CHAPTER 11: RESILIENT CITIES

I. The patterns of urbanization around the world

We have discussed the world's great ecosystems, including rainforests, oceans, drylands, and polar ecosystems. It is time to focus on where most of people live: the cities. Something remarkable happened in 2008 according to the UN official data: for the first time in all of human history, more than half of the human population lives in cities. Our species started out as hunters and gatherers, without settlements. Around 10,000 years ago, civilization began with the discovery and development of sedentary agriculture. Rather than hunting and gathering, humanity began to stay in one place. As a food surplus was gradually generated in the farm sector, an urban economy arose, with urban areas characterized mainly by the fact that the urban workforce is not (at least primarily) agriculturalists. Since their start 10,000 years ago, cities produced urban manufactures and services – food processing, light and heavy industry, public administration, religious rites, entertainment, finance, trade, banking – which it traded for food from the countryside.

Up to the time of the Industrial Revolution, the farm sector simply was not productive enough to support a large urban economy. Even though we think of the great historic monuments of Egypt, Rome, Beijing, Constantinople, Paris, London, and the other great cities of the world before the Industrial Age, the share of the world's population actually living in cities was consistently around 10% or less. The vast majority of people in the vast majority of places and times lived in farm households in rural communities, engaged in local food production.

Then came the scientific, agricultural, and industrial revolutions beginning in the 18th century. With better farm practices (e.g. improved rotations of crops), better access to soil nutrients (e.g. the green and chemical fertilizers to boost soil nitrogen), and better transport conditions, the farm areas were able to produce more output per farmer, and thereby to support a much larger population in urban areas not growing food. The age of industrialization also coincided with the start of mass urbanization. As in other spheres of economic development, England and the Netherlands came first. According to one leading expert in this area, the late economic historian Paul Bairoch, Europe's average urbanization rate in 1800 was 10.9% (with urban areas defined by the threshold of 5,000 people or more in one aggregation). Yet by that year, the UK urbanization rate was 19.2%, and the Netherlands' urbanization rate was a record-setting 37.4%. By 1850, the UK had reached 39.6% and the Netherlands was at around 35.6% while Europe as a whole was at 16.4% urban. Even by 1910, after more than a century since the start of the industrial revolution, Europe's overall urbanization rate was no more than one-third (32.9% in Bairoch's estimate), though the UK, Netherlands, and Belgium had passed the 50% mark.

The Industrial Revolution and its aftermath dramatically increased the output per farmer. This has been the result of several factors: improved scientific knowledge; higher yield crop varieties; scientific management of soil nutrients; and of course machinery, enabling an individual farmer to manage a much greater land area in terms of clearing, preparation of soils, planting, harvesting, and transporting

of output. The Haber-Bosch process to make nitrogen-based fertilizers at industrial scale has dramatically increased the yields of grain crops, as have a series of Green Revolutions in the 20th century centered on improved crop varieties. All of these advances mean that a smaller proportion of the population engaged in farming can grow the food for a rising share of the population living in cities.

Agriculture has two other properties that give it a distinctive role in the economy compared with industry and services. The first is that that the demand for agricultural output does not increase in proportion with income. As GDP per capita rises, the consumption of food per capita does not rise at the same rate. A person who is 10 times richer than another person will not eat 10 times as much. We say that the income elasticity of food demand is less than one: food demand increases with income, but much less than proportionately. Food is a "necessity," not a luxury good. (A luxury good is one that rises in demand even faster than income, thereby assuming a growing share of consumption of richer households.) This means that as economic development takes place, agriculture will not keep pace as a share of the total economy.

The second property is that agriculture is land dependent, while industry and services are not. Farmers need land more than they need close neighbors. On the other hand, service providers such as barbers, doctors, lawyers, bankers, and movie-theater operators need customers and neighbors more than they need large open spaces. Similarly, manufacturing companies need close access to both upstream suppliers (who provide semi-finished goods to the factory) and downstream consumers and shippers. The result is that that farmers need to live in sparsely settled areas, with lots of land per person, while industrial and service workers need to live in crowded areas, close to suppliers and buyers. Agriculture, in short, is intrinsically rural, while industry and services are intrinsically urban. (Of course, these statements apply more to services than to manufacturers, and at least some industrial activities are intrinsically rural, close to farms or mines rather than to customers and urban suppliers.)

The implication is straightforward and very important. Alongside the shift from agriculture to industry and services comes a parallel and fundamental shift, from rural areas of dispersed populations to urban areas of densely settled populations. Moreover, one specific kind of activities is heavily concentrated in cities: research and development, built on scientific innovation and engineering breakthroughs. Cities are the major home of technological advances, even the technological advances (like the Haber-Bosch process) that greatly benefit farming. This leads to a dynamic symbiosis of farms and cities. More productive farms enable cities to grow, while cities in turn provide technological advances for farms that lead to even greater farm productivity. Much of the 200-year dynamic of modern economic growth marks a constructive interplay in which advances on farms spur cities that in turn spur farms to further advances.

Figure 11.1 confirms that economic development is accompanied by urbanization. On the horizontal axis is GDP per capita, and on the vertical axis is the proportion of the country that is living in urban areas. This scatter plot is a worldwide snapshot for the year 2000. There is an upward sloping curve, where higher per capita incomes are associated with a higher proportion of urbanization. We expect that future global growth will therefore be accompanied by increasing urbanization.

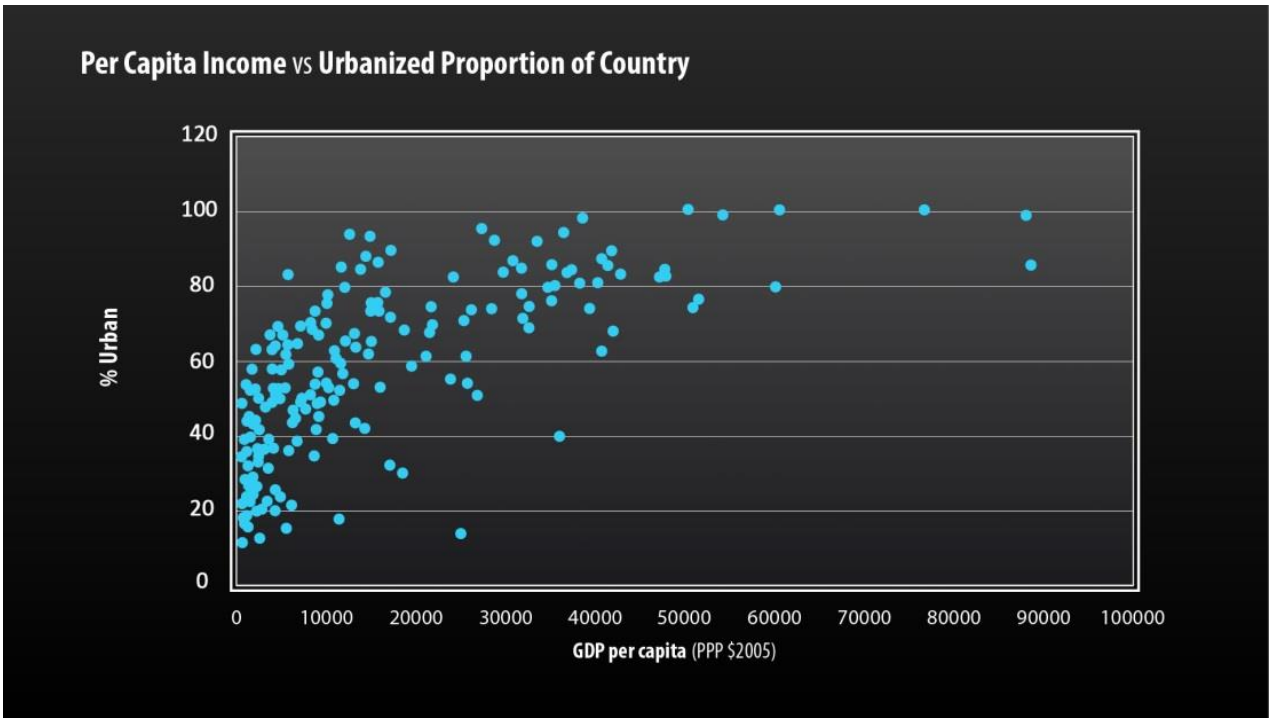

Figure 11.1. Per Capita Income vs. Urbanized Proportion of Country

Cities are also where most politics are settled. Capital cities are often places of great political contention and drama. There has been rising instability in recent years in the major cities around the world. Urban publics have protested some of the consequences of globalization itself: the rising inequalities and the rising unemployment that have resulted from shifting technologies and shifting trade patterns in many countries. The information age has also made people far more aware of political processes and has increased the capacity of people to organize protests and even to overthrow governments. Protests and unrest, supported by social media such as Twitter and Facebook, are seemingly on the rise in the major cities. Yet the dynamics are complicated since the information age has also enabled governments to use the new technologies to spy on their citizens and to crack down on protest movements.

Let us consider some of the factors that are distinctive about cities. First, cities have high concentrations of population. By definition, an urban area is a "densely settled area" of a certain minimum threshold, often taken to be 2,000 people or 5,000 people. (The definitions vary across countries.) Of course the largest cities are not in the thousands, but in the millions, and mega-cities have over 10 million people and significantly growing populations. The UN estimates that there are around 30 urban agglomerations worldwide with 10 million or more people (29 make that threshold, and the 30th, Chennai, India, comes in at an estimated 9.9 million in 2015). The list of these mega-cities is shown in Figure 11.2. Note that these are not the populations of cities defined according to political boundaries, but rather of cities defined as a single concentration of population, often including dozens of individual legal entities that are grouped together in one contiguous geographical area termed an "urban agglomeration" by the UN Population Division.

