Geels, F. W. The impact of the financial-economic crisis on sustainability transitions: financial investment, governance and public discourse. *Environ. Innov. Soc. Transit.* **6**, 67–95 (2013).
13. Fraser, T., Cunningham, L. & Nasongo, A. Build back better? Effects of crisis on climate change adaptation through solar power in Japan and the United States. *Glob. Environ. Polit.* **21**, 54–75 (2021).
14. Tienhaara, K. Varieties of green capitalism: economy and environment in the wake of the global financial crisis. *Environ. Polit.* **23**, 187–204 (2014).
15. Kalafatis, S. E. Comparing climate change policy adoption and its extension across areas of city policymaking. *Policy Stud. J.* **46**, 700–719 (2018).
16. Westman, L. et al. Compound urban crises. *Ambio* **51**, 1402–1415 (2022).
17. Krause, R. M., Yi, H. & Feiock, R. C. Applying policy termination theory to the abandonment of climate protection initiatives by U.S. local governments. *Policy Stud. J.* **44**, 176–195 (2016).
18. Fraser, T. How governance and disasters shape renewable energy transitions: the case of Japanese mega-solar. *Social Sci. Q.* **100**, 975–990 (2019).
19. Mochizuki, J. & Chang, S. E. Disasters as opportunity for change: tsunami recovery and energy transition in Japan. *Int. J. Disaster Risk Reduct.* **21**, 331–339 (2017).

