MA681 Research Project Proposal

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Data I will be using:

<https://data.boston.gov/dataset/greenhouse-gas-emissions/resource/d2b83ed7-ce3c-448d-b20a-971ed911d9e7>

This data set is shows the total GHG emissions by fuel type, municipal department and fiscal year for all Boston Local Government Operations.

The dataset has 8 variables, 6 of which are of importance and will be used in statistical methods. These variables of interest include: Department Longname, Department, Sector, Fuel Type, Fiscal Year (2005-2018), GHG Emissions (CO2e). The data has 1014 observations with some NA’s.

Question or questions I will try to answer: Does a particular type of fuel used have a greater contribution to GHG emissions? Do any departments/sectors in particular emit more GHG emissions than other departments do? To what extent are vast differences in GHG emissions present across the years 2005-2018 for certain fuels? Do some fuels contribute more to GHG emissions than other fuels over a fixed period of time?

Main model/predictive analysis: Multiple Linear Regression model with GHG emissions as dependent variable and the rest as independent

Types of statistical techniques that might be used: hypothesis testing, bootstrapping and confidence intervals, multiple linear regression/ANOVA

(although I did come across a similar dataset with lot more observations and variables, I feel this dataset focuses more on the key ideas I would like to highlight. However, I would like to discuss the possibility of using the other one instead too: <https://data.ca.gov/dataset/state-agency-co2e/resource/e5f58431-351b-41ba-a170-20d6df41701a>)

Main storyline/points about claims in CAP about ghg emissions:

We start first w/ 2007 CAP Menino’s: **executive order to meet Kyoto protocol and 80% goal by 2050; About 78 percent of Boston’s greenhouse gas emissions are related to buildings, their heating and cooling and electricity; 139 schools and other buildings that are part of the Boston public school (BPS) system account for about 17 percent of the greenhouse gas emissions from municipal operations of the City of Boston**; Boston Transportation Department (BTD) is converting all City traffic signals to LEDs (light-emitting diodes), which use about 90 percent less energy than incandescent bulbs and save taxpayers about $400,000 annually; Mayor’s executive order on climate action requires that, by 2012, at least 15 percent of electricity purchased by municipal departments shall come from renewable sources; **Transportation accounts for about 18 percent of Boston’s greenhouse gas emissions. Most of this is from automobile traffic**; 2005, Mayor Menino announced that all new vehicles purchased by the City of Boston will be alternative fuel vehicles or the most fuel-efficient vehicles available, a directive reinforced in the recent executive order

2011 CAP Menino’s: In 2009, the Boston community was responsible for the emission of about 8.2 million tons of greenhouse gases (measured as carbon dioxide equivalent, eCO2). Twothirds of the emissions are tracked by the measurement of energy actually used; the other one-third of emissions come from sources that require estimates based on models and other approximations; Roughly half of the emissions come from commercial, industrial, and institutional sources, one-fourth from residences, and one-fourth from transportation or three-fourths of emissions come from building use and one-fourth comes from transportation; The 2009 total was slightly less than the 2005, 2007, and 2008 emissions, but greater than the 2004 and 2006 totals; Given fluctuations in weather from year to year that affect energy use, the 2009 economic recession, and other sources of variation, there is no clear sign yet of an overall change in Boston’s GHG emissions; **In 2007, Mayor Menino set the goal of reducing municipal GHG emissions 7 percent by 2012;** Climate Action committees recommended that the Boston community reduce its overall greenhouse gas emissions 25 percent by 2020 and 80 percent by 2050; The Economic Benefits of GHG Reduction - Climate mitigation will bring economic gains to Boston. After accounting for initial costs, residents, businesses, and institutions will have total net savings of $2 billion in energy costs by 2020. In addition, Boston will benefit from improved public health and reduced health care costs from reductions in air pollution, less traffic congestion, and a safer, cleaner environment; Climate mitigation will also bring jobs. The Commonwealth of Massachusetts estimates that implementation of its plan will create 42,000 to 48,000 jobs in the entire state. City Government is establishing programs to ensure that Boston residents and businesses are prepared to take advantage of those job opportunities; 2008 GHG emissions: 0.2 million tons eCO2 (2 percent of community total) 2020 reduction goal: 25 percent Primary indicators: Total electricity, natural gas, diesel fuel, and gasoline use **In fiscal year (FY) 2009, Boston’s municipal operations were responsible for the emission of about 190,000 tons of GHGs.** Energy needs included heating and electricity for the city’s schools, libraries, police stations, community centers, traffic and street lights, and other public facilities and equipment, and gasoline and diesel fuel for school buses, police cars, fire trucks, and other municipal vehicles. Overall, buildings and streetlights accounted for about 80 percent of GHG emissions, and transportation for 20 percent; Boston City Government has met the 2012 goal established by the Mayor (Kyoto). In FY2010, unadjusted GHG emissions from municipal operations were 10 percent lower than those in FY2000. Adjusted emissions, which include reductions for municipal purchasing of renewable energy credits and for the use of biodiesel were even lower. (Because the earliest reliable inventory of municipal emissions is from FY2000, the FY1990 baseline is assumed to be roughly the same, in line with calculations and assumptions by the Commonwealth of Massachusetts and the Leadership Committee). **One major contributor to municipal GHG reduction was the replacement of old boilers that ran on fuel oil with more efficient boilers—often combined heat-and-power (CHP) units—that ran on natural gas, which produces fewer GHGs per BTU than fuel oil**; **Boston City Government intends to reduce the GHG emissions from municipal operations at least 25 percent below 1990 levels by 2020. Because GHG emissions are roughly proportional to energy use, successful completion of the Energy Reduction Plan will mean that the goal of 25 percent GHG reductions for municipal operations will be met by 2015 or 2016;** all new municipal buildings meet LEED Silver standards, which will have significant long-term effects (2007); **Green schools - The Boston Public Schools (BPS) have been leaders in energy efficiency since the 1980s and contributed half of municipal GHG emissions reductions from 2005 to 2010;** In addition to the savings in buildings, the Energy Reduction Plan specifies a 40-percent reduction in the energy use of street lights. In the next five years, City Government, supported by funding from NStar, will place more-efficient LED bulbs in 29,000 of its 64,000 electric street lights; municipal departments must purchase hybrid, alternative-fueled, or high-efficiency vehicles whenever possible (2007). Hybrids in the municipal fleet now number over 80. **The Energy Reduction Plan lays out additional measures to reduce energy use for municipal transportation 20 percent between 2010 and 2015;**

