Energy for Sustainable Development 23 (2014) 46–58

Contents lists available at ScienceDirect

Energy for Sustainable Development

New York City can eliminate the carbon footprint of its buildings by 2050

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ARTICLE INFO

Article history:
Received 11 March 2014
Revised 23 June 2014
Accepted 25 June 2014
Available online 12 August 2014

Keywords:
Climate change mitigation
Energy modeling
Scenario analysis

ABSTRACT

Climate scientists agree that a drastic reduction in carbon emissions in the coming decades is necessary to avoid major disasters due to global warming. Using computer modeling, citywide data sets, and insights from experts in the building community, we show how New York City (NYC) can lead the way toward climate change mitigation by improving the efficiency of its building sector (which is currently responsible for 75% of its greenhouse gas emissions) by 2050 using technologies available today. Though the total elimination of greenhouse gas emissions is possible only with the use of carbon-free energy sources, emissions can be reduced by over 60% from energy efficiency measures alone. After eliminating fuel combustion, carbon-free electric energy roughly equal to total electric energy used in 2010 would be consumed, but with a peak demand 60% higher than today's, establishing requirements for generation capacity and storage. Our economic analysis of the building measures shows them to be essentially cost-neutral over time.

Introduction

Nearly all climate scientists (Allen et al., 2009; Hansen et al., 2013; Meinshausen et al., 2009) tell us that to avoid catastrophic global warming we must dramatically reduce carbon emissions in the global economy by 2050. For developed countries, emissions must be at least 80% below current (2005–2010) levels by 2050 to limit the atmospheric carbon dioxide (CO_2) concentration to less than 450 ppm, which could maintain global temperature increases of less than 2 °C (IPCC, 2013; Union of Concerned Scientists, 2007).

A key component of realizing this reduction is the radical reduction of carbon emissions from the built environment. We show that when deep efficiency improvements are combined with carbon-free electric energy, complete elimination of these emissions is possible. In determining the feasibility of this goal, we have focused on what is possible in the building sector with presently available technology. We refer to reduction "measures" rather than "proposals" to indicate that we do not recommend any specific steps. Rather, we construct one illustrative scenario to demonstrate feasibility. An actual future reaching our targets will employ a much wider range of specific reduction measures. Also, the buildings we examine are taken as average in performance. In reality, some buildings will not be able to meet our goals, but others, especially in new construction, will exceed these goals substantially.

We did not examine year-by-year developments over the coming decades. Instead, we examined the city as a whole, and looked in detail only at the two endpoints, 2010 and 2050. We believe this allows us to sketch a credible future that meets the reduction goal. However, significant development of trajectories will be required to serve as a basis for specific policy proposals (City of New York, 2013).

Material and methods

Building sector emissions in 2010

We created computer models for eight buildings representative of NYC's building stock, scaled their energy use and emissions to reflect citywide data, and tuned the models to match actual consumption and emissions in 2010.

Approach

Since 2007, NYC has maintained a detailed accounting of greenhouse gas (GHG) emissions as part of plaNYC (City of New York, 2011). In this work we used the September 2011 release of the "Inventory of NYC Greenhouse Gas Emissions" (Inventory) to provide a detailed picture of emissions in 2010, which we used as our base year. Our study was restricted to Scope 1 and Scope 2 emissions (California Air Resources Board, 2010) as reported in the Inventory. Scope 1 covers direct emissions, such as from boilers and cars, and Scope 2 covers emissions due to energy consumed in the city but generated elsewhere, such as electricity. Scope 3, which we omitted, includes items such as the emissions associated with food and goods consumed within the city but produced elsewhere, and jet fuel loaded into airplanes at the city's airports. We

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http://dx.doi.org/10.1016/j.esd.2014.06.006
0973-0826/

focused on buildings since they are responsible for 75% of the city's greenhouse gas emissions (Inventory).

We described NYC buildings in a way that allows us to calculate total current and future emissions of greenhouse gases. To do this we selected eight types of buildings that spanned the typical structures of the city. We then defined the characteristics of these building types, using data from the NYC Department of City Planning's PLUTO database (NYC Department of City Planning, 2011) on existing city buildings to determine how many actual buildings correspond to each of our eight building types, and what total citywide floor area each type occupies. This allowed us to scale the fuel, electricity usage, and associated emissions of individual buildings up to citywide levels for comparison with Inventory values. We also determined the dimensions for each building that would make them most representative of that building type as described below.