20. Yeganeh, A. J., McCoy, A. P. & Schenk, T. Determinants of climate change policy adoption: a meta-analysis. *Urban Clim.* **31**, 100547 (2020).
21. Dong, E., Du, H. & Gardner, L. An interactive web-based dashboard to track COVID-19 in real time. *Lancet Infect. Dis.* **20**, 533–534 (2020).
22. World GDP growth (annual %) *World Bank National Accounts and OECD National Accounts* https://data.worldbank.org/indicator/NY.GDP.MKTP.KD.ZG (2023).
23. Reilly, J. M., Chen, Y. H. H. & Jacoby, H. D. The COVID-19 effect on the Paris Agreement. *Humanit. Social Sci. Commun.* **8**, 1–4 (2021).
24. Dupont, C., Oberthür, S. & Von Homeyer, I. The Covid-19 crisis: a critical juncture for EU climate policy development? *J. Eur. Integr.* **42**, 1095–1110 (2020).
25. Corfee-Morlot, J., Depledge, J. & Winkler, H. COVID-19 recovery and climate policy. *Clim. Policy* **21**, 1249–1256 (2021).
26. *CDP Cities, States and Regions Open Data Portal* (CDP, 2022); https://data.cdp.net/
27. Elkerbout, M. et al. *The European Green Deal after Corona: Implications for EU Climate Policy* (CEPS, 2020).
28. Kalafatis, S. E. When do climate change, sustainability, and economic development considerations overlap in cities?. *Environ. Polit.* **27**, 115–138 (2018).
29. Romsdahl, R. J., Kirilenko, A., Wood, R. S. & Hultquist, A. Assessing national discourse and local governance framing of climate change for adaptation in the United Kingdom. *Environ. Commun.* **11**, 515–536 (2017).
30. Chomaitong, S. & Perera, R. Adoption of the low carbon society policy in locally-governed urban areas: experience from Thai municipalities. *Mitigation Adapt. Strategies Glob. Change* **19**, 1255–1275 (2014).
31. Wang, R. Adopting local climate policies: what have California cities done and why? *Urban Aff. Rev.* **49**, 593–613 (2013).
32. Hawkins, C. V., Krause, R. M., Feiock, R. C. & Curley, C. Making meaningful commitments: accounting for variation in cities' investments of staff and fiscal resources to sustainability. *Urban Stud.* **53**, 1902–1924 (2015).
33. Salvia, M. et al. Will climate mitigation ambitions lead to carbon neutrality? An analysis of the local-level plans of 327 cities in the EU. *Renew. Sustain. Energy Rev.* **135**, 110253 (2021).
34. Lee, T., Yang, H. & Blok, A. Does mitigation shape adaptation? The urban climate mitigation–adaptation nexus. *Clim. Policy* **20**, 341–353 (2020).
35. Rashidi, K. & Patt, A. Subsistence over symbolism: the role of transnational municipal networks on cities' climate policy innovation and adoption. *Mitigation Adapt. Strateg. Glob. Change* **23**, 507–523 (2018).
36. Hawkins, C. V., Kwon, S. W. & Bae, J. Balance between local economic development and environmental sustainability: a multi-level governance perspective. *Int. J. Public Adm.* **39**, 803–811 (2016).
37. Yi, H., Feiock, R. C. & Berry, F. S. Overcoming collective action barriers to energy sustainability: a longitudinal study of climate protection accord adoption by local governments. *Renew. Sustain. Energy Rev.* **79**, 339–346 (2017).
38. Portney, K. E. Local Sustainability policies and programs as economic development: is the new economic development sustainable development? *Cityscape.* **15**, 45–62 (2013).
39. Bae, J. & Feiock, R. Forms of government and climate change policies in US cities. *Urban Stud.* https://doi.org/10.1177/0042098012450481 (2012).
40. Feiock, R. C. & Bae, J. Politics, institutions and entrepreneurship: city decisions leading to inventoried GHG emissions. *Carbon Manage.* **2**, 443–453 (2011).
41. Tang, Z., Brody, S. D., Li, R., Quinn, C. & Zhao, N. Examining locally driven climate change policy efforts in three Pacific states. *Ocean Coastal Manage.* **54**, 415–426 (2011).
42. Heidrich, O. et al. National climate policies across Europe and their impacts on cities strategies. *J. Environ. Manage.* **168**, 36–45 (2016).
43. Haines, A. Health co-benefits of climate action. *Lancet. Planet. Health* **1**, e4–e5 (2017).
44. Boyd, D., Pathak, M., van Diemen, R. & Skea, J. Mitigation co-benefits of climate change adaptation: a case-study analysis of eight cities. *Sustain. Cities Soc.* **77**, 103563 (2022).
45. Kwan, S. C. & Hashim, J. H. A review on co-benefits of mass public transportation in climate change mitigation. *Sustain. Cities Soc.* **22**, 11–18 (2016).
46. Orr, C. J. & Fyles, J. W. Progressive selection and the erosion of Canadian environmental governance: evidence from elite interviews. *Environ. Polit.* **32**, 838–860 (2023).
47. Hui, I., Smith, G. & Kimmel, C. Think globally, act locally: adoption of climate action plans in California. *Climatic Change* **155**, 489–509 (2019).
48. Krause, R. M. Political decision-making and the local provision of public goods: the case of municipal climate protection in the US. *Urban Stud.* **49**, 2399–2417 (2012).
49. Sharp, E. B., Daley, D. M. & Lynch, M. S. Understanding local adoption and implementation of climate change mitigation policy. *Urban Aff. Rev.* **47**, 433–457 (2011).
50. Krause, R. M. An assessment of the impact that participation in local climate networks has on cities' implementation of climate, energy, and transportation policies. *Rev. Policy Res.* **29**, 585–604 (2012).
51. Zahran, S., Grover, H., Brody, S. D. & Vedlitz, A. Risk, stress, and capacity: explaining metropolitan commitment to climate protection. *Urban Aff. Rev.* **43**, 447–474 (2008).
52. Salon, D., Murphy, S. & Sciara, G. C. Local climate action: motives, enabling factors and barriers. *Carbon Manage.* **5**, 67–79 (2014).
53. Wurster, S. Comparing ecological sustainability in autocracies and democracies. in *Comparing autocracies in the early Twenty-first Century* (eds Croissant, A. et al.) 141–158 (Routledge, 2016).
54. Von Stein, J. Democracy, autocracy, and everything in between: how domestic institutions affect environmental protection. *Br. J. Polit. Sci.* **52**, 339–357 (2022).
55. Colenbrander, S., Dodman, D. & Mitlin, D. Using climate finance to advance climate justice: the politics and practice of channelling resources to the local level. *Clim. Policy* **18**, 902–915 (2017).
56. Hsu, A. et al. ClimActor, harmonized transnational data on climate network participation by city and regional governments. *Sci. Data* **7**, 374 (2020).
57. Elvidge, C. D., Zhizhin, M., Ghosh, T., Hsu, F. C. & Taneja, J. Annual time series of global VIIRS nighttime lights derived from monthly averages: 2012 to 2019. *Remote Sens.* **13**, 922 (2021).
58. Krotkov, N. A. et al. OMI/Aura nitrogen dioxide (NO_2) total and tropospheric column 1-orbit L2 swath 13×24 km (OMNO2) V003, Greenbelt, MD, USA, Goddard Earth Sciences Data and Information Services Center (GES DISC) https://doi.org/10.5067/Aura/OMI/DATA2017 (2022).
59. Population density, v4.11: gridded population of the world (GPW), v4. *SEDAC & CIESIN* https://sedac.ciesin.columbia.edu/data/set/gpw-v4-population-density-rev11 (2021).
60. World urban areas dataset, Vol. 10.3. *Esri Data & Maps* https://apps.gis.ucla.edu/geodata/dataset/world_urban_areas (2018).
61. Hale, T. et al. A global panel database of pandemic policies (Oxford COVID-19 government response tracker). *Nat. Hum. Behav.* **5**, 529–538 (2021).
62. Coppedge, M. et al. V-Dem Dataset v12 Varieties of Democracy (V-Dem) Project https://doi. org/10.23696/vdemds21 (2022).