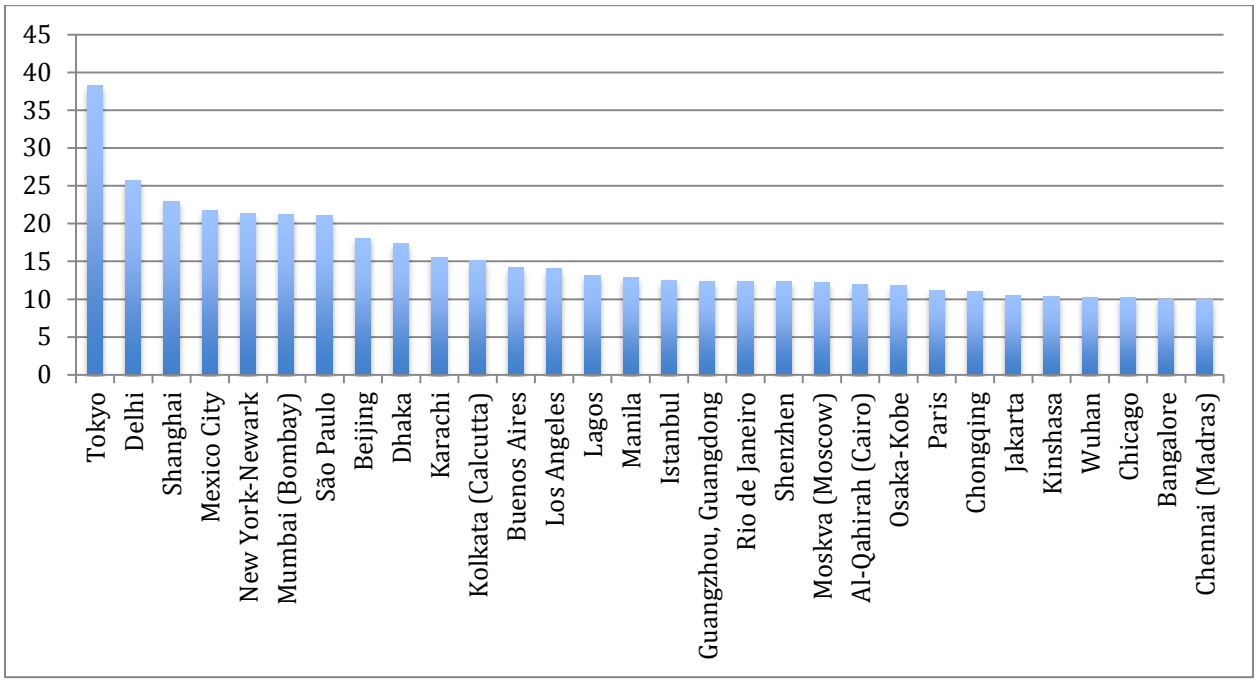

Figure 11.2. The World's Largest Urban Areas, Estimated Population as of 2015 (UN Population Division)

Second, cities are distinguished by the kind of economic activity that they host. While cities are home to a small amount of farming, cities by and large are home to industry and services. In the high-income countries, services are the overwhelming activity. Retail and wholesale trade, education, finance, law, medicine, entertainment, public administration, and other service activities, dominate the city economies.

Third, cities are relatively productivity areas of the national economy. The average output per person in urban areas is often two or three times higher than in the rural areas of the same country. The migration of workers from rural to urban areas is often accompanied by a significant rise in national productivity, measured as total output per worker.

Fourth, as noted earlier, cities are the locus of a tremendous amount of innovative activities, whether it is universities, research laboratories, or major businesses introducing new products. Innovations then spread to outlying areas from the cities.

Fifth, cities are trading centers, where a tremendous amount of activity involves the exchange of goods. Cities indeed exist as concentrated centers in large part to facilitate trade, exchange, and contracting, all greatly supported by proximity of buyers and sellers.

Sixth, major cities are generally coastal, to take advantage of the lower costs of sea-based shipping of goods. This recalls the observation of Adam Smith in 1776 that development normally starts at the coast and moves gradually to the interior. Most of the largest cities in the world are at or near the coast,

where it is possible to move goods internationally at low cost. Inputs can be received from the rest of the world for the great cities, and goods can be moved along major riverways that connect the ocean ports with the country's interior. Great cities are often at the estuaries of great rivers. Cities like New York and Shanghai connect their respective countries with world markets, and open up the interior of the countries to world markets via the Hudson River and the Yangtze River systems, respectively.

Have a look again at the great urban agglomerations in Figure 11.2. Most of the cities are within 100km of a major port if not directly on the coast themselves, as we see in Figure 11.3 for the world's mega-cities in 2012. Most of the truly interior cities are on major inland waterways that connect them with the oceans via rivers (e.g. Chicago and Chongqing). Only a few like Mexico City, Moscow and Bangalore are interior cities without major rivers connecting them to the coast. And consider New York City, my hometown. It is not only a great trading city, but it is also the terminus of a major sea-based network. On one hand, goods come from the Atlantic Ocean trade, and on the other, the interior of the United States is connected to New York through a waterway system that started operating at the beginning of the 19th century. Goods could come from Chicago, an inland city, then be carried by ship through the Great Lakes, the Erie Canal, and down to New York City via the Hudson River, which enters into the Atlantic Ocean. New York's marvelous location on the eastern seaboard allowed New York not only to connect the United States with the world, but also to connect the interior of the United States with the coast. That is one of the reasons why the Chicago-New York linkage was so essential. A close counterpart is Shanghai, China's greatest industrial city, which is also the terminus of the major Yangtze River. The Yangtze connects Shanghai with great interior cities in China, notably Chengdu and Chongqing, and subsequently from Shanghai to world markets.

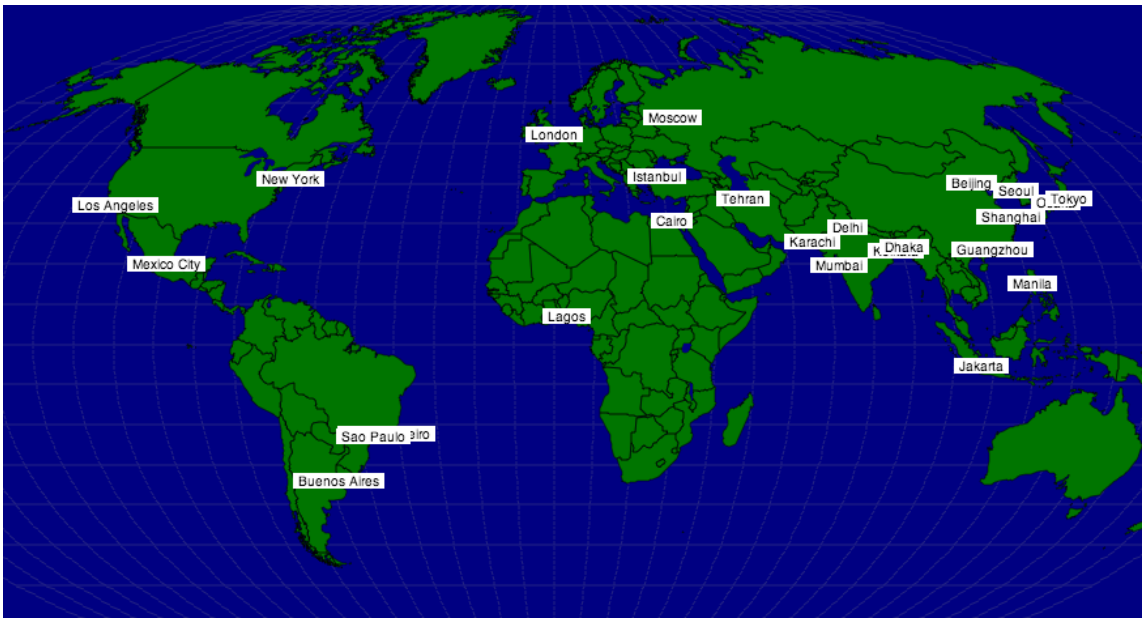

Figure 11.3. Large Global Cities

Seventh, cities are places of rapid population growth. They are the only places in the world that are growing right now, because rural areas have peaked in population.

Eighth, cities are often places of glaring inequality. (Rural areas of course can be as well, between large landowners and the landless.) Cities can put the rich and the poor next to each other, often in shocking proximity, as seen in Figure 11.4 of Rio de Janeiro with its grand, towering modern buildings right next door to the favelas. New York City is not very different in this regard. It puts some of the richest parts of the United States (e.g. the Upper East Side of Manhattan) just next to some of the poorest areas, such as Harlem to the north of the Upper East Side.

Figure 11.4. Favelas of Rio de Janeiro

Ninth, cities enjoy enormous advantages of economies of scope and scale, meaning that their productivity is enhanced by the large markets that they offer, making possible an enormous range of activities and depth of specialization (economies of scope) and enormous scale of production.

Tenth, and finally, cities face major challenges of "urban externalities," resulting from the high density of population and economic activities. Cities must cope with intense pollution of air and water, massive traffic congestion, and the rapid transmission of diseases if left uncontrolled. Many cities must cope with the potential for massive crime and violence resulting from the high concentrations of human contacts. Yet we should also mention that the concentration of population and economic activity may work to the advantage of the provision of public services (e.g. access to vaccines to stop disease transmission), pollution control (through infrastructure), and policing against crime.