2014 CAP Walsh (second update to the original 2007 plan) : Emissions from City government operations have been reduced by almost 25 percent since 2005;

In Boston, City-owned buildings account for nearly three-quarters of carbon emissions from local municipal operations. With this in mind, Boston has been working to reduce the carbon footprint of its buildings. **It reports that emissions from local municipal operations in 2017 were 41 per cent less than in 2005, exceeding Boston’s goal set for 2020, which was to reduce municipal ghg emissions by 25% by 2020.** (<https://www.smartcitiesworld.net/news/news/bostons-climate-plan-update-targets-major-source-of-emissions--buildings-4672>)

2019 CAP Walsh: Boston reached its 2020 carbon target for municipal operations (ghg report); In 2011, the City of Boston set carbon reduction goals of 25 percent by 2020 and 80 percent by 2050 below 2005 levels; Our carbon neutrality goal means that Boston is fulfilling our commitment to the Paris Climate Agreement and leading efforts to keep global warming under 1.5 degrees Celsius; **By 2017, the City of Boston reduced emissions from municipal buildings and fleets by more than 40 percent below 2005 levels**. **Based on the progress the City expects to make in energy efficiency and renewable energy, this Plan increases our reduction goal for municipal operations from 50 percent to 60 percent by 2030;** The City of Boston will strengthen its new municipal building requirements to a multi-tiered Zero Net Carbon (ZNC) standard. This standard will significantly reduce or completely eliminate the use of fossil fuels in future City buildings. By implementing this multi-tiered ZNC standard, along with high-efficiency climate and lighting systems, and efficient building enclosures, consumption of energy generated by fossil fuels will be significantly reduced, if not totally eliminated. **Because municipal buildings account for threequarters of carbon emissions from local municipal operations, higher standards for building energy performance are essential to reach the Mayor’s goal, and prepare Boston and its residents for future challenges; Renew Boston Trust uses energy performance contracts to finance energy efficiency measures in municipal buildings; Fuel used to power the City of Boston’s vehicle fleet accounts for 0.5 percent of Boston’s total emissions, and 25 percent of the local government emissions.** The City will work to accelerate the deployment of zero- and low-emissions vehicles in municipal fleets. Zero-emission vehicles (ZEVs)—such as some plug-in hybrid vehicles, battery electric vehicles, hydrogen fuel cell vehicles—generate fewer emissions than gas- and diesel-powered vehicles and don’t produce tailpipe pollution; **Currently, 30 percent of municipal vehicles in the Central Fleet are electric vehicles or hybrids. Eliminate up to 25 percent of carbon emissions from municipal operations (benefit);**