63. *Stata Structural Equation Modeling Reference Manual Release 18* (Stata Press, 2023).
64. Bryan, M. L. & Jenkins, S. P. Multilevel modelling of country effects: a cautionary tale. *Eur. Sociol. Rev.* **32**, 3–22 (2016).
65. Park, S. & Lake, E. T. Multilevel modeling of a clustered continuous outcome: nurses' work hours and burnout. *Nurs. Res.* **54**, 406 (2005).
66. Sommet, N. & Morselli, D. Keep calm and learn multilevel logistic modeling: a simplified three-step procedure using stata, R, Mplus, and SPSS. *Int. Rev. Social Psychol.* **30**, 203–218 (2017).
67. Maas, C. J. M. & Hox, J. J. Sufficient sample sizes for multilevel modeling. *Methodology* **1**, 86–92 (2006).
68. Elvidge, C. D., Ghosh, T., Hsu, F. C., Zhizhin, M. & Bazilian, M. The dimming of lights in China during the COVID-19 pandemic. *Remote Sens.* **12**, 2851 (2020).
69. Liu, H., Luo, N. & Hu, C. Detection of county economic development using LJ1-01 nighttime light imagery: a comparison with NPP-VIIRS data. *Sensors* **20**, 6633 (2020).
70. Roberts, M. Tracking economic activity in response to the COVID-19 crisis using nighttime lights—the case of Morocco. *Dev. Eng.* **6**, 100067 (2021).
71. Beyer, R. C. M., Franco-Bedoya, S. & Galdo, V. Examining the economic impact of COVID-19 in India through daily electricity consumption and nighttime light intensity. *World Dev.* **140**, 105287 (2021).

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Author contributions
All co-authors designed the research; T.O., V.K. and A.D. collected and organized data; T.O. and V.K. analyzed the data; all co-authors co-wrote and revised the paper.

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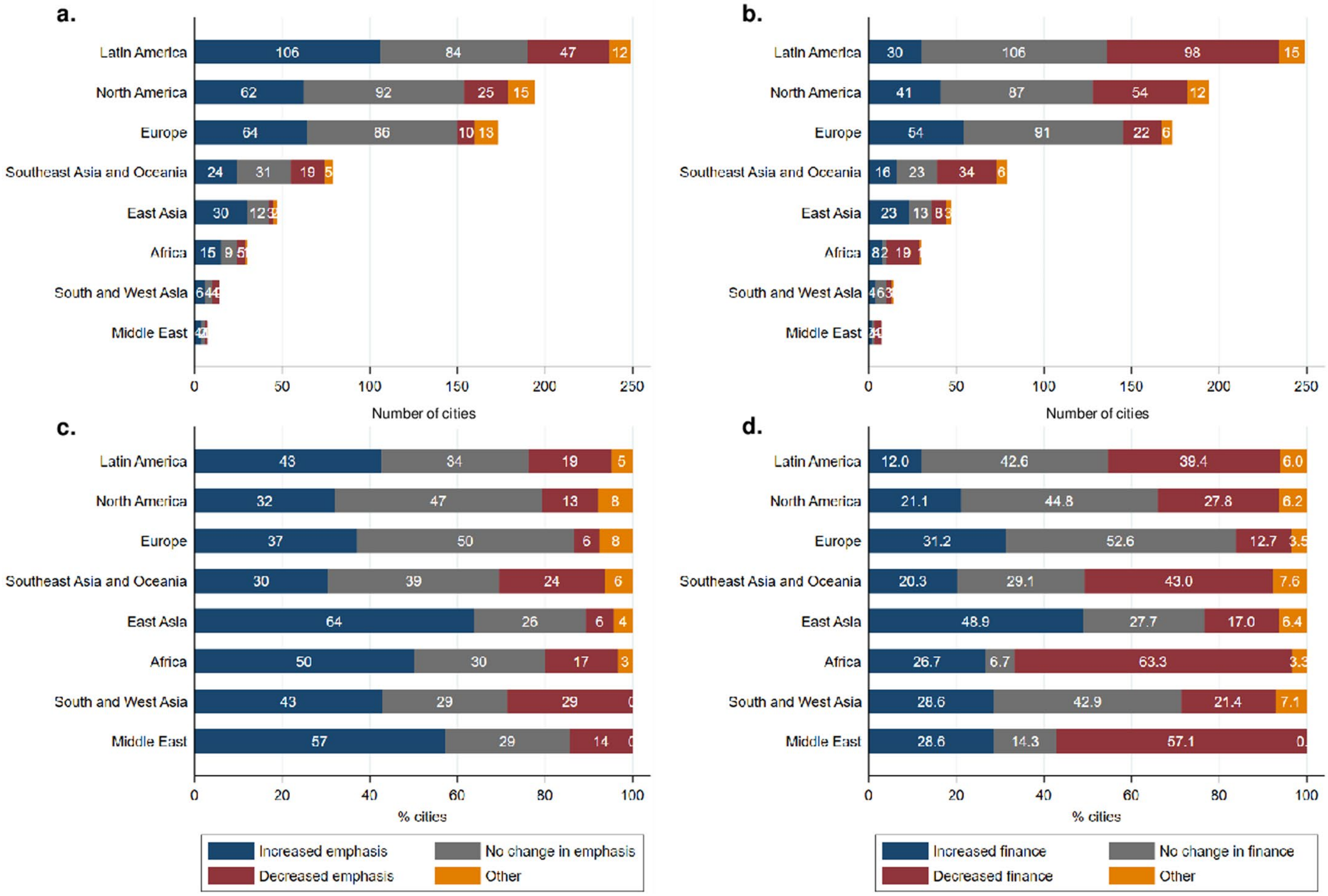