As the world economy continues to grow and develop in the 21st century, and as rural productivity increases (assuming that the agricultural gains are not choked off by climate change), the world's urban areas are expected to continue growing, as seen in Figure 11.5. In 2008, the rural-urban populations crossed, and for the first time half the world became urban. There is no looking back. The United Nations Population Division forecasts that by 2030, urban areas will be an estimated 60% of the world's

population; and by 2050, 67% of the world's population will live in urban areas. In other words, all of the increase of population expected onwards, going from 7.2 billion to 8 billion and beyond, will be associated with a rising urban population, and a stable or even declining absolute rural population.

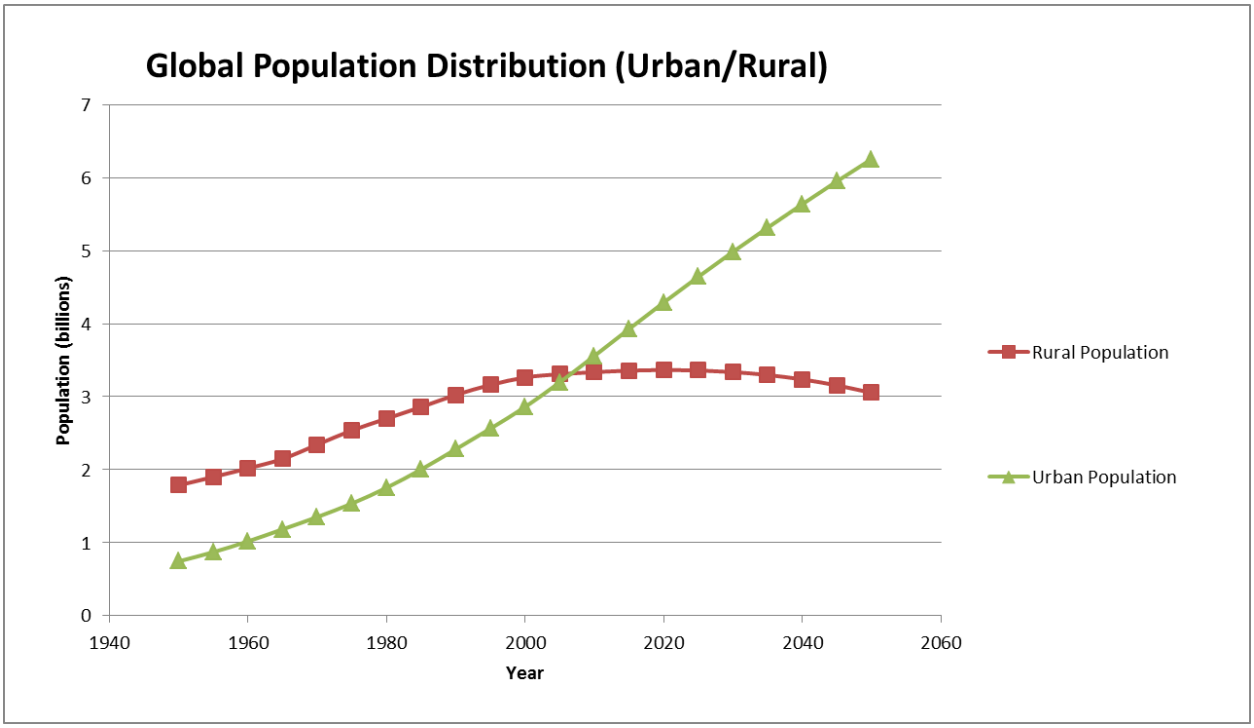

Figure 11.5. Global Population Distribution (Urban vs. Rural)

As with GDP per capita and health, there is also now a tendency towards convergence of urbanization rates across regions of the world. Just as poor countries now tend to grow faster than rich countries, poor countries also tend to urbanize more rapidly than the rich countries, which are already nearly entirely urban. Figure 11.6 shows the increase of urbanization rates for different regions. Asia and Africa are the two dynamic urbanizing regions of the world now – they are becoming urban societies after a long history of being village-based rural societies.

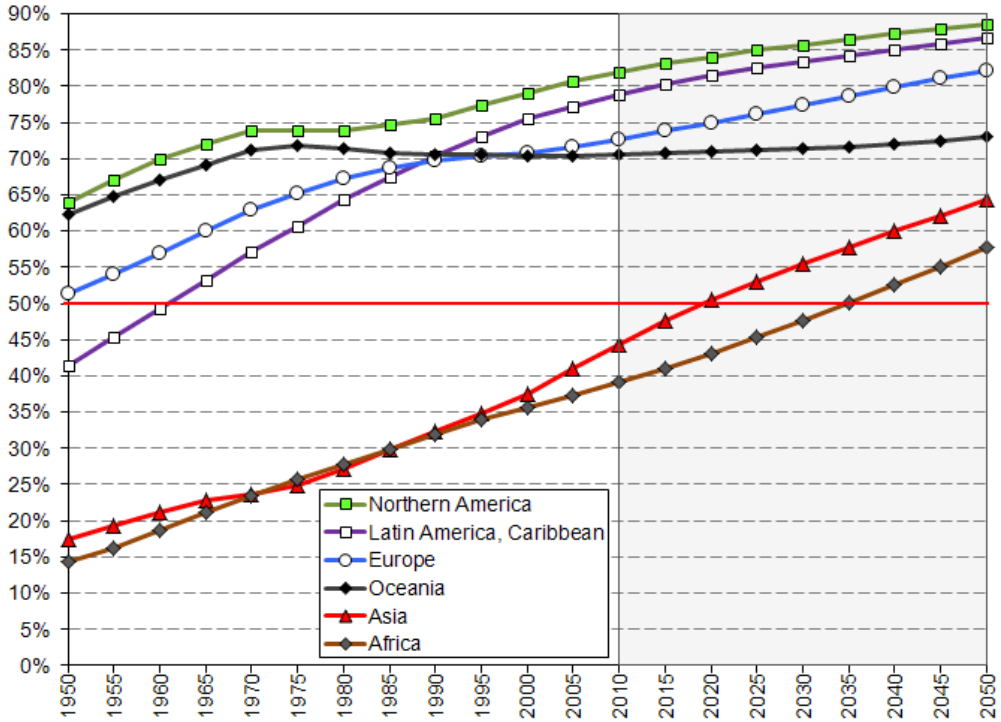

Figure 11.6. Regional Urbanization Rates

When we examine the share of the world population in different regions, we see that something quite remarkable is happening. The global distribution of urbanization, just like the global distribution of the world economy, is shifting in a fundamental way. According to Figure 11.7, in 1950, 38% of the world's urban population was in Europe. Europe was the site of the imperial powers, and dominated the rest of the world economically and politically. The European and North American populations in 1950 constituted an amazing 53% of the world's urban population, compared with around 29% of the global population. Yet by 2050, a time in which Asia and Africa will have substantially urbanized, the UN forecasts that Europe will only be 9% of the world's urban population. This is because Europe's share of total population is falling while the rest of the world is urbanizing. North America will be 6%. Rather than 53% of the world's urban areas as in 1950, together Europe and North America will constitute just 15%. The era when the West, and Western cities in particular, led the world is coming to an end.

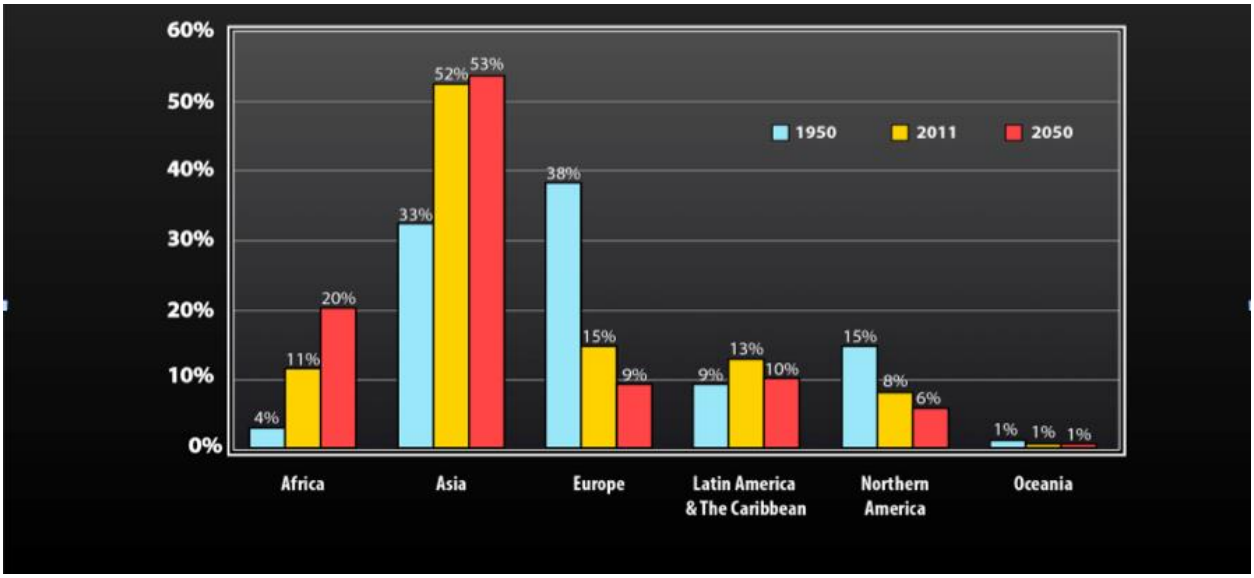

Figure 11.7. Distribution of World Urban Populations

This is also borne out by the dynamics of the world's largest cities. Back in 1950, there were just two mega-cities with more than 10 million people, both in the developed world: Tokyo and New York. In 1990, there were 10 mega-cities, four from high-income countries (Tokyo, Osaka, New York, Los Angeles), and six from developing countries (Mexico City, Sao Paulo, Mumbai, Calcutta, Seoul and Buenos Aires). By 2011, there were 23 such mega cities, with only six in the high-income countries, and the remaining 17 in today's developing world. As of 2015, as shown in Figure 11.2, of the 29 urban agglomerations with more than 10 million, only five are from today's high-income world: Tokyo, New York, Los Angeles, Paris, and Chicago. According to the UN's forecast for 2025, there will be an astounding 36 mega-cities. Only seven of them will be in the high-income world, roughly 20% of the total number.