GHG Inventory: **Boston Local Government Operations emitted 132 thousand metric tons of GHGs in 2017, a 41% reduction from 2005, including renewable energy credits (RECs), and a 33% reduction without RECs**. In 2015, the City of Boston already met the 2020 goal of reducing municipal GHGs by 25% below 2005 levels, five years ahead of schedule; GHGs reported in the waste sector refer to emissions from wastewater treatment only and account for less than 1% of total emissions (17 thousand tCO2e). All, or almost all, of Boston’s solid waste is sent to Waste-To-Energy (WTE) incineration plants that feed the electricity grid, so emissions are counted as part of regional electricity generation within this inventory. This means solid waste emissions are embedded in the emissions from electricity used in buildings and transportation; **The inventory employs measured data, projections, models, and, where data is scarce, best estimates. All of these sources have some level of uncertainty, most of which have not been quantified. Furthermore, the inventory is frequently revised as new and better data become available, models are improved, new methodology is developed, and international standards evolve. For these reasons, longer term trends are likely more reliable than absolute numbers or year-to-year changes;** Local Government Operations (LGO) inventory **calculates all greenhouse gas emissions generated by municipal operations in the City of Boston. This includes the burning of fuels in the City’s facilities, vehicles, and other equipment, and the energy used in municipal buildings, vehicles, parks, street lights, and traffic signals. The LGO inventory is based on the ICLEI greenhouse gas reporting protocol for local government operations. Emissions from the Boston Housing Authority, the Massachusetts Water Resources Authority (MWRA), and the Boston Planning and Development Agency (BPDA) are not included in the inventory. Those from the Boston Public Health Commission (BPHC) and the Boston Water and Sewer Commission (BWSC) are included;** LGO should be considered to be largely overlapping but not completely contained within the Citywide inventory; FY17 municipal emissions are down more than 33% from 2005, before including adjustments for the purchase of renewable energy credits. Adjusting for the City of Boston’s purchases of Green-E Certified Renewable Energy Certificates (RECs) equal to approximately one fourth of our total electricity consumption, emissions in FY17 are down nearly 41% from 2005 levels; emissions by energy source: **Boston’s LGO emissions are dominated by building energy consumption. Electricity and gas consumption by buildings each make up about one third of total GHG emissions. Transportation fuels, diesel and gasoline, together make up one fourth of total municipal GHG emissions. Similar to the community-wide inventory, Boston’s municipal operations GHG inventory trends are driven by a number of external and internal factors. Diesel consumption is continuing to decrease as Boston Public Schools switches its fleets from diesel- to propane-powered school buses. The continued downward trend in the regional electric grid emissions rate also contributed to reduced emissions;** **departmental emissions: As the department with the largest building portfolio, and the second largest vehicle inventory (after Boston Police Department), Boston Public Schools (BPS) represent the largest source of municipal emissions. BPS owns and operates approximately 12 million of the City’s 16 million square feet of building space across the roughly 127 school buildings in the district. 16 These buildings represent approximately one third of municipal electricity consumption and two thirds of municipal gas consumption. The BPS Department of Transportation (DOT) fleet of over 700 vehicles uses nearly two thirds of all the diesel fuel consumed by City government. BPS has continued their replacement of the oldest, dirtiest diesel buses to lower emissions propane engines, which now comprise over one quarter of the fleet. Since BPS-DOT is on a roughly 10 year replacement cycle, these lower emissions vehicles will provide emissions reductions over the next decade. The next largest source of GHG emissions from municipal operations is the Public Works Department’s street lights. The 66,000 electric street lights and the 2,800 natural gas street lights found in Boston’s historic districts account for 9% of total municipal GHG emissions. Street lighting used to make up a much larger share of Boston’s municipal GHG profile; however, aggressive conversions of electric street lights to LEDs dating back to 2010 have cut emissions from street lights in half. While gas lamps comprise just 4% of total street light fixtures, they produce 31% of GHG emissions from street lights.**

**Factors driving change: The electricity emissions factor decreased as described in the community inventory. ● Natural gas and heating oil use has decreased over the long term (especially in recent fiscal years) as the City converted some older schools from oil to gas, and opened new, energy-efficient buildings that use natural gas for heat and hot water. ● Beginning in FY15, Boston has seen a dramatic reduction in fuel oil use resulting from the closure of the Boston Public Health Commission’s Long Island facility, which relied primarily on fuel oil as a heating source. ● Electricity use has decreased over the long term, primarily driven by the near complete conversion of Boston’s 66,000 electric streetlights to more efficient LED fixtures. Boston has also invested in building energy efficiency measures on a project-by-project basis, and plans to engage in deeper energy efficiency retrofits as part of the Renew Boston Trust. 17 ● Steam use has decreased over the long term due to the reduction in steam use at City Hall, and the conversion of the West End Branch library from steam to gas**