Extended Data Fig. 1 | Distribution of impacts of COVID-19 on climate action and climate finance by CDP geographic region. **a.** and **b.** show distributions of impacts of COVID-19 on climate action and finance in terms of counts (numbers of cities), while **c.** and **d.** show distributions of impacts in terms of percentages.

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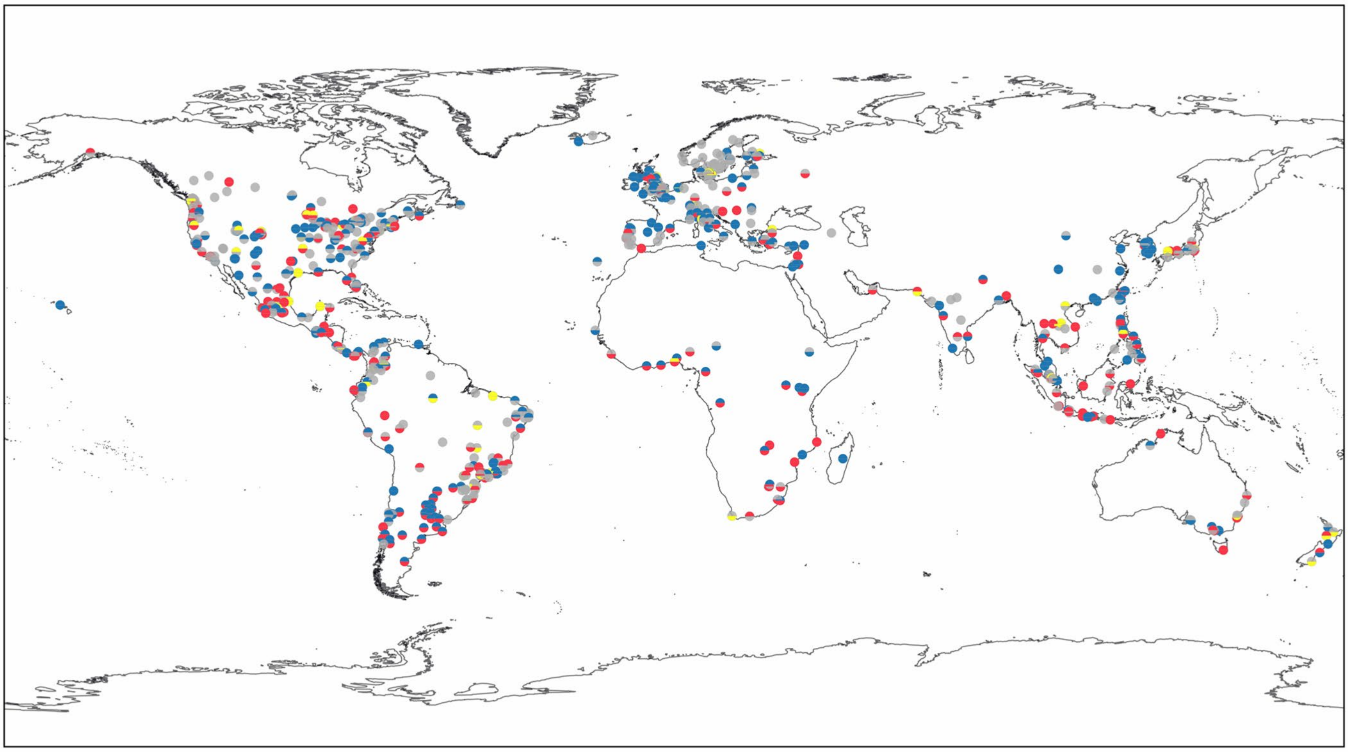

Extended Data Fig. 2 | Geographic distribution of impacts of COVID-19 on climate action and climate finance combined. Impacts on climate action are shown as the top half of each dot; impacts on climate finance are shown as the bottom half. Colours: blue - increased emphasis on climate action/climate finance; red - decreased emphasis on climate action/reduced climate finance; grey - no change in emphasis on climate action/climate finance; yellow - other. Sample of n = 793 cities. Map was produced using QGIS desktop 3.20.3 and basemap (coastline v4.1.0) from Natural Earth (https://www.naturalearthdata.com).