II. What makes a city sustainable, green & resilient?

Since most the world will live in cities, it is important to ask what makes a city sustainable. The answer is threefold (according to the three dimensions of sustainable development). Sustainable cities are economically productive, socially (and politically) inclusive, and environmentally sustainable. In other words, they must promote efficient economic activities, ensure that all of the citizens can benefit from them, and must do so in a way to preserve the biodiversity, safe air and water, and physical health and safety of the citizens, especially in an age of climate change and increasing vulnerability to extreme climate catastrophes.

In the age of the Anthropocene, cities will be buffeted by environmental shocks. When mega-cities are on the coasts and sea levels are rising, the cities will become far more vulnerable to intense storms and storm surges, as New York City learned painfully with Hurricane Sandy in October 2012. Cities need to prepare for those shocks, not as disasters that seemingly come out of the blue, but rather as events that are rising in frequency even if specific occurrences cannot be well predicted in advance.

Urban sustainability is therefore an enormous task. We can summarize some of the major features of sustainability in the following schematic manner.

Urban productivity. Cities need to be places where individuals can find decent, productive work, and businesses can produce and trade efficiently. The basis for success is a productive infrastructure: the networks of roads, public transport, power, connectivity, water and sewerage, waste flows, and other "connective tissue" that enables the urban economy to operate with low transactions costs. Infrastructure also includes "software" like an effective court system to enforce contracts. When the urban infrastructure fails, the city is overwhelmed by congestion, crime, pollution, and broken contracts that impede business, job creation, and forward-looking investment.

Social inclusion. Cities can be places that create high social mobility, or places that widen the divides between the rich and the poor. Neighborhoods can be mixed by income and ethnicity, or divided by class and race. Schools can be unified in a strong public system or divided between strong private schools for the rich and weak public schools for the rest. The social stability, trust, and harmony in the society (including political stability and level of violence) will be affected by the extent of social mobility. When it is low and falling, protest, unrest, and even conflict are more likely to ensue.

Environmental sustainability. By definition, cities are places of high population density. They are therefore highly vulnerable to environmental ills: pollution of the air and water, despoliation of the land, the rapid spread of communicable diseases, and climate shocks and other catastrophes such as droughts, floods, extreme storms (e.g. tropical cyclones), and seismological disasters such as volcanic eruptions and earthquakes (in certain geological zones). Cities need to make two kinds of environmental efforts. The first, *mitigation*, is to reduce their own "ecological footprint," e.g. the greenhouse gas emissions caused by urban activities. The second, broadly speaking, is *adaptation*, meaning preparedness and resilience to changing environmental conditions, e.g. rising temperatures and sea levels (for coastal cities).

How effectively a city plans and prepares for the future is decisive in determining its prospects for sustainable development. None of these core issues – infrastructure, social mobility, quality education, and environmental preparedness – can be solved by market forces alone. Urban productivity, social inclusion, and environmental sustainability require considerable brainstorming, planning, deliberation, and political engagement of stakeholders.

Urban Sprawl versus High Density

One key determinant of a city's productivity and environmental footprint is its density, the concentration of population per square kilometer. Densely settled cities, if properly designed, tend to be more productive and to emit fewer greenhouse gases than sprawling, low-density settlements. This may seem surprising. High density implies that a lot of people are jammed together. Yet in high-density areas, it is also possible to achieve lower emissions in transportation (including via walking and public transportation) and more efficient trade (with smaller distances to cover). So places of high population

density tend to be places with lower ecological impacts, including lower carbon emissions per person of the population. The overall urban agglomeration of New York City is about 33,000 people per square mile, as seen in Figure 11.8. Compare that with Los Angeles, for example, at about 12,000 people per square mile. It is not surprising that Los Angeles is an automobile city whereas New York is not. Density makes a huge difference. Atlanta, which is decidedly an automobile city, is just one-fifteenth of the density of New York, at about 2,000 people per square mile. It is estimated that about 36% of all commutes or transit in New York are by walking or public transit. Compare that with an automobile city. For LA, the estimate is 8%, and in Atlanta, only about 5% travel is by public transit or walking. It is important to keep in mind that how one defines the geography of these urban agglomerations makes a difference in the precise comparisons. Yet, the general patterns hold: higher density means more walking and low-emission public transit.

URBANIZED AREA	PERCEIVED DENSITY (people per square mile) (rank)	DENSITY GRADIENT INDEX (rank)	PERCENTAGE OF COMMUTES BY PUBLIC TRANSIT (rank)	PERCENTAGE OF COMMUTES BY PUBLIC TRANSIT OR WALKING (rank)
New York--Newark, NY--NJ--CT	33,029 (1)	6.2 (1)	30.6% (1)	36.5% (1)
San Francisco--Oakland, CA	15,032 (2)	2.2 (5)	15.9% (2)	20.5% (2)
Los Angeles--Long Beach--Santa Ana, CA	12,557 (3)	1.8 (8)	5.8% (8)	8.2% (8)
Chicago, IL--IN	10,270 (4)	2.6 (4)	11.9% (4)	14.7% (5)
Philadelphia, PA--NJ--DE--MD	8,457 (5)	3.0 (3)	9.7% (6)	13.3% (6)
Boston, MA--NH--RI	7,711 (6)	3.3 (2)	11.6% (5)	16.1% (4)
San Diego, CA	7,186 (7)	2.1 (6)	3.1% (12)	5.0% (11)
Washington, DC--VA--MD	6,835 (8)	2.0 (7)	15.7% (3)	18.6% (3)
Miami, FL	6,810 (9)	1.6 (12)	3.6% (10)	5.3% (9)
Phoenix--Mesa, AZ	5,238 (10)	1.4 (14)	2.5% (13)	4.1% (13)
Detroit, MI	4,955 (11)	1.6 (10)	1.7% (15)	3.0% (15)
Seattle, WA	4,747 (12)	1.7 (9)	7.6% (7)	10.3% (7)
Dallas--Fort Worth--Arlington, TX	4,641 (13)	1.6 (11)	1.9% (14)	3.2% (14)
Houston, TX	4,514 (14)	1.5 (13)	3.2% (11)	4.6% (12)
Atlanta, GA	2,362 (15)	1.3 (15)	4.0% (9)	5.1% (10)

Figure 11.8. Urban Density and Commutes

New York City's density and transport infrastructure means it is doing quite well compared to the rest of the United States in carbon emissions. On average, around 2008 Americans were emitting about 20 tons of CO2 per person per year (more recently, emissions are around 17 tons per person). New York City, however, was roughly one-third of that, at around six tons of CO2 per capita. Figure 11.9 shows New York City at the low end of CO2 emissions. The benefits are not only in transport but also the heating and cooling of buildings. Emissions per person in apartment buildings and row houses tend to be lower than in large stand-alone houses found in most other cities and suburbs.

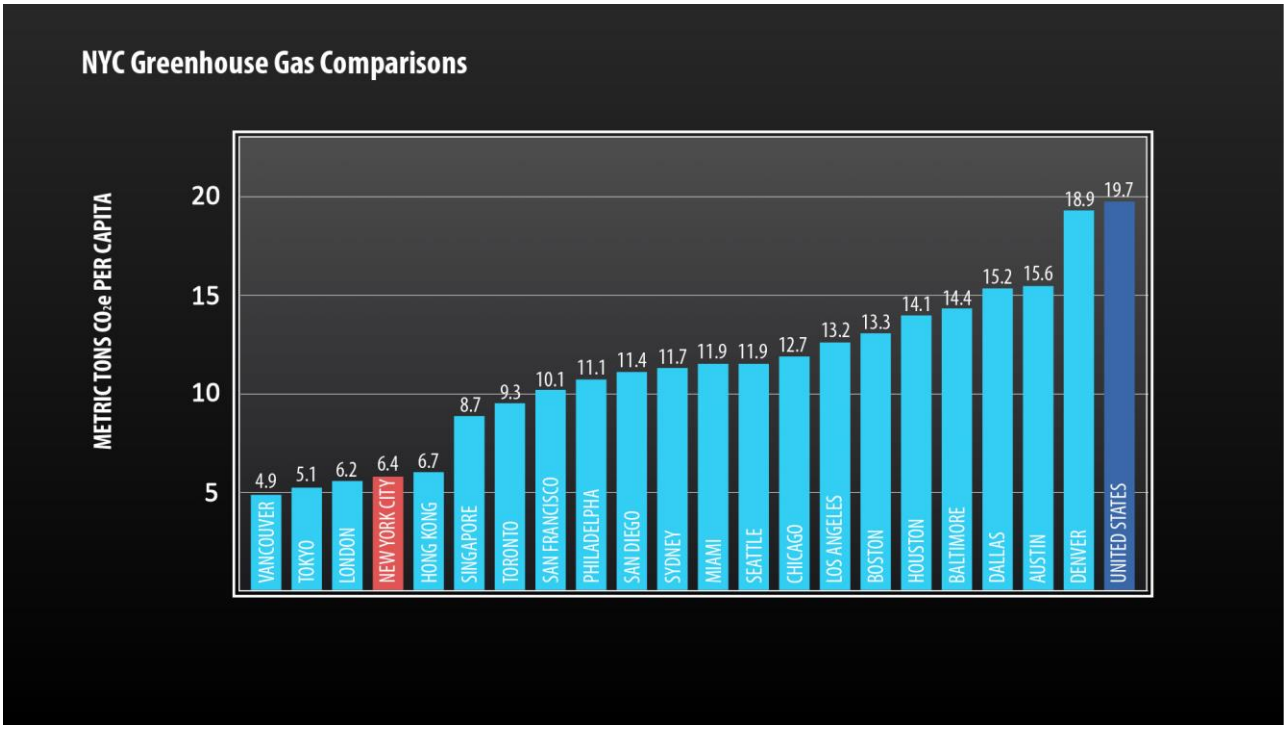

Figure 11.9. NYC Greenhouse Gas Comparisons to Other American Cities

If cities are smart in the kinds of energy and transport systems they build, and in the encouragement of high-density settlements with close proximity of people to shops, offices, amenities, and of course other people, then urbanization offers a real chance for a lower ecological footprint and lower carbon emission levels per capita. To get the best of what cities can offer in terms of combined low ecological footprint, high productivity, ease of movement, low congestion, and low level of time wasted, we have to look at how cities invest in the infrastructure and what choices they make.

