Aspen Global Change Institute Energy Project

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Cities on the Frontlines of Climate Change Impacts and Response

In the wake of the Trump Administration choosing to initiate the process to withdraw the United States from the Paris Climate Accord, cities and regional governments within the U.S. have been individually reaffirming their commitment to adhering to the Accord. This review explores why it is in cities' best interests to continue confronting climate change, illustrating why they are uniquely vulnerable and impacted by global warming. While cities cover only about one percent of Earth's surface, their true footprint extends far beyond that – while cities generate 80 percent of gross world product (Estrada et al. 2017), they also consume 78 percent of global energy and produce, and are responsible for over 60 percent of CO_2 emissions. Cities will be increasingly affected by climate change both directly and indirectly, locally and through far-reaching supply channels. The economies, physical structures, food security, and energy consumption of cities are already undergoing significant impacts from climate change; thus underscoring the incentive many cities have in recommitting to global mitigation efforts.

Direct Effects

Amplified Urban Heat Island Effect

For centuries, researchers have reflected on the phenomenon now known as the 'Urban Heat Island Effect,' in which cities are measurably warmer than the surrounding countryside. This is caused by decreased vegetation in cities (less natural cooling from evapotranspiration), coupled with more buildings and built surfaces that absorb the sun's heat. Recent studies point to the fact that the urban heat island effect is often excluded from climate projections, so while there may be an average increase in climate for a region of 1-2°C, in reality the increase can be twice that in urban centers. Additionally, studies are finding that the urban heat island effect is likely to amplify and worsen with climate change. Urban heat island impacts include increased energy use for cooling, higher air pollutant emissions, human health risks and discomfort, lower water quality, and exacerbated heat waves – all resulting in compromised productivity (Estrada et al. 2017). Projected decreases in GDP due to climate change alone are relatively small, but when factoring in local amplification from urban heat island effect, productivity in some cities may decline by more than 10 percent by 2100. By ignoring the impacts of urban heat island effect, projections can significantly underestimate the true effects of global warming – not only on temperatures, but on economies. When urban heat island impacts are factored in to economic projections, the true costs of global warming are 2.6 times higher than when urban heat island impacts are ignored.

On average (across the 1,692 largest cities in the world), the urban heat island effect currently adds 0.7°C to city temperatures, but with climate change it is projected to add close to 1°C additional warming by 2100 (Estrada et al. 2017). And that is just on average across cities – some hot spots within the densest parts of cities experience warming significantly above average (an additional 3°C as opposed to the average near 1°C) (Koomen and Diogo 2015). Business as usual scenarios show that when additional warming from urban heat island effect is taken into account the vast majority of cities are expected to warm by more than 3°C by 2050, and more than 5.5°C by 2100 – with over 25 percent of cities warming more than 7°C (Estrada et al. 2017). This has sobering implications for human health (see *The Coupled Human-Climate System: Heat Stress and Mortality in a Changing Climate* in this Quarterly Research Review).

Estrada et al. (2017) also finds, however, that local actions to dampen the urban heat island effect can be an extremely important tool in combatting this amplified warming. Local mitigation efforts include increased vegetation in cities, green roofs (completely or partially covered in vegetation), cool roofs (constructed from lighter-colored materials that reflect more of the sun's rays), and cool pavements. Without local mitigation actions to reduce urban heat island effect, global mitigation efforts to reduce climate change are far less effective. By replacing 20 percent of a city's roofs with cool and green roofs, a city could offset 0.8°C of urban heat island effect, resulting in overall savings up to 12 times the cost of installation. To carry out this degree of mitigation on the global scale, this scenario would cost 1.5 percent of global urban product, but would reduce losses from climate change by 9.7-18.3 percent. Greater benefits can be achieved by scaling up these efforts, though the benefit-cost ratio is not as high. However, this analysis only factors in temperature benefits, and not the other benefits provided by green roofs such as storm water management, reduction in air pollution, and health benefits. The benefit-cost ratio would therefore be much higher for these scenarios if indirect benefits were also factored in (Estrada et al. 2017).

Air Pollution & Human Health

Climate change and air pollution are both rooted in greenhouse gas emissions, and therefore are integrally tied. Reactive air pollutant concentrations of particulate matter (PM 2.5) have been reported above healthy levels in cities all over the world (Figure 1). Increased air pollution associated with climate change is not only directly harmful to human health, but also chemically reacts with the epithelial lining fluid of the respiratory tract, compromising immune function, and predisposing the human body more towards allergic reactions to air pollution and other allergens (Lakey et al., 2016). Predisposition towards more allergic reactions can be compounded by the fact that climate change has been demonstrated to increase the range, pollen production and/or sporulation of invasive allergenic plants and molds, all of which exacerbate allergies (Reinmuth-Selze et al. 2017).