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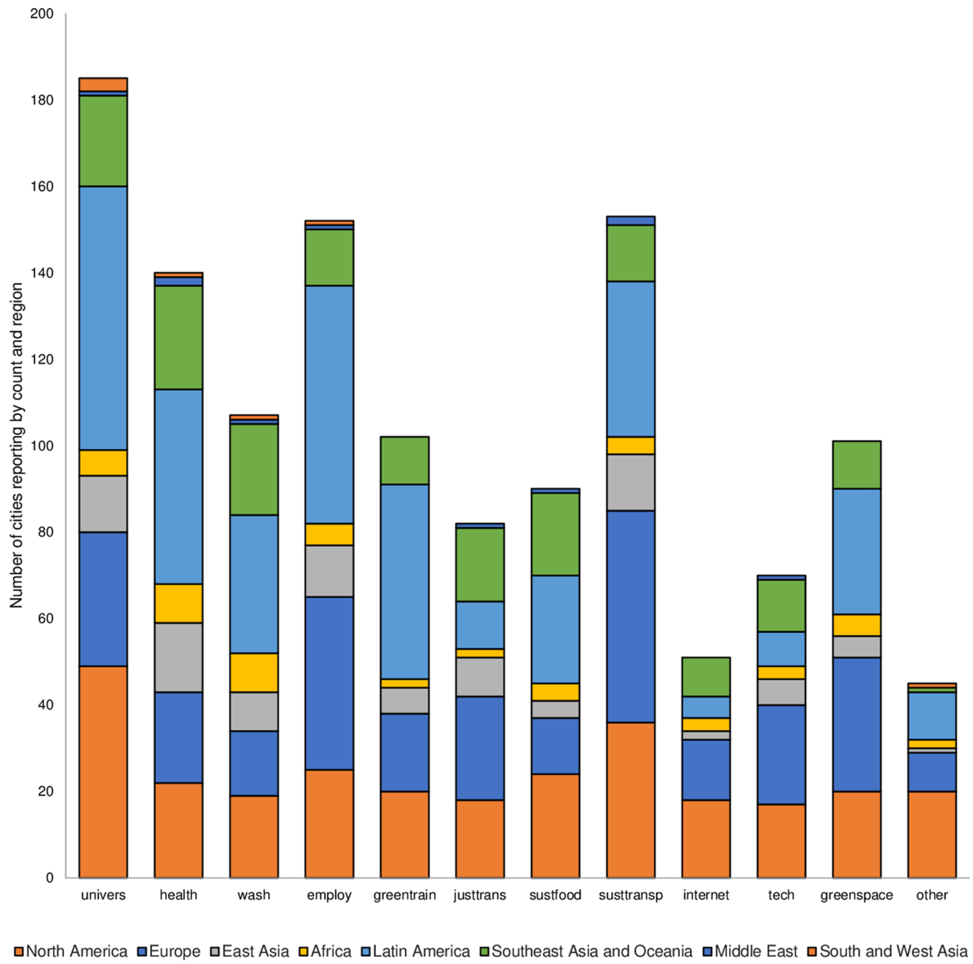

Extended Data Fig. 3 | Count of green recovery Interventions in cities by CDP geographic region. Count of cities reporting each recovery intervention type (total n = 793 cities). Bars indicate different recovery interventions: univers - development/strengthening universal social protection systems that enhance resilience to shocks, including climate change; health - development/strengthening health care services in city that enhance resilience to shocks, including climate change; wash - increased investment in Water, Sanitation, and Hygiene (WASH) services, facilities and/or infrastructure; employ - focus on employment opportunities in green sectors; greentrain - provide residents with effective access to training programs related to green sectors; justtrans - support just transition strategies for workers and communities; sustfood - channel investment in sustainable, resilient agriculture and food supply chains; susttransp - boost public and sustainable transport options; internet - build out broadband and internet services to those with inadequate access; tech - scale up investments in and access to digital technologies, funding mechanisms, and capacity-building solutions to enhance resilience to shocks, including climate change; greenspace - increase access to urban green spaces; and other.