III. Smart Infrastructure

Cities need to make choices about infrastructure. How will they handle energy, transport, water, and waste? Cities are complex systems, with millions of people interacting with each other and with industrial processes, and complex transportation, communication, water, sewerage, and waste systems. What kind of infrastructure is best for such systems? Cities that plan and design infrastructure well are able to maximize economic opportunities, improve quality of life, promote public health, and minimize the impact of the population on the natural environment, including through a relatively low-carbon economy.

One aspect of this core infrastructure includes transportation in densely settled areas. Relying on the automobile is a recipe for massive congestion, air pollution and high greenhouse gas emissions from the tailpipes of vehicles. There are much better options of public transport, such as buses, metro systems, and properly managed biking and walking routes. Some cities manage their transport well, and other

places are chaotic beyond imagination. Figure 11.10 shows commuters in Indonesia, packed to a life-threatening extent, and crowds entering a train station in the Philippines.

Figure 11.10. Commuters in Indonesia; Line to Enter a Train Station in the Philippines

Compare that with the picture in Figure 11.11 of one of the world's most sparkling, efficient, and dynamic metro systems in Seoul, South Korea. They have a huge, highly efficient system of hundreds of kilometers of rail lines and modern stations, shown in Figure 11.12. Many Chinese cities including Beijing have also built metro systems in recent years that serve them very well. This is a wise investment in mass public transportation, because the alternative for China would be huge explosion of automobile use, with all of the accompanying ecological and economic ills.

Figure 11.11. Seoul Subway Station

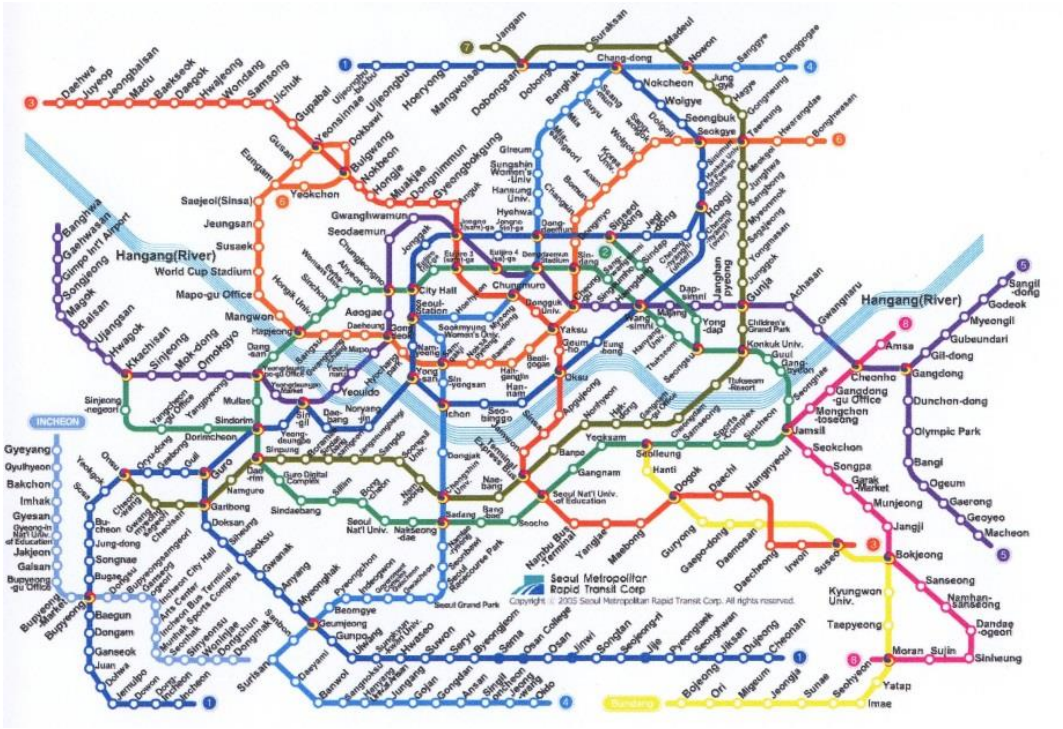

Figure 11.12. Seoul Metro Map

Bogotá, Colombia offers a well-known example of another kind of public transportation: bus rapid transit. It, in turn, followed another city, Curitiba, Brazil, which pioneered bus rapid transit in the 1970s. The idea is to encourage people to shift from automobiles to buses by giving buses favorable conditions of access on dedicated lanes. There is very frequent service, comfortable ways for people to get in and out of buses, and convenient waiting areas in stations. Many people are learning the lessons of Curitiba's rapid transit system and it consequently has emulators around the world.

Recently cities have started to make a full arc to their earlier patterns by making sure there are safe open areas for bicycling, and sidewalks and footpaths for walking. Europe has taken the lead with bicycle lanes and with innovative smart-card-based shared-bicycle systems. An example is the Vélib bike sharing system in Paris, which is leading to a surge in bicycling. Bicycles were once discarded in favor of the car, but because of congestion, expenses of managing automobiles, difficulties of parking, traffic jams, and individuals' concerns with their contributions to climate change and their personal health, people are seeking healthier ways to travel. Bicycling is returning to New York City, London, and other cities, and walking through Manhattan's dazzling shopping streets keeps the city vibrant and the population in better health.

Urbanites in countless cities around the world have recently come to appreciate the need for walking and cycling. The health costs of urban, sedentary life styles, including obesity, diabetes, and heart disease, are very high. Increasing numbers of urbanites are therefore eager to find ways to get back out onto the sidewalks and bike paths.

Public policies make a huge difference. In the 1950s, America doubled-down on the automobile with the Federal Aid Highway Act of 1956, which created a national interstate highway system, and with the encouragement of new roads and land development in the suburbs. This new road network had a very large economic impact, helping to move goods and people, and greatly facilitating suburban sprawl. The exodus from the densely populated central cities to the more dispersed suburbs contributed to America's remarkably high ecological footprint, and its extraordinarily high level of CO2 emissions per capita.

Now it is China's turn to choose, as rapid urbanization is bringing hundreds of millions of people into China's cities. China has the world's largest network of large cities, with more than 100 urban agglomerations of more than 1 million people each. China's record of encouraging automobiles versus public transit and walking is so far a mixed one. The cities themselves are increasingly automobile dependent. China is already by far the world's largest automobile market for new car sales, well over 20 million units per year. By the end of the decade, if not sooner, China will equal the US in the number of personal vehicles, around 250 million. That number could soon double or even more if China tries to emulate the US pattern of very high personal car ownership. (The US has around 250 million vehicles for 316 million people; the equivalent for China would be 1 billion vehicles for 1.3 billion Chinese people!)

Yet Chinese leaders also appreciate the dangers of such high car dependency in an already very crowded country. China is already courting massive air pollution, amongst the world's highest, as well as massive dependency on imported oil, unrelieved traffic congestion, and huge emissions of CO2 from petroleum use. This is why China is emphasizing public underground metro systems in all major cities, as well as fast rail rather than car-based highway traffic for inter-city transport.

Still, China's main urban transport choices still lie ahead. Will China emphasize walking, rapid bus transit, and densely settled cities, or sprawling automobile cities with an American-style ownership of personal vehicles? Will China continue to produce and use automobiles powered by internal combustion engines and imported oil, or will China aim to deploy electric or fuel-cell vehicles powered by low-carbon electricity? These choices lie ahead, and they will do much to determine China's own environmental sustainability as well as China's emissions of greenhouse gases, already the highest in the world for any country (though not the highest in per capita terms).

Water supplies for future cities

Another key aspect of infrastructure is water supply. Every big city has to provide drinking water for its population, as well as water for other uses including periurban agriculture, healthy ecosystems, and industrial processes. How to provide that water safely, fairly, reliably, sustainably and at reasonable cost, is a massive challenge. In New York City, this issue has been addressed for more than a century by tapping into two watersheds outside of the city, the Catskill and Croton watersheds, and then carrying the water from these watersheds to the city via huge underground pipes.