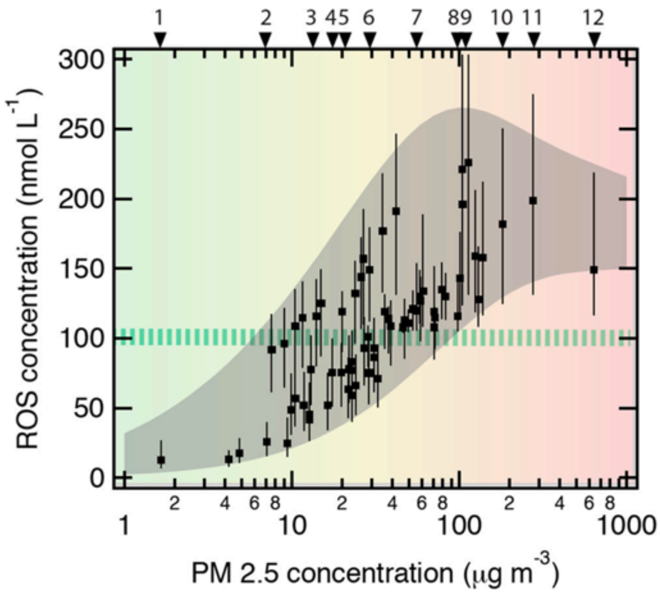

Figure 1. High concentrations of particulate matter (PM 2.5) air pollutants chemically react with the human respiratory system to produce unhealthy levels of reactive oxygen species (ROS) in human lungs. Healthy ROS levels are indicated by the green hashed line. Unhealthy levels of ROS have been observed in humans in cities all over the world, compromising immune systems (Lakey et al., 2016).

Not only will air pollution continue to persist while we rely on greenhouse gas-producing energy sources and technologies, but due to climate change, new circulation patterns may further exacerbate exposure to extreme pollution in some cities such as Beijing. Large scale circulation changes (such as the upward shift of the Arctic Oscillation, and the weakening of the East Asia winter monsoon), are projected to create more frequent and persistent weather patterns and inversions that cause extreme haze episodes in Beijing (Cai et al. 2017).

Sea Level Rise

Another direct impact of climate change on cities is sea level rise. Buchanan et al. (2017) cite sea level rise as one of the most economically damaging consequence of climate change on cities, due to impacts such as loss of infrastructure, vulnerability to storms, long-term effects on municipal services, and potential contamination of groundwater. Houser et al. (2015) project that the most economically damaging consequence of climate change on coastal areas will be flooding amplified by sea level rise. Current projections of sea level rise this century estimate a median 40-fold increase in annual 100-year floods—meaning floods of a certain magnitude that used to occur once every century are now expected to occur 40 times within a century. In addition to flood frequency, flood height is projected to increase significantly as well. There is variation across cities in how amplification of flooding will occur (whether more frequent 10-year floods vs. 500-year floods). San Francisco, New York City, Baltimore, Washington, D.C., and Key West will be disproportionately prone to more higher frequency (10-year) floods, whereas Seattle, San Diego, and Los Angeles will be prone to more lower frequency (500-year) floods. For example, 10-year, 100-year, and 500-year floods are projected to occur 148, 16, and four times as often in Charleston, vs. 109, 335, and 814 times as often in Seattle (Buchanan et al. 2017). Because city infrastructure has typically been locked in for decades or even centuries, urban populations are already having to face difficult decisions about when to reinforce infrastructure, and when to retreat from advancing sea levels. Cities can use research like that of Buchanan et al. (2017) to inform policy in light of what types of sea level rise flooding they can expect to see more of in the future (10-year vs 500-year).

Indirect Vulnerabilities of Cities to Climate Change

Food Security

Cities consume 78 percent of global produce (Estrada et al. 2017), the vast majority of which is produced well outside city limits. Cities have a far-reaching footprint of supply, and therefore their sources of potential climate vulnerability are global in scale. Research on causal mechanisms is ongoing, but many studies have indicated a significant impact on global food production caused by climate change. In some areas (Russia, northern Europe, and Canada) productivity is likely to increase due to longer growing seasons, but in hotter and more arid regions, climate change will likely compromise food security. Overall, crop yields for staple cereal crops such as corn, wheat, and rice are all projected to decrease with increasing temperatures. Varying precipitation, changes in snow runoff timing and quantity, drought, elevated evaporation and evapotranspiration, increased pest and disease ranges, more extreme weather events (like heat waves and flooding) all have significantly negative effects on crop productivity and food security (Gornall et al. 2010). Urban populations will therefore likely become increasingly vulnerable to changes in crop availability and prices, without much agency to control agricultural processes.