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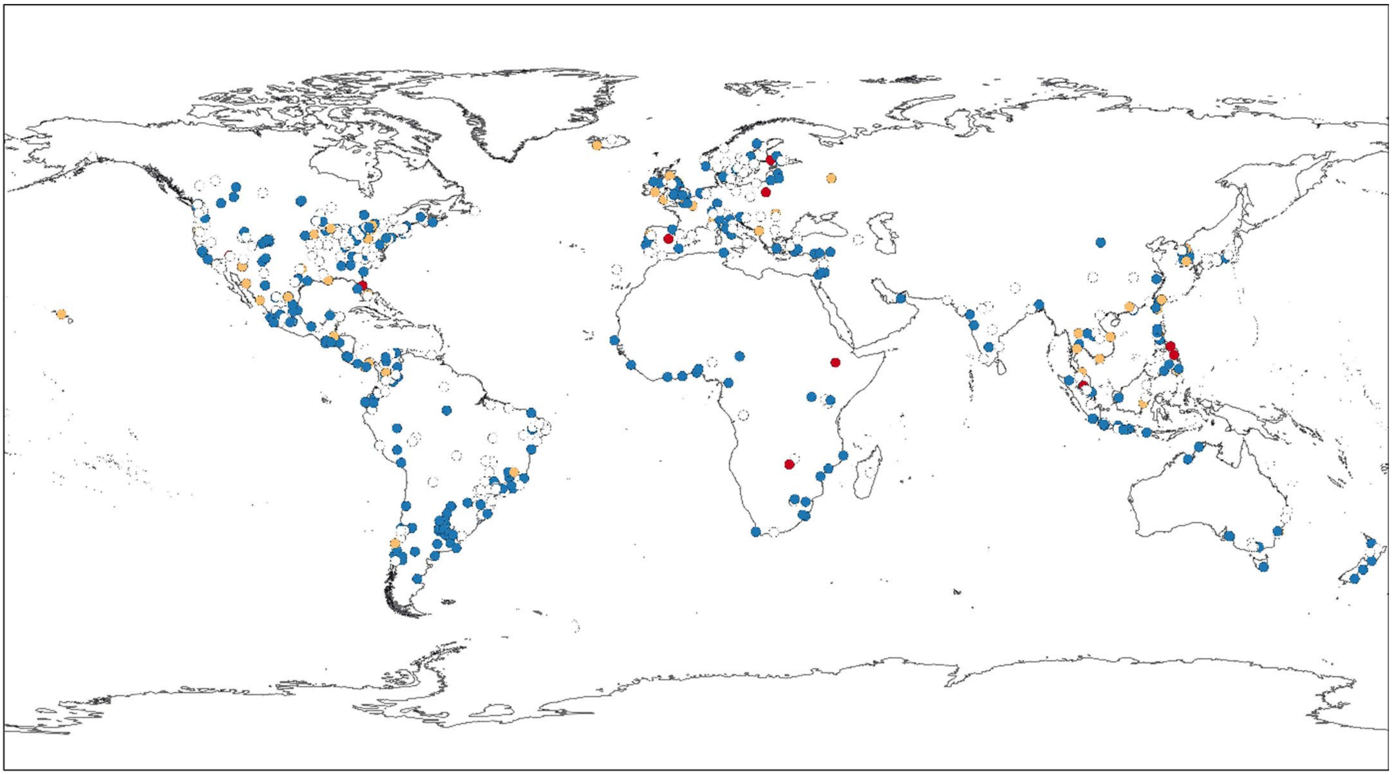

Extended Data Fig. 4 | Geographic distribution of number of green recovery interventions implemented in cities. Circle colours indicate number of green recovery interventions implemented by cities, with white circles showing 0 (zero), blue circles - 1 to 4, yellow circles - 5 to 8, red circles - 9+ green recovery interventions. Map was produced using QGIS desktop 3.20.3 and basemap (coastline v4.1.0) from Natural Earth (https://www.naturalearthdata.com).

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Extended Data Table 1 | Indicators selected for identified factors