Data: **Boston’s GHG inventories are reported in CO2 equivalents (or CO2e) which is a universal unit of measurement that accounts for the global warming potential (GWP) of different greenhouse gases. Boston’s GHG inventory includes carbon dioxide (CO2), methane (CH4), and nitrous oxide (N2O), and uses Global Warming Potentials (GWPs) from the latest version of the International Panel on Climate Change (IPCC) Guidelines (currently 5AR). The formula used to determine the CO2e from a given energy use is Activity Data x Emissions Factor 1+2+3 = GHG Emissions from the activity.**

# Abstract

In 2017, Mayor Martin J. Walsh fortified existing GHG (short for greenhouse gas) emissions reduction goals to achieve carbon neutrality (no net carbon emissions released into the atmosphere) by the year 2050 in the City of Boston. This research paper aims to analyse the significance of the changes in GHG emissions generated by municipial operations in the City of Boston from the year 2005 to 2018. The City had pledged in the year 2000, when it enlisted itself in the Cities for Climate Protection Campaign of ICLEI (Local Governments for Sustainability) network, to take an active, leading role in advancing climate action. Therefore, a statistical examination of the local government's progress of combating global warming would help us benchmark their successes against claims laid out in updated versions of the Climate Action Plan (CAP) and other documents. To test these claims, the main tools used were hypothesis testing, general linear models, including ANCOVA, and general linear mixed models, assuming an Autoregressive (Lag 1) correlation structure between greenhouse gas emissions and year. The results obtained were mostly in accordance with the numerous sources I use in the report to cross refer my findings with.

# Introduction

Initially in 2007, Mayor Thomas Menino signed an executive order for the City of Boston to meet or exceed the goal of reducing its annual greenhouse gas emissions 7% below 1990 levels by 2012 (referring to Kyoto Protocol targets), and to begin releasing and updating a Climate Action Plan (CAP) that laid out strategies to reduce greenhouse gas emissions by 80 percent by 2050 in both municipal operations and in the entire Boston community. Later, in 2017, Mayor Walsh set a more ambitious goal of making Boston carbon neutral by 2050 and highlighted the steps to do so in the 2019 CAP Report. The reason to undertake this responsibility was to fulfill Boston's commitment to the Paris Climate Agreement and to keep global warming under 1.5 degrees Celsius.

Between the years 2005 and 2019, numerous policies, results, and goals were presented to the Boston public in different versions of the CAP reports as well as in the City of Boston Greenhouse Gas Emissions Inventory. In this project, I assess select information from these reports and sources to compare it to my analysis, given the capacity of my dataset. To explain in more detail, we first need to understand the differences between the community and Local Government Operations (LGO) GHG inventories. Reporting for the annual GHG inventory for the City of Boston is divided into community-wide and local government (municipal) operations inventories. Emissions associated with LGO's (fuel use from fleet vehicles and energy use in city government buildings), are included as part of the community-wide inventory. It should also be noted that emissions from the Boston Housing Authority, the Massachusetts Water Resources Authority (MWRA), and the Boston Planning and Development Agency (BPDA) are not included in the municipal GHG inventory, but those from the Boston Public Health Commission (BPHC), and the Boston Water and Sewer Commission (BWSC) are. Moreover, LGO's should be considered to be largely overlapping, but not completely contained within the Citywide inventory.

The LGO inventory calculates all greenhouse gas emissions generated by municipal operations in the City of Boston. This includes the burning of fuels in the City’s facilities, vehicles, and other equipment, and the energy used in municipal buildings, vehicles, parks, street lights, and traffic signals. The LGO inventory is based on the ICLEI greenhouse gas reporting protocol for local government operations. As we shall see in the next section, the dataset used corresponds to the data collected from this inventory from the years 2005-2018.

To iterate again, it should be noted that all the results and data of my research are only part of the municipal operations inventories. The main problem to analyse in this research paper is to validate the results of GHG reduction efforts of municipal operations present in the 4 versions of the CAP and in the City of Boston GHG Emissions Inventory Report (2005-2017). A significant claim is that emissions from LGO's in 2017 were 41 per cent less than they were in 2005, hence exceeding Boston’s goal to reduce municipal GHG emissions by 25% from 2005 to 2020. In fact, in the 2011 CAP, it was highlighted that because GHG emissions are roughly proportional to energy use, successful completion of the Energy Reduction Plan meant that the goal of 25% GHG reductions for municipal operations will be met by 2015 or 2016. Even better news came out when the 2014 CAP reported that LGO emissions had been reduced by almost 25 percent since 2005, saving Boston an additional year or two. The Energy Reduction Plan specified a 40-percent reduction in the energy use of street lights from 2011 to 2016 and laid out additional measures to reduce energy use for municipal transportation to 20% between 2010 and 2015.