Electricity Production

As global warming accelerates, the heating and cooling needs of cities will also change. Under a business as usual scenario, researchers have found that while average generation of electricity is likely to increase by only a small amount by 2100 (a 2.8 percent increase), demand for peak load generation is likely to increase much more significantly (a 7.2 percent increase) (Auffhammer et al. 2017). Global warming will also exert more pressure on grids during cooling seasons due to increased reliance on air conditioning (Shen 2017). These additional demands in peak electricity generation can be seen across the country (Figure 2), but as the primary consumers of electricity with minimal agency over energy production policies, urban populations will be more susceptible to any shortfalls in the abilities of electricity producers to meet peak demands. This finding underscores the incentive for cities to be leaders in pushing for sustainable energy systems and policies, such as increases in solar capacity, energy storage, and real-time prices, all of which can help shift energy use from peak to off-peak times (Auffhammer et al. 2017).

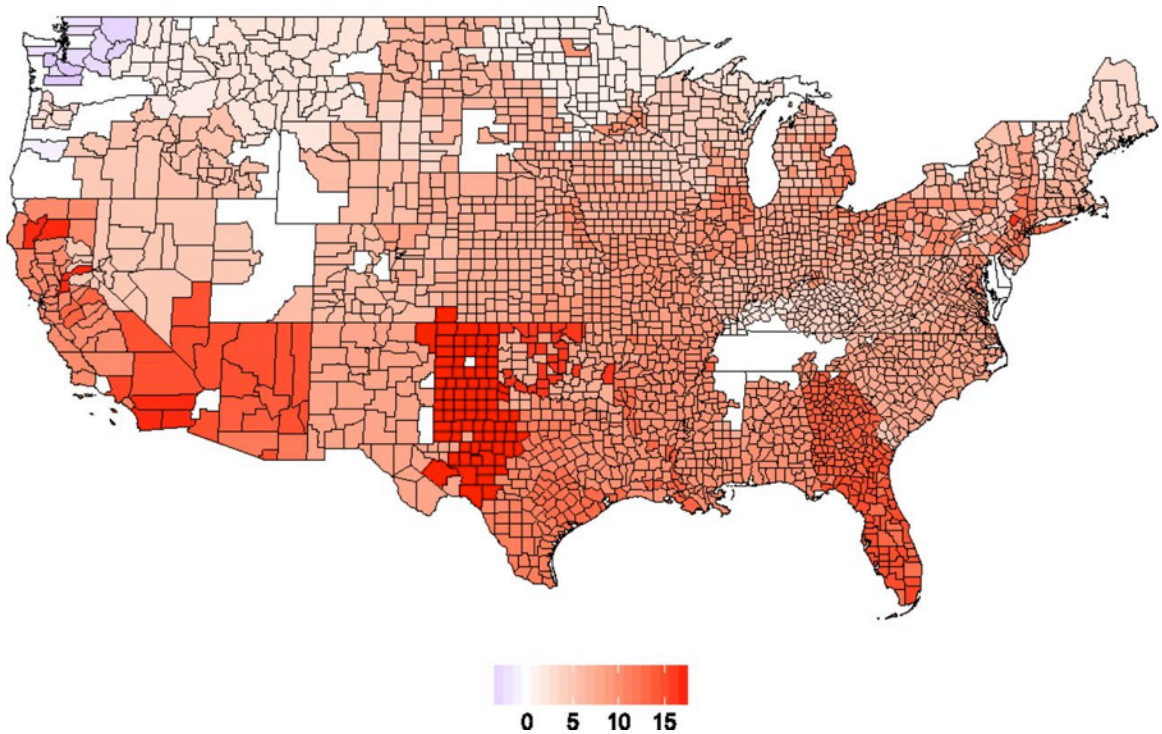

Figure 2. Demand for electricity during peak hours is projected to increase throughout much of the United States under a business-as-usual scenario (RCP8.5), with the largest increases in the South and West. Coloring reflects projected percentage increases in the daily peak, with an average increase of 7.2 percent (Auffhammer et al. 2017).

In summary, the threats posed to cities by climate change are significant, in part due to amplification of impacts within cities, and in part due to their far-reaching metabolism that connects them with susceptible systems all over the world. These impacts pervade all sectors (food, industry, real estate, water, etc.), and are often compounded by cascading effects (both direct and indirect). Economic analysis of these interconnected effects is poorly understood, both in terms of damages to quality of human life and the environment. Studies such as Estrada et al. (2017) and others are helping urban decision-makers gain a better understanding of how mitigation and adaptation are fundamental to urban environments succeeding in the 21st century of climate change.

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