Variable	Description	Source
Exposure to environmental stress		
Climate-related health issues	Total number of climate-related health issues faced by the city as reported in 2021	CDP Cities 2021, https://data.cdp.net/, Section 2, Q2.3a
Air pollution (NO2, pre COVID-19)	Value of tropospheric NO2 column in units of 10^15 (quadrillion) molecule/cm^2, using mean values for a 25 km buffer zone.	NASA/ Goddard Earth Sciences Data and Information Services Center (GES DISC) (Version: Jul-2022) https://disc.gsfc.nasa.gov/
Climate change hazards	Total number of medium-high or high-probability hazards faced by the city as reported in 2021	CDP Cities 2021, https://data.cdp.net/, Section 2, Q2.1
Early engagement in addressing climate and sustainability		
Network membership (2020-2021)	Whether city is a member of an international climate network (specifically: Climate Mayors; EU Covenant of Mayors; Global Covenant of Mayors; Race to Zero; Under2 Coalition)	ClimActor, https://github.com/datadrivenenvirolab/ClimActor using "subnational_contextuals_database_June2021.csv"
Pre-2021 climate targets	Whether a city had a short-term (pre-2021) climate target; used as a proxy for commitment to action; assumes longer-term engagement and commitment in cities with pre-2021 targets	CDP Cities 2021 https://data.cdp.net/, Section 5, Q5 & Qs5.0a - Q5.0d
Collaboration with business	Whether a city collaborates with businesses on sustainability projects as reported in 2021	CDP Cities 2021 https://data.cdp.net/, Section 6, Q6.2
Sustainability opportunities	Total number of opportunities identified as a result of addressing climate change (reported in 2021)	CDP Cities 2021 https://data.cdp.net/, Section 6, Q6.0
COVID-19 impacts		
Economic impact (night-time lights)	Impact of COVID-19 on economic activity during 2020, measured as difference in actual 2020 night-time lights versus counterfactual 2020 night-time lights values (see Supplementary information 1). Values are expressed as (positive and negative) percentage points.	Earth Observation Group platform (Annual VNL, V2) (https://eogdata.mines.edu/nighttime_light/annual/v21/)
COVID-19 deaths (2020-2021) (national)	Rolling sum of deaths from COVID-19 in 2020 and 2021 at the national level, reported per thousands.	Our World in Data Coronavirus Deaths (Version: Jul-2022) https://ourworldindata.org/coronavirus
Government response index	An index score ranging from '0' to '100', with higher values indicating better government response to the COVID-19 pandemic. Used as a proxy for good GDP governance.	Oxford COVID-19 Government Response Tracker (Version: Jul-2022) https://github.com/OxCGRT/COVID-policy-tracker
Controls		
Log of economic activity (lights, pre-COVID-19)	Value of average-masked annual global VIIRS night-time lights for 2019, using mean values for 25 km buffer zone, expressed in log form.	Earth Observation Group platform (Annual VNL, V2) (https://eogdata.mines.edu/nighttime_light/annual/v21/)
Population density	Population density for 2020, reported in units of ten thousands of persons per square kilometre, using maximum values for a 25 km buffer zone.	Socioeconomic Data and Application Center (SEDAC) Center for Earth Science Information Network (V4.11, 2021) http://dx.doi.org/10.7927/H4F47M2C
Log of GDP (national)	National GDP for 2019, reported in current USD, expressed as a logarithm	World Bank national accounts data & OECD National Accounts Data Files (Version: Oct-2022) https://data.worldbank.org/indicator/NY.GDP.MKTP.KD.ZG
Liberal democracy index (national)	An index score ranging from '0' to '1', with higher values indicating that the ideal of liberal democracy is achieved to a greater extent, rescaled to 0-100.	Varieties of Democracy Project Dataset (V-Dem), (V12, pub Mar-2022) https://www.v-dem.net/data/the-v-dem-dataset/

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Reporting Summary

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For all statistical analyses, confirm that the following items are present in the figure legend, table legend, main text, or Methods section.

n/a	Confirmed	
☐	☒	The exact sample size (n) for each experimental group/condition, given as a discrete number and unit of measurement
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☐	☒	A description of all covariates tested
☐	☒	A description of any assumptions or corrections, such as tests of normality and adjustment for multiple comparisons
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☐	☒	For null hypothesis testing, the test statistic (e.g. F, t, r) with confidence intervals, effect sizes, degrees of freedom and P value noted *Give P values as exact values whenever suitable.*
☒	☐	For Bayesian analysis, information on the choice of priors and Markov chain Monte Carlo settings
☒	☐	For hierarchical and complex designs, identification of the appropriate level for tests and full reporting of outcomes
☐	☒	Estimates of effect sizes (e.g. Cohen's d, Pearson's r), indicating how they were calculated

Our web collection on statistics for biologists contains articles on many of the points above.

Software and code

Policy information about availability of computer code

Data collection	No software or code was used to download the data for this study. This was done manually, and all data was downloaded in raw form from publicly available sources
Data analysis	We used Stata 17.0 for cleaning, organising and analysing the data; the code used for all these processes is available at https://github.com/climateactiondata/climatecitiesproject/. Maps were produced using [DETAILS]. ClimActor data was processed using ClimActor R package (version June-2021) downloaded from https://github.com/datadrivenenvirolab/ClimActor/tree/master/data-raw/Archive

For manuscripts utilizing custom algorithms or software that are central to the research but not yet described in published literature, software must be made available to editors and reviewers. We strongly encourage code deposition in a community repository (e.g. GitHub). See the Nature Portfolio guidelines for submitting code & software for further information.