Boston’s LGO emissions are dominated by building energy consumption. Electricity and gas consumption by buildings each make up about one third of total GHG emissions. Transportation fuels, diesel and gasoline, together make up one fourth of total municipal GHG emissions. Similar to the community-wide inventory, Boston’s municipal operations GHG inventory trends are driven by a number of external and internal factors. Diesel consumption is continuing to decrease as Boston Public Schools switches its fleets from diesel- to propane-powered school buses. The continued downward trend in the regional electric grid emissions rate also contributed to reduced emissions.

As the department with the largest building portfolio, and the second largest vehicle inventory (after Boston Police Department), Boston Public Schools (BPS) represent the largest source of municipal emissions. BPS owns and operates approximately 12 million of the City’s 16 million square feet of building space across the roughly 127 school buildings in the district. 16 These buildings represent approximately one third of municipal electricity consumption and two thirds of municipal gas consumption. The BPS Department of Transportation (DOT) fleet of over 700 vehicles uses nearly two thirds of all the diesel fuel consumed by City government. BPS has continued their replacement of the oldest, dirtiest diesel buses to lower emissions propane engines, which now comprise over one quarter of the fleet. Since BPS-DOT is on a roughly 10 year replacement cycle, these lower emissions vehicles will provide emissions reductions over the next decade.

The next largest source of GHG emissions from municipal operations is the Public Works Department’s street lights. The 66,000 electric street lights and the 2,800 natural gas street lights found in Boston’s historic districts account for 9% of total municipal GHG emissions. Street lighting used to make up a much larger share of Boston’s municipal GHG profile; however, aggressive conversions of electric street lights to LEDs dating back to 2010 have cut emissions from street lights in half. While gas lamps comprise just 4% of total street light fixtures, they produce 31% of GHG emissions from street lights.

Readers of this paper and the general public should be kept updated about their local government's steps and policies to important issues, such as global warming and climate change. As a coastal city, Boston is particularly vulnerable to sea level rise, as well as other effects of climate change such as extreme temperatures and precipitation. These effects will disproportionately affect communities of color, women, youth, disabled people, elderly people and people with limited English proficiency. Therefore, reducing GHG emissions would bring economic and social gains to Boston. According to the 2011 CAP, after accounting for initial costs, residents, businesses, and institutions will have total net savings of $2 billion in energy costs by 2020. In addition, Boston will benefit from improved public health and reduced health care costs from reductions in air pollution, less traffic congestion, and a safer, cleaner environment.

In the following Main Sections portion of the paper, under the EDA and Methods section, I shall evaluate and present my findings of these municipal operations GHG reduction results.

# Main Sections

## Data

The dataset was obtained from the data.boston.gov website that stores multifarious datasets related to the City of Boston. The dataset contains the total GHG emissions by municipal department, asset use, fuel type, and fiscal year for all LGOs. Originally, the dataset had 7 variables, 5 of which were used for analysis. The 2 variables not of use were "Department", which was the acronym for department responsible for energy use, and "Protocol", indicating the protocol used for data reporting. The renamed variables of interest include: "Department" (full name of the department), "Facility" (GHG producing asset), "Fuel Type" (Type of energy producing GHGs), "Year" (Fiscal period of energy consumed from 2005-2018), and "Emission" (Numeric quantity of GHGs produced in tons of carbon dioxide equivalents, CO2e). The original data had 1014 observations with all 159 NA’s being removed during data cleaning. Initially after reading in the data, the "Emission" column was read in as a factor; hence, its datatype was changed to numeric.

It should also be noted that Boston’s GHG inventories are reported in CO2 equivalents (or CO2e), which is a universal unit of measurement that accounts for the global warming potential (GWP) of different greenhouse gases. Boston’s GHG inventory includes carbon dioxide (CO2), methane (CH4), and nitrous oxide (N2O), and uses Global Warming Potentials (GWPs) from the latest version of the International Panel on Climate Change (IPCC) Guidelines. The formula used to determine the CO2e from a given energy use is Activity Data x Emissions Factor = GHG Emissions from the activity.

## Exploratory Data Analysis

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