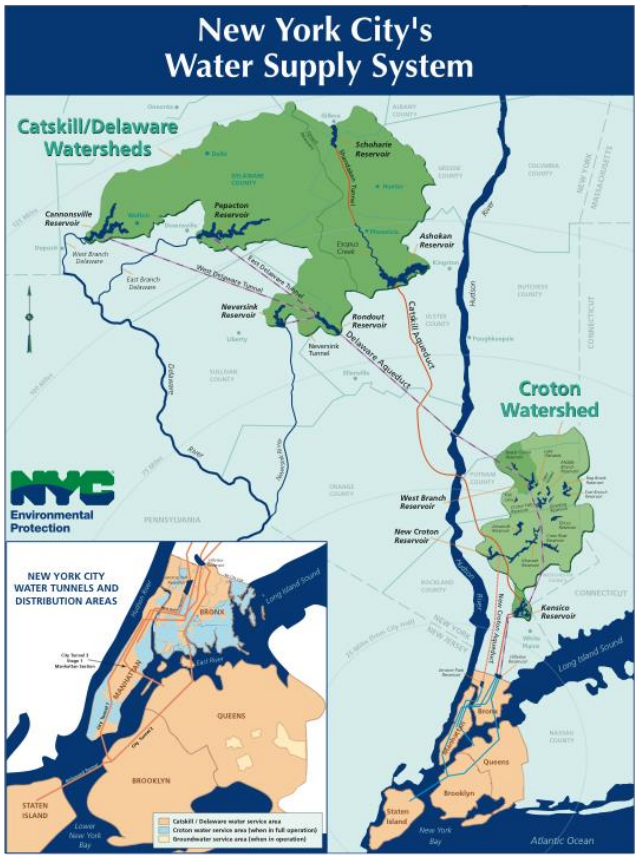

Figure 11.13. NYC's Water Supply System

About 15 years ago New York faced the problem that water coming from both of these areas was becoming polluted and increasingly contained chemical products from the outflow of industrial and farm activities in the areas nearby. The proposal at the time was to build new, multi-billion dollar water treatment sites to keep New York City water safe. This was an intuitive step; when the water is becoming less safe, the city should treat and clean it. Giant water treatment sites for a city of 8 million people (and an metropolitan area with around 20 million people) seemed inevitable, yet the New York City planners at the time had a clever realization. It would be safer and smarter to encourage the out-of-city areas near the watersheds to engage in fewer activities that endangered the water, so that these multi-billion dollar investments in water treatment would not have to be made.

Of course, those outlying areas had their own economic interests, so New York City realized that it would have to provide a *financial incentive* to both the Catskill and Croton watershed areas so that they would agree to desist from the kinds of farm and industrial activities (e.g. the use of fertilizers, pesticides, and chemical industry effluents) that were endangering New York City's drinking water. The city therefore negotiated a financial transfer to these outlying areas to compensate them for agreeing to cut back on the activities that threatened the NYC water supply. The arrangement proved to be ingenious. NYC preserved the safety and quality of its water supply. The watershed areas were

compensated for the lost economic opportunities. And both parties came out ahead, since what New York City paid the outlying areas was considerably less than what would have been the cost of building and operating giant water treatment plants.

This solution was of course specific for New York City. Every major urban agglomeration has to solve problems like this. New York's solution was a very interesting one, because it is very unusual and it had to be put together with a lot of creativity, insight, and good political management. It also highlights something very important: sustainable development is inherently an exercise in *problem solving*. It is about being creative and creating new models to combine economic, social, and environmental concerns.

The challenges of urban water supplies will become far more important, and even dire in many regions. The continued massive growth in urban populations and industry will raise the demand for water just as climate change, groundwater depletion, and the melting of glaciers due to global warming, will lead to reduced availability of fresh water, and greater competition between cities and farmers for scarce water supplies. Cities will also have to invest massively in urban water-related infrastructure.

Urban waste management

There is yet another aspect of urban infrastructure that is absolutely essential: waste management. Some waste, like paper and plastics, may be recyclable. Some of the scrap metal can be reprocessed. A lot of the urban waste is organic, such as rotted food. Some is highly toxic. How should cities handle all of this waste?

The typical way was to put it someplace, such as landfills. Many large cities around the world have built massive human waste dumps that are eyesores, nose sores, carriers of pollution, and sites of massive methane emissions as the organic wastes are decomposed by bacteria. Engineers have increasingly understood that simply filling land with this kind of waste is unwise and actually dangerous for the land, water supply, residents living nearby, and the greenhouse gas emissions of methane. Landfills also represent a huge missed economic opportunity, because a lot of what is placed into the landfills are potential inputs for recycling, industrial processing, and energy.

During the past 20 years, cities have experimented with many different kinds of recycling programs and innovative waste-to-energy facilities. For example, a facility in Ankara, Turkey (shown in Figure 11.14) sorts waste into plastics, organics, and metals. Some of the waste is composted for fertilizer, and some is recycled through industrial processes. The organic waste is fed into a large bio-digester unit where it is decomposed through bacterial action, releasing methane that is collected into large storage tanks and then used for electricity generation. The electricity is sold back into the urban grid, and the heat from the methane combustion is then fed into two pipes, one that runs to a series of greenhouses that grow food products, and the other to heat a new retail mall. Indeed the nearby mall could only be built after the landfill had been converted into the waste processing plant, thereby eliminating the noxious odors and gases that had previously made the area too polluted for other use. In short, what was once a

polluting stinking landfill is now a profitable recycling operation and source of waste-to-energy power. This kind of clever waste management is now being considered and adopted in many parts of the world.

Figure 11.14. Ankara Landfill Gas to Energy Facility

The Ankara facility is an example of "smart infrastructure" that reconfigures the urban metabolism to give off less pollution (including greenhouse gases) and to use materials and energy flows far more efficiently. Smart transport systems will more seamlessly connect public transport, car sharing, and walking, into an integrated system. Smart power grids will enable buildings with photovoltaic panels and electric vehicles to sell power to the grid as well as to draw power from it. Smart power grids will have time-of-day pricing and other management tools to enable the urban area to economize on power use and smooth the peaks of power generation. One underlying commonality of these smart systems will be the incorporation of extensive information technology – meters, monitors, machine-to-machine communications – to enhance efficiency and convenience.

IV. Urban Resilience

Cities can choose to be efficient and have low carbon emissions per capita through the right kind of infrastructure. Cities must also plan for a future of rising ecological shocks resulting from human-induced climate change and other environmental change. Even if humanity does everything it ought to do to head off the worst of climate change, we are still going to be living through many decades where average temperatures will be increasing, extreme climate-related events (including heat waves, storms, floods, and droughts) will increase in frequency, and sea levels will be rising. We will examine some of these threats in more detail in future chapters.

Infrastructure must be designed or refitted to be ready to face these threats. The massive flooding, loss of life, and horrendous damage in New Orleans caused by Hurricane Katrina in 2005 was due to a failure of infrastructure: the breaking of the levees that protected the low-lying city from flooding. Engineers had warned for years that New Orleans' levees were under threat, yet because of budget constraints the city put off the necessary reinforcements to the levee system. The levees burst, New Orleans flooded, and death and disaster ensued. Many cities around the world face this kind of risk, are being warned of it, and yet are still not taking it seriously or face financial constraints that make them unable to respond.

Pollution is likely to worsen as well, through combinations of changing weather patterns, higher proportions of automobiles per household, and an increase in industrial activity and other smog-related sources. Beijing residents were shocked in January 2013 when a major smog descended on Beijing that was so heavy it exceeded the global guidelines for particulate pollution by 20 or 30 times (Figure 11.15a). The smog brought much of the city to a halt. It was a wakeup call for China to take on its challenge of massive air pollution. Another intense smog crisis hit Beijing in January 2014 (Figure 11.15b).

Figure 11.15(a) Beijing Smog, January 2013

Figure 11.15(b) Beijing Smog, January 2014

The good news is that it is possible for cities to overcome such crises. New York City and London had similar smog attacks in the 1950s and 1960s. Since then, pollution regulations and a shift of energy use from coal to gas and other cleaner sources have cleared the air. Economists speak of the **co-benefits** of moving from coal to low-carbon energy: cleaner, safer air as well as the reduction of CO2 emissions.

Figure 11.16. Smog Attack in New York City (1966)

Earthquakes are another profound threat to many cities, those that lie in seismically active zones, typically at the boundaries of tectonic plates. The high earthquake zones are shown in Figure 11.17, which records earthquakes during the period 1977-1992. Many populous cities are located in the danger zones. Large cities at high risk include Los Angeles, Manila, Istanbul, Lima, Tehran, Santiago de Chile, San Francisco, Kunming, Nagoya, and Izmir.

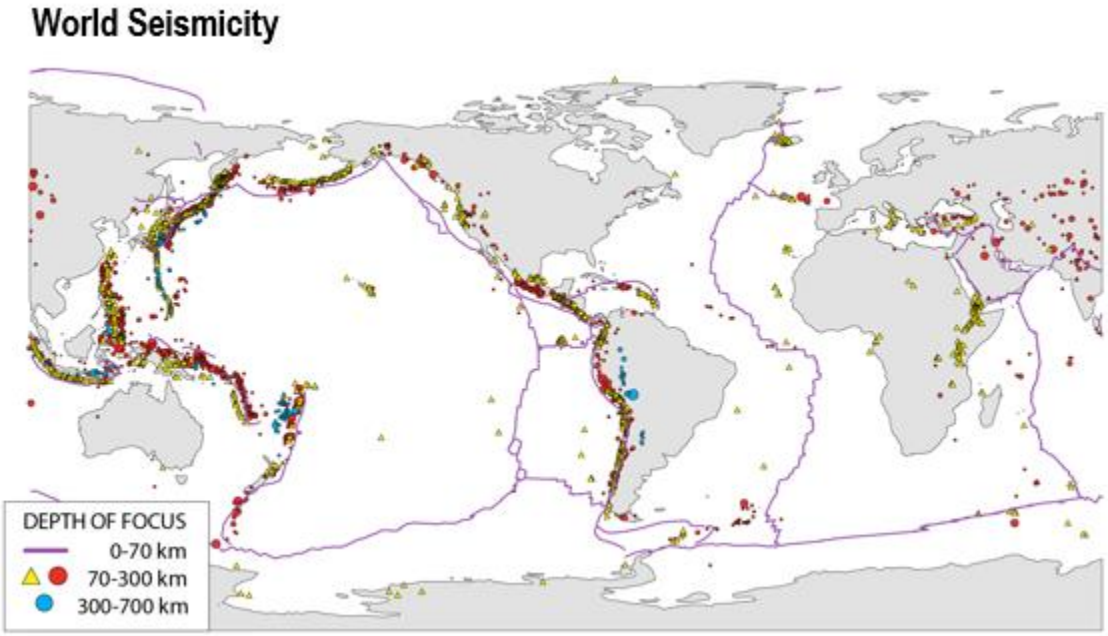

Figure 11.17. World Seismicity

Cities in earthquake zones can take preparations. Buildings can be reinforced at relatively low cost. When this is not done, tragedies ensue like the earthquake that hit Port-au-Prince, Haiti in January 2010, causing more than 100,000 deaths. Yet when a similar magnitude earthquake hit Kobe, Japan a few years earlier, the death toll was high at about 5,000, yet nothing akin to the deaths and devastation in Haiti. Haiti, a very poor country, had not taken earthquake precautions. The buildings were constructed of rock or brick and were not fortified against earthquake risk. Moreover, many settlements were on steep hillsides that suffered calamitous landslides following the earthquake. Better zoning can also help to prevent such massive deaths by preventing building and settlements in dangerous areas.

Figure 11.18. Port au Prince, Haiti After 2010 Earthquake

Floods are another risk for cities along the coasts, which is most of the large cities. Tokyo, Delhi, Mexico City, New York, Shanghai, Sao Palo, Dhaka, Calcutta, Buenos Aires, and Rio de Janeiro are all cities at risk of flash floods as a result of their topography, climate, and coastal proximity. Even the most sophisticated cities are not necessarily very well prepared. Figure 11.19 shows downtown Manhattan, one of the richest places on the planet, in darkness following the storm and flooding caused by Superstorm Sandy in October 2012. It turned out that New York City was not well prepared for such a major storm. Power stations were flooded; backup generators for hospitals were in the basements, quickly submerged in water. Major hospitals required emergency evacuations. Many New York City scientists and engineers had been predicting for years that New York would be highly vulnerable to a major storm surge and ensuing flood. The warnings had been given, but far too few preparations had actually been made.

Figure 11.19. Downtown Manhattan Post-Hurricane Sandy

Cities are now finding that they must protect themselves against a rising sea level. The Netherlands is probably the world's most experienced place in battling the sea level. Much of the country is significantly below sea level, so throughout its history, it has had to create special fortifications, dykes and other barriers to protect the land and habitation from floods. When the Netherlands experienced horrible episodes of flooding and loss of life in the 1950s, its engineers once again became world leaders in new creative solutions. This time they aimed not only to protect the land from the sea, but also to do so in a way that would protect the fragile ecology of the coastal ecosystems. In particular, the engineers realized that simply blocking the ocean from the land with traditional barriers would damage estuaries where the rise or fall of the tides is key to the ecology. The engineers therefore sought solutions that would allow for normal ecosystem functioning but also protect against major storms. Figure 11.20 shows the Eastern Scheldt barrier, an ingenious multi-billion dollar creation of Dutch engineering that allows for protection against storm surges using gates that close off during storms but that remain open at other times, thereby allowing for the normal ocean flow and tidal fluctuations.

Figure 11.20. Eastern Scheldt Barrier, the Netherlands

There are many ways in which ongoing climate change and other environmental changes are interacting with rising populations and more crowded cities to create new risks. It is important for every city to assess those changing risks in a detailed and rigorous way. There is not a fixed blueprint. Each city has distinctive topography, population densities, and vulnerabilities. Each city needs to assess its particular challenges. The United Nations Population Division has made a valuable classification of the hazards facing the world's major cities; this includes tropical cyclones, droughts, earthquakes, floods, landslides and volcanoes as major hazards that need to be modeled, understood and anticipated by each city.

These hazards are on the rise. This is consistent with the idea that we have entered a new era, the Age of the Anthropocene or the Age of Sustainable Development. We need forward-looking planning that combines ecology, engineering and public policy to keep our cities resilient and desirable places to live in the 21st century.

V. Planning Sustainable Development

Sustainable cities are green and resilient to hazards. They are green in the sense that they have a low ecological impact, low greenhouse gas emissions per capita, and a pleasant and healthful environment for people to live and work, including safe and clean air, accessible parks, and ways for people to remain active and healthy through walking, bicycling, and other means. Sustainable cities are resilient because they recognize and plan ahead for the shocks they may experience in the future.

My own city, New York City, has been making a major effort to become green and resilient, one that has become even more urgent in the wake of Superstorm Sandy, which has exposed the extent of the risks that the city faces. That single storm caused an estimated $60 billion or so in damages! Earlier and more effective planning might have saved many lives and tens of billions of dollars.

Two very green US cities, Portland and Seattle, were perhaps the first in the US to adopt comprehensive sustainability plans and they have a rightly deserved reputation for great environmental sensitivity and foresight. (See the timeline in Figure 11.21.) Back in 1994, they looked at how they could reduce greenhouse gas emissions and become more resilient to climate change. Other cities began this kind of serious planning, and New York City was also relatively early in adopting its PlaNYC in 2007. Copenhagen followed with a major program in 2009, Rotterdam in 2010, and various cities around the world are now adopting similar sustainable development plans. As the UN itself adopts Sustainable Development Goals, this hopefully will spur thousands of cities around the world to do the same. Indeed, there is a powerful argument that Sustainable Cities should be one of the major Sustainable Development Goals, thereby sending a clear signal to mayors and city governments around the world that sustainable development is a subject for their focused attention, not one that can or should be left to the national government!

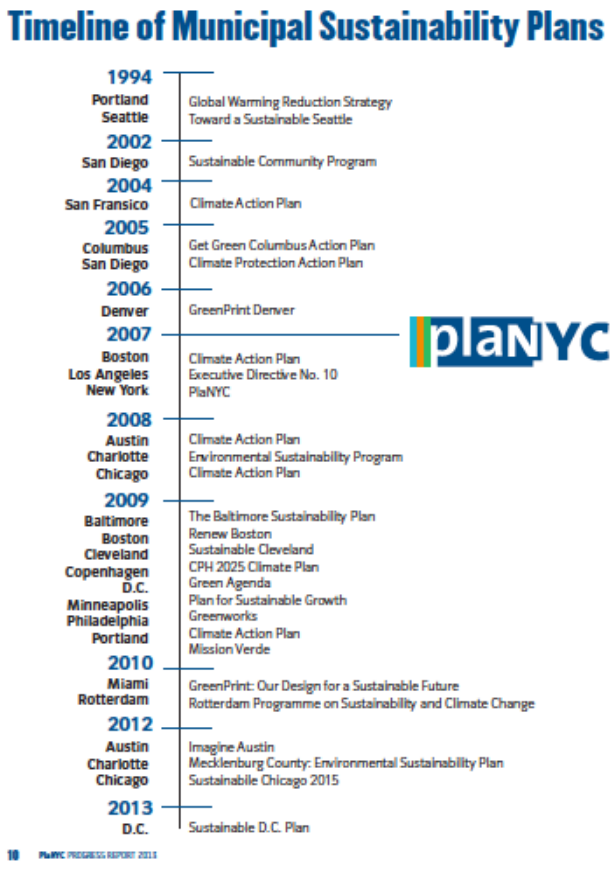

Figure 11.21. PlaNYC's timeline of Municipal Sustainability Plans

What does New York City's PlaNYC call for? It has 10 Sustainable Development Goals shown in Figure 11.22. Goal 1 is to anticipate a rise of roughly 1 million in New York City's population by 2030, and to therefore plan for more affordable housing and neighborhoods. Goal 2 is to create more parks and public spaces, which are vital for the quality of life and public health. Goal 3 is to clean up polluted areas, the so-called "brownfields." Goal 4 is to improve the quality of waterways for transport,

recreation, water safety, and coastal ecosystems. Goal 5 is to ensure the safety and adequacy of New York City's water supply. Goal 6 is a robust, resilient, efficient, low-cost, and ecologically sound public transportation system. Goal 7 is energy efficiency and reliability. Goal 8 is to improve air quality. Goal 9 is to manage solid wastes from the traditional landfill model to new approaches such as waste-to-energy and more recycling. Goal 10 is to reduce the city's greenhouse gas emissions.

New York's per capita CO2 emissions are already less than a third of the US national average, but at around 6 tons per capita, NYC's emissions are still far higher than the very low level of CO2 emissions the world will need to achieve by mid-century. As we shall note later, global emissions should probably not exceed 1.7 tons per person as of 2050, if the world is to keep the rise of global temperatures below 2-degrees centigrade, as the world's governments have agreed. Thus, New York City is going to have to make major efforts in reducing CO2 emissions, and the rest of the US will have to do even more.

Figure 11.22. PlaNYC's Sustainable Development Goals for New York

As part of PlaNYC, New York City has adopted a goal of reducing its carbon dioxide emissions by 30% by the year 2030. As shown in Figure 11.22, PlaNYC anticipates several means to achieve this goal, including more energy efficient buildings, cleaner sources of energy, more sustainable transportation systems, and improved waste management. NYC's emissions goal is notable for a number of reasons, including the specifics of the plans as well as the fact that New York City is moving forward on emissions reduction even while the US Federal Government remains gridlocked on climate policy.

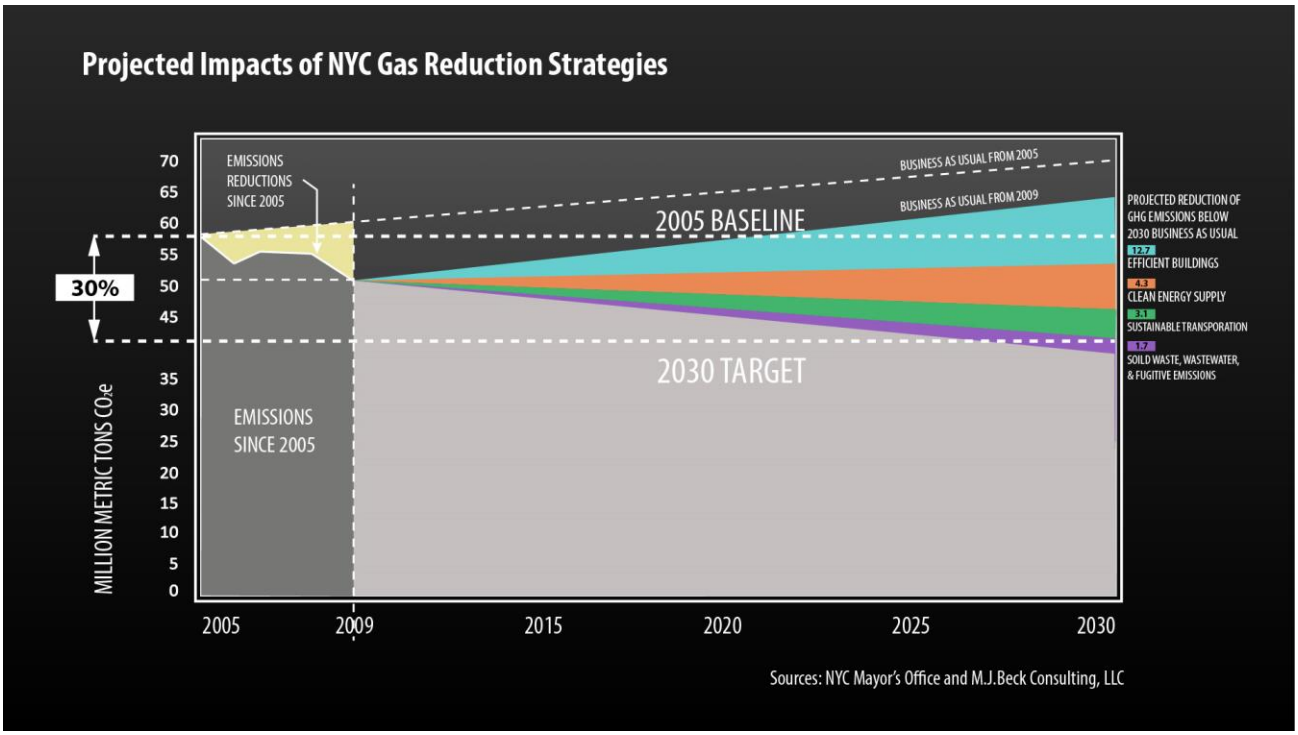

Figure 11.22. Projected Impacts of NYC Gas Reduction Strategies

The New York City action plan identifies four major categories for emissions reduction. The first is a reduction of CO2 emissions in the heating, cooling, and ventilation of buildings. This can be achieved through a variety of means, including better air seals and insulation, natural heating and cooling, use of heat pumps in place of boilers and furnaces, and the co-generation of electricity and heat by power stations.

The second is a cleaner energy supply, one that moves away from fossil fuels and towards renewable energy such as solar arrays on New York's roofs. New York also has plans to bring in more hydroelectric power from Canada through long distance transmission lines as part of its strategy for reducing CO2 emissions. Offshore wind power is a third large-scale possibility.

The third component of emissions reduction is sustainable transportation. Vehicle fleets should be transitioned to electrification (e.g. battery-powered or fuel-cell-powered vehicles), and transportation should be increasingly directed towards mass transit, walking, and bicycling.

The fourth category is improved management of solid wastes. By moving from landfills to recycling and waste-to-energy systems as in Ankara, CO2 emissions are reduced by the lower methane emissions at landfills and the harnessing of energy in the organic waste.

A last and extremely important part of PlaNYC is the use of new metrics. The dashboard in Figure 11.23 describes for each category of goal: a specific quantification of what the goal is supposed to accomplish, the most recent data, and whether the city is making progress or falling further behind.

CATEGORY	METRIC	2030 TARGET	FIGURE FOR MOST RECENT YEAR	TREND SINCE BASE YEAR
HOUSING AND NEIGHBORHOODS	Create homes for almost a million more New Yorkers while making housing and neighborhoods more affordable and sustainable			
	Increase in new housing units since January, 2007	314,000	125,837[1]	↗
	Total units of housing in NYC	INCREASE	3,415,500[1]	↗
	% of housing affordable to median-income NYC household	INCREASE	60.0%[2]	↘
	Vacancy rate of least expensive rental apartments	INCREASE	1.0%[3]	↗
	% of new units within a 1/2 mile of transit	> 70%	93.9%[2]	↗
	Residential building energy use per capita (source MMBTU) (3 yr rolling avg)	DECREASE	47.28[2]	↘
PARKS AND PUBLIC SPACE	Ensure all New Yorkers live within a 10-minute walk of a park			
	% of New Yorkers that live within a 1/4 mile of a park	85%	76.3%[2]	↗
BROWNFIELDS	Clean up all contamined land in New York City			
	Number of vacant tax lots presumed to be contaminated	DECREASE	1,500 – 2,000[1]	NEUTRAL
	Number of tax lots remediated in NYC annually through the Brownfield Cleanup Program	INCREASE	11[1]	↗
WATERWAYS	Improve the quality of our waterways to increase opportunities for recreation and restore coastal ecosystems			
	Fecal coliform rates in New York Harbor (Cells/100mL) (5 yr rolling avg)	Decrease	42.97[1]	↗
	Dissolved oxygen rates in New York Harbor (mg/L) (5 yr rolling avg)	INCREASE	6.5[1]	NEUTRAL
WATER SUPPLY	Ensure the high quality and reliability of our water supply system			
	Number of drinking water analyses below maximum contaminant level	100%	99.9%[2]	↗
	Water usage per capita (gallons per day) (3 yr rolling avg)	DECREASE	124.46[1]	↘
TRANSPORTATION	Expand sustainable transportation choices and ensure the reliability and high quality of our transportation network			
	Sustainable transportation mode share (Manhattan CBD bound commute)	INCREASE	74%[2]	↗
	Change in transit volume minus change in auto traffic volume since 2007	POSITIVE	0.9%[4]	↗
	Vehicle revenue miles (Miles transit vehicles travel in revenue service)	INCREASE	915,096,265[2]	↗
	% of bridges meeting a state of good repair (FY)	100%	41.4%[2]	NEUTRAL
	% of roads meeting a state of good repair (FY)	100%	73%[1]	↗
	% of transit station components meeting a state of good repair	100%	71%[1]	↗
ENERGY	Reduce energy consumption and make our energy systems cleaner and more reliable			
	Greenhouse gas emissions per unit of electrical power (MWh)	DECREASE	657.69[2]	↘
	System reliability: CAIDI (Customer Average Interruption Duration Index)	DECREASE	2.39[1]	↗
	System reliability: SAIFI (System Average Interruption Frequency Index)	DECREASE	1.04[1]	↘
	Energy use per capita (source MMBTU) (3 yr rolling avg)	DECREASE	123.20[2]	↘
AIR QUALITY	Achieve the cleanest air quality of any big U.S. city			
	City ranking in average $PM_{2.5}$ (3 yr rolling avg)	#1 (LEAST)	5.67[2]	↘
	Change in average $PM_{2.5}$ (Year-on-year % change in 3 yr rolling avg)	DECREASE	-9.4%[3]	↘
SOLID WASTE	Divert 75% of our solid waste from landfills			
	Percentage of waste diverted from landfills (includes fill)	75%	54%[2]	↘
CLIMATE CHANGE	Reduce greenhouse gas emissions by over 30%			
	Increase the resilience of our communities, natural systems, and infrastructure to climate risks			
	Greenhouse gas emissions ($MtCO_2e$)	DECREASE 30%	53,358,868[2]	↘
	Greenhouse gas emissions (100% = 2005 GHG emissions)	70%	84%[2]	↘
	Greenhouse gas emissions ($MtCO_2e$ per GCP ($M))	DECREASE	93.82[2]	↘
	Greenhouse gas emissions ($MtCO_2e$ per capita	DECREASE 30%	6.47[2]	↘

1 Results are for FY or CY 2011
2 Results are for FY or CY 2010; data is only available with a lag
3 Data updated every three years
4 Updated data not available

Figure 11.23. PlaNYC Sustainable Development Dashboard

The fact there is a lot of green on the dashboard in the final column is an indication of some progress. Yet there are also many areas that require enhanced policy efforts. Dashboards like this on water supplies, transport, CO_2 emissions, energy, and on the other dimensions of sustainable development, will help governments to remain focused on sustainable development goals, and will help civil society to keep the governments accountable for their promises. The indicators help to create a feedback from measurement to policy action or policy correction, thereby accelerating the transition to sustainable development.