Data

Policy information about availability of data

All manuscripts must include a data availability statement. This statement should provide the following information, where applicable:

- Accession codes, unique identifiers, or web links for publicly available datasets
- A description of any restrictions on data availability
- For clinical datasets or third party data, please ensure that the statement adheres to our policy

All the source data used in this study is publicly available. The full (raw) CDP dataset can be downloaded from the CDP website at https://data.cdp.net/ (version

Jan-2022 used for this study). Data sources associated with independent variables used in this study are detailed in Extended Data Table 1. They include:
• NO2 data from NASA/ Goddard Earth Sciences Data and Information Services Center (GES DISC) (Version: Jul-2022) (https://disc.gsfc.nasa.gov/)
• Nighttime lights data from Earth Observation Group platform (Annual VNL V2, Jul-2022) (https://eogdata.mines.edu/nighttime_light/annual/v21/)
• Our World in Data Coronavirus Deaths (Version: Jul-2022) (https://ourworldindata.org/coronavirus)
• Oxford COVID-19 Government Response Tracker (Version: Jul-2022) (https://github.com/OxCGRT/COVID-policy-tracker)
• Population density data from Socioeconomic Data and Application Center (SEDAC) Center for Earth Science Information Network (V4.11, 2021) (http://dx.doi.org/10.7927/H4F47M2C)
• National GDP data from the World Bank national accounts data & OECD National Accounts Data Files (Version: Oct-2022) (https://data.worldbank.org/indicator/NY.GDP.MKTP.KD.ZG)
• Liberal democracy data from the Varieties of Democracy Project Dataset (V-Dem), (V12, published Mar-2022) (https://www.v-dem.net/data/the-v-dem-dataset/)

Additional data sources used to identify city coordinates and boundaries (where available) include:
• World Cities Database (Version: Mar-2022) (https://simplemaps.com/data/world-cities)
• ESRI Data & Maps (Version 10.3, Nov-2015) (https://apps.gis.ucla.edu/geodata/dataset/world_urban_areas),
• ClimActor data (Version Jun-2021) using "subnational_contextuals_database_June2021.csv" (https://github.com/datadrivenenvirolab/ClimActor/tree/master/data-raw/Archive).
Some coordinates were also obtained from GeoHack (Accessed Jun-2022) at https://www.mediawiki.org/wiki/GeoHack.
The final clean dataset used for analysis in this paper can be found at https://github.com/climateactiondata/climatecitiesproject/

Human research participants

Policy information about studies involving human research participants and Sex and Gender in Research.

Reporting on sex and gender	not applicable
Population characteristics	not applicable
Recruitment	not applicable
Ethics oversight	not applicable

Note that full information on the approval of the study protocol must also be provided in the manuscript.

Field-specific reporting

Please select the one below that is the best fit for your research. If you are not sure, read the appropriate sections before making your selection.

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Behavioural & social sciences study design

All studies must disclose on these points even when the disclosure is negative.

Study description	This study uses quantitative data. All data used here is publicly available; no primary data was collected for this study.
Research sample	The sample consists of n=793 cities from around the world (48% from the Global South) that provided information about the impact of COVID-19 on climate actions and finance, and green recovery interventions in the CDP 2021 survey. Given the lack of unified and consistent global data on cities, it is not possible to identify to what extent this sample of cities from 82 countries is representative of all cities worldwide.
Sampling strategy	We sampled all cities from the CDP 2021 database (total n=1,070, data downloaded Jan 24th 2022) that had provided information about the impact of COVID-19 on climate actions and finance, and green recovery interventions (final sample in or study is n=793).
Data collection	Data collection by CDP involves self-reports by city officials; the procedure for data collection is described at https://www.cdp.net/en/cities. Data collection from CDP by authors of this paper was done manually; all data was downloaded in raw form.
Timing	CDP data was downloaded on 24th January 2022. Details of timing of downloads of other data used in this study is provided in previous sections (under Data Availability)
Data exclusions	No data was excluded; sample size variations across models are due to missing data for key explanatory variables (explained in Figure legends where relevant)
Non-participation	Not applicable. This study is based on self-reports by cities.

Randomization	Not applicable. This study is based on self-reports by cities, and was not designed to identify causal impacts (for which randomization would be appropriate).

Reporting for specific materials, systems and methods

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Materials & experimental systems

n/a	Involved in the study
☒	☐ Antibodies
☒	☐ Eukaryotic cell lines
☒	☐ Palaeontology and archaeology
☒	☐ Animals and other organisms
☒	☐ Clinical data
☒	☐ Dual use research of concern

Methods

n/a	Involved in the study
☒	☐ ChIP-seq
☒	☐ Flow cytometry
☒	☐ MRI-based neuroimaging