We then prepared detailed models of each of these buildings using the eQUEST building energy simulation program (eQUEST, 2013), and adjusted the thermal and energy characteristics so that each building's energy use corresponded to current energy use estimates, and the total citywide fuel use and CO_2 emissions from buildings agreed with the Inventory.

Building types

The Inventory provides data on four categories of buildings in NYC: residential, commercial, industrial, and institutional. Given the limitations on available data, we subsumed all nonresidential buildings into one category, which we refer to as "commercial". Table 1 presents the basic characteristics of our eight building models.

Building characteristics and populations

Several steps were needed to ensure that each of our models represented a significant amount of floor space in NYC, but that none of that space was represented by more than one model. Specific ranges of data such as building area, dimensions, and number of floors were assigned to each building type, such that each of the building lots in PLUTO could be allocated to one of the eight models. Each record in PLUTO corresponds to a single tax lot, which often contains more than one building. In that case, the total floor area gives the correct number for the lot, but other characteristics, such as height and footprint, describe the "principal building" on the lot. Our models match the characteristics of the "principle building," but our scaling was done using the total floor area for the lots.

Although PLUTO is based on NYC tax and real estate sales records, we know that it must contain errors. However, there is no comparable data against which to test it, and it is used to validate less accurate data sets (Kontokosta, 2012). Given the many uncertainties implicit in projecting over 35 years, we have taken the PLUTO data as accurate.

We used these PLUTO data fields to determine the building type representing the entire lot. This allowed us to assign each lot to one of the eight building types and derive total citywide floor areas corresponding to each type. Some of our criteria follow, and are summarized in Table 2 and Fig. 1.

- Lots were deemed residential if 50% or more of the total building floor area was listed as residential and commercial if less than 50%.
- Based on PLUTO data, buildings with seven stories or fewer were considered "low-rise", and those with eight or more stories, "high-rise."
- Smaller residential buildings were classified as row houses if classified as "attached" or "semi-attached" in PLUTO, and as 1–2 family houses or residential low-rise (based on size) if "detached."
- PLUTO contains no information regarding building construction materials, and no other citywide information was readily available. To distinguish construction types, we used "year built" as a proxy. For the residential sector, the more modern window wall architecture was assigned to buildings constructed in 2000 or later, as long as they had 12 or more floors. All other residential high-rise buildings are considered masonry. For commercial buildings, all buildings constructed before 2000 were designated as masonry, while high-rise buildings constructed during or after 2000 were designated as curtain wall. The selection of 2000 as a cut-off year was based on discussions with members of the construction community, but is clearly a surrogate since curtain wall construction has been in use since the 1960s.

With these assignments complete, the eight building models were refined by evaluating the average values of the number of floors and, for residential buildings, dwelling units from PLUTO data for each building type. The floor area per building in each category was found by considering all the buildings in that category and dividing the total floor area by the number of buildings. These data are shown in Table 1.

The shape of the buildings varied to match the data. For the row house and all commercial buildings, we adjusted the frontage and depth to give a rectangular footprint and floor area that agreed with these overall average floor areas. For the 1–2 family house, we adopted an L-shaped footprint, and for the other residential buildings, a U-shaped footprint, with dimensions chosen so that the frontage and depth agreed with the average values of the principal buildings for each type, while the areas agreed with the overall averages for that type. The "L" and "U" shapes were necessary to ensure that all rooms in residential buildings had windows.

Building simulation

eQUEST is a widely used and comprehensive building simulation modeling tool. Able to represent many construction types, equipment choices, and building characteristics, it calculates the thermal energy gained or lost and the equipment operations necessary to maintain specified indoor conditions. The software calculates the total energy used over one year using Typical Meteorological Year weather files (TMY2; Crawley and Huang, 1997) by performing 8760 energy balances for the building, one for each hour of the year.

The construction techniques modeled in each building type were typical for such buildings, but were adjusted to calibrate energy use to

Table 1
Characteristics of building models.

Type	Stories above ground	Area above ground		Residential units	Construction
		m^2	sf		
1–2 family house	2	126	1352	1–2	Wood frame
Row house	3	185	1992	2	Masonry
Low-rise residential	4	795	8558	9	Masonry
Masonry high-rise residential	15	11,424	122,972	117	Masonry — punch windows
Window wall high-rise residential	26	17,168	184,793	142	Floor-to-ceiling glazing
Low-rise commercial	2	1409	15,170	N/A	Masonry
Masonry high-rise commercial	17	21,298	229,249	N/A	Masonry — punch windows
Curtain wall high-rise commercial	21	17,912	192,808	N/A	Steel frame/curtain wall