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Comparing three methods for estimating ozone depleting substance substitute greenhouse gases: Case study of the New York City Region

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by

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Abstract

This thesis evaluates the United States Environmental Protection Agency (EPA) method for estimating emissions from one source, Ozone Depleting Substances Substitutes (ODS substitutes) by comparing results for the New York City Metropolitan Statistical Area (NYC-MSA) with results from two other methodologies. The EPA's method utilizes population data and GDP data to estimate and geographically allocate emissions, with little regard for the geographies of industrial activity. The two alternative methods use data for industrial employment and activity to provide results for comparison and perhaps a more accurate accounting and allocation of emissions throughout the NYC-MSA.

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1. Introduction

While CO2 gas makes up the majority of greenhouse gas (GHG) in the atmosphere, ODS substitutes are of increasing importance in global and regional GHG emissions because, pound for pound, they have much more global warming potential (GWP) and their reduction may be a more cost-effective way of achieving GHG reductions (Rao, 2006). Rao and Riahi (2006) argue that these types of emissions are expected to grow in the long term. Moreover, while reducing the warming influence of GHGs will be possible only with substantial cuts in emissions of CO2, reducing non-CO2 greenhouse gas emissions would be a relatively quick way of contributing to this goal (Montzka et al., 2011). Accurate estimation of the levels of ODS substitutes is crucial to both urban GHG protocol development and identification of appropriate and urgent mitigation strategies.

The United States Environmental Protection Agency (EPA) provides estimation methods for all GHG sources in their *Draft Regional Greenhouse Gas Inventory Guidance* document. The goal of the document is to help municipalities, planning agencies, and other researchers to estimate GHG emissions from all sources within their borders and allocate them geographically. The document provides equations that utilize various proxy data. In the case of ODS substitutes, population and gross domestic product (GDP) values are the proxy data. While this method uses data that is easily accessible, it might be possible to generate better estimates and allocate them more accurately within the NYC-MSA by using more relevant proxies.

A general knowledge of the NYC-MSA reveals that population and wealth (GDP) are centralized in the city core, while manufacturing and other industrial activities are outside of the city core. While the EPA's equation uses population levels and GDP to calculate estimates, it seems logical that a closer look into where relevant manufacturing is located, and where ODS substitutes are actually used, may reveal more accurate geographies of ODS substitute emissions. The two alternate estimation methods in this paper approach the problem by using data that is more specific to the geographies of industry and manufacturing. The use of alternative methods to the EPA’s protocol for estimating ODS substitutes at the sub-regional level, and geographic visualization of the input variables, may reveal considerable differences in the geographies of ODS substitute emissions in the NYC-MSA, and mark an improvement in this accounting procedure.

The first alternate method uses industrial employment data from the United States Bureau of Labor Statistics as its proxy, and the second alternate method uses emissions data from the European Commission, which uses a combination of population and industrial activity as its proxy data. Geographic projection of the results provides a means for comparison of the three methods.

The results of these comparisons suggest that, given the state of publically accessible data, the EPA’s method may be the best method currently available for estimating emissions. The results also bring to light how improvements in industrial data availability could aid greatly in future ODS substitute emissions estimation.

2. Literature and Background

Section 2 provides a geographic foundation of the study area by defining the boundaries and character of the NYC-MSA and its sub-regions, and a close look at the distribution of population and GDP within the region. The section then clarifies how ODS substitutes fit within the broad category of GHGs, the specific gases involved, and the related industrial activities. Applying the EPA protocol to generate estimates requires no knowledge of the industries involved or the gases emitted, but when proposing alternate methods that utilize more relevant data, such background knowledge is vital.

2.1.1 Defining the NYC-MSA and its five sub-regions

The NYC region has been defined in many ways by various planning and government agencies to suit their own investigations and projections. For the sake of this paper, the New York City region geography being analyzed is that which has been identified by The Regional Plan Association (RPA) and referred to as the NYC-MSA with defined boundaries. Since the 1920's RPA has been developing long-range plans to guide the growth of the New York metropolitan area. These efforts have shaped and improved the region's economic health, environmental sustainability and quality of life. Ideas and recommendations put forth in these plans have led to the establishment of some of the New York metropolitan region's most significant infrastructure, open space and economic development projects, including new bridges and roadways, improvements to New York's transit network, the preservation of vital open space and the renewed emphasis on creating sustainable communities centered around jobs and transit (Regional Plan Association, 2015).

RPA calculates that nearly one- third of income earned in New York City ends up in the pockets of commuters from outside the city core, around $44 billion annually. More than ever, the economies, societies, and environments of all the communities in the Tri-State Metropolitan Region are intertwined, transcending arbitrary political divisions. NYC-MSA cities and suburbs share a common destiny (Regional Plan Association, 2015).

Understanding this economic interconnectivity between the city proper and its surrounding suburbs, RPA defines the NYC-MSA as the thirty-one counties that compose and surround the city. It includes counties in five sub-regions referred to in this paper as: Connecticut, New Jersey, Mid-Hudson, Long Island, and New York City. The NYC sub-region is considered as the city core in this paper. As of July 1, 2010, the entire NYC-MSA includes over 24 million people, a more than half-trillion dollar economy, and nearly 800 cities, towns, and villages spread across 13,000 square miles. This ranks the NYC-MSA as the largest metropolitan area, in terms of population, in the United States (Regional Plan Association, 2015).

The employment profile of the NYC Region has been dynamic through history but its current state is shown in table 1.

Table 1: Employment in the NYC Region of the eight largest sectors from high to low in numbers of jobs (Regional Plan Association, 2015)

1. Services
2. Retail
3. Government
4. Finance, Insurance and Real Estate
5. Manufacturing
6. Transportation and Utilities
7. Wholesale Trade
8. Construction

The NYC-MSA is composed of 31 counties in the New York, New Jersey and Connecticut Tri-State Area. This includes the three westernmost counties of Connecticut, fourteen counties of northern New Jersey, the two counties of Long Island in NY State, the seven counties of the Mid-Hudson Valley Region in New York State, and the five counties/boroughs of New York City. The fourteen counties of New York State are displayed as three sub-regions in figure 1, below, each in a different shade of blue, to highlight them as culturally and economically distinct from each other but linked administratively. The included portions of Connecticut and New Jersey are shown respectively in pink and orange. Figure 1 shows the boundaries of all five sub-regions of the NYC-MSA and how they fit within the region.

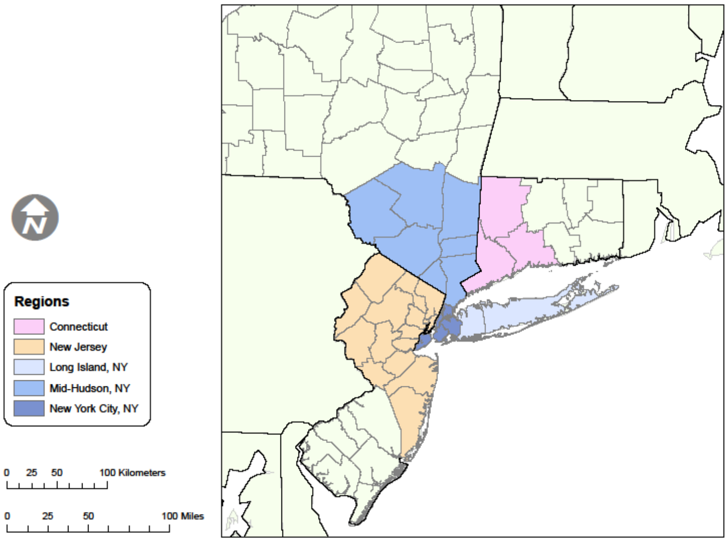

Figure 1: The NYC-MSA (thirty-one counties) aggregated to the five sub-regions

2.1.2 The population distribution of the NYC-MSA

A close look at population distribution not only provides a clearer picture of the texture of the NYC-MSA, but is also a factor in estimating and understanding GHG emissions levels. In the comparison of the three estimation methods presented in this paper, population data is used as a direct proxy in one method, and as a component of proxy data in another method.

Tables 1, 2, and 3 and figures 2, 3, and 4 are included to provide a general picture of how the population is distributed in the 31 counties and five sub-regions of the NYC-MSA. In general, the five counties of NYC rank highest in these areas with a notable exception being the NYC county of Richmond which has a much lower population density than the rest of NYC. The two counties of Long Island just east of the city, the counties of West Chester, NY and Fairfield, CT just north of NYC, and a handful of New Jersey counties just west of the city generally rank one-level below NYC, and the counties furthest from NYC generally rank at the bottom.

Table 2 displays the NYC-MSA as five contiguous but distinct sub-regions which are composed of thirty-one counties in total. The three sub-regions in shades of blue are all administered by New York State.

Table 2: Population values of the five sub-regions and thirty-one counties of the NYC-MSA (United States Census Bureau [US Census Bureau], 2015)

States	Sub-regions	Sub-region Population	Counties	County Population
Connecticut	Connecticut	1,971,258	Fairfield	918,814
			Litchfield	189,741
			New Haven	862,703
New Jersey	New Jersey	6,956,648	Bergen	906,597
			Essex	784,592
			Hudson	635,682
			Hunterdon	128,357
			Mercer	367,093
			Middlesex	811,266
			Monmouth	630,821
			Morris	492,899
			Ocean	577,697
			Passaic	501,796
			Somerset	324,118
			Sussex	149,221
			Union	537,816
			Warren	108,693
New York	Long Island	2,836,048	Nassau	1,341,285
	Long Island		Suffolk	1,494,763
	Mid-Hudson	2,294,095	Dutchess	297,772
	Mid-Hudson		Orange	373,524
	Mid-Hudson		Putnam	99,784
	Mid-Hudson		Rockland	312,517
	Mid-Hudson		Sullivan	77,427
	Mid-Hudson		Ulster	182,395
	Mid-Hudson		Westchester	950,676
	New York City	8,189,997	Bronx	1,387,672
	New York City		Kings	2,509,723
	New York City		New York	1,588,032
	New York City		Queens	2,235,040
	New York City		Richmond	469,530
			NYC-MSA Total Population	22,248,046

When the five sub-region populations are aggregated at the state level in table 3, the three New York State sub-regions combine to nearly double the population of the New Jersey sub-region and nearly seven times the Connecticut sub-region.

Table 3: Population values of the NYC-MSA when aggregated by state (US Census Bureau, 2015)

States	Population
Connecticut	1,971,258
New Jersey	6,956,648
New York	13,320,140

Table 4 displays the NYC-MSA population juxtaposed with the United States population. The population of the NYC-MSA composes slightly more than 7% of the nation’s population.

Table 4: Population values of the NYC-MSA and the United States

(US Census Bureau, 2015)

	Population
NYC-MSA	22,248,046
United States	308,745,538

Figure 2 references the county populations shown in table 2. The top two counties for population are Kings and Queens counties, both within New York City. They are followed closely by Manhattan and the Bronx, also both within New York City, and the two counties of Long Island. A handful of counties very near New York City fill out the middle range of population before a natural drop-off happens further from the city center.

In general, the top two population categories are those with the best commuter transit connections to the city. Some of those areas are as far as approximately 120 miles driving from New York's City Hall building, the center of the city's government (Bureau, 2015).

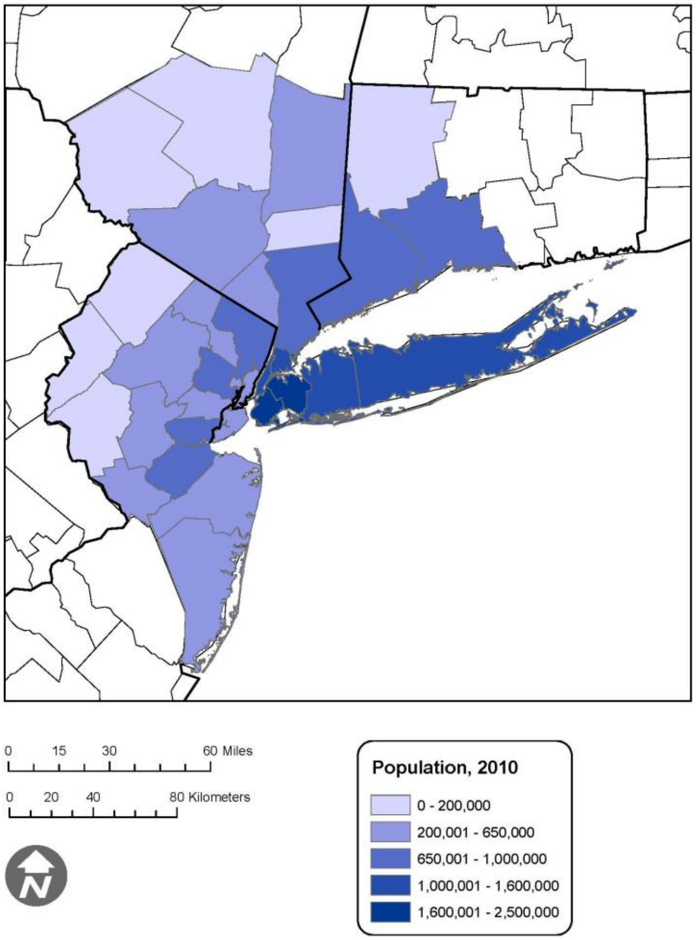

Figure 2: Population values by county, data is from (US Census Bureau, 2015)

Figure 3 shows population density per square mile and further highlights how tightly clustered the population is around the core of NYC. In this map, the top two population categories only include towns within 20 driving miles of New York's City Hall.

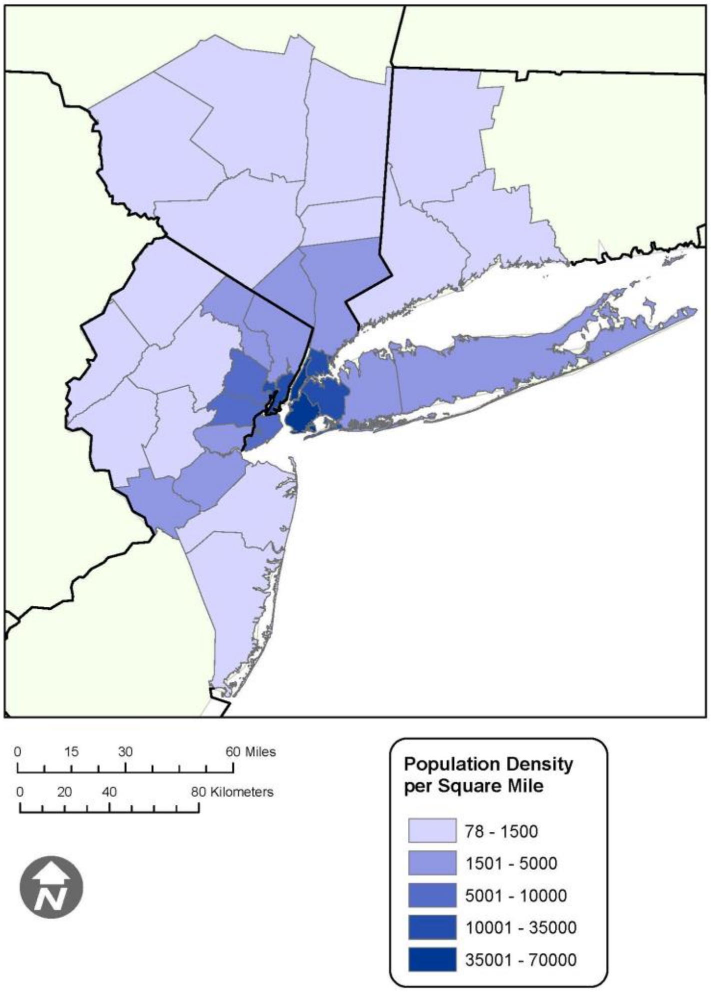

Figure 3: Population density by county, data is from (US Census Bureau, 2015)

Figure 4 aggregates the populations to the five sub-regions being analyzed for this paper. New York City leads the list and is followed closely by the New Jersey sub-region. Then there is a substantial drop-off of almost 60% down to the third ranked sub-region of Long Island.

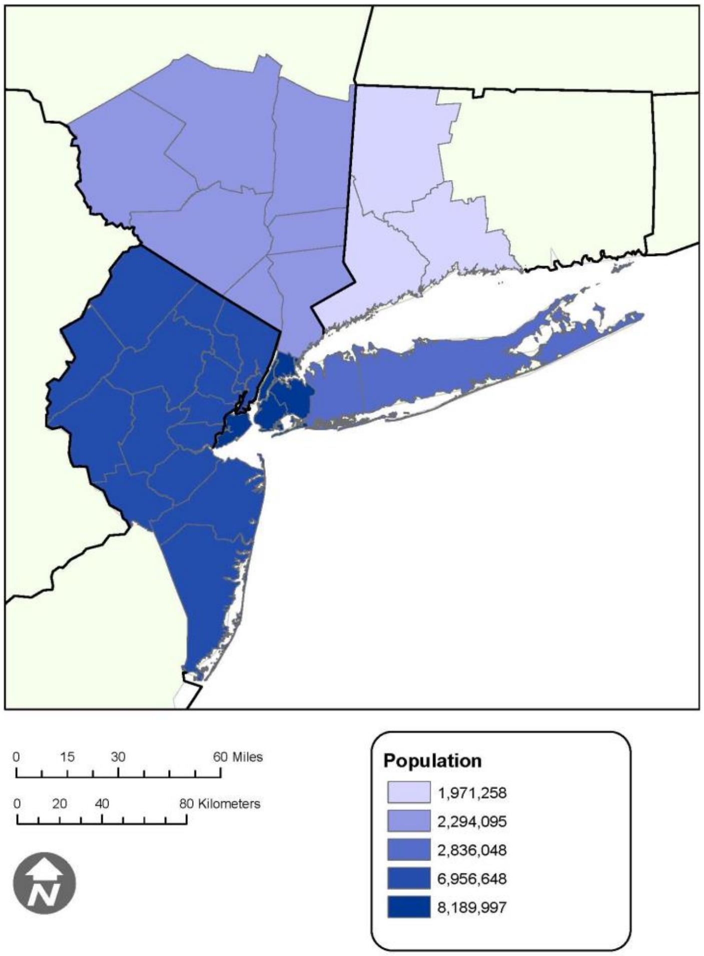

Figure 4: Population values by sub-region, data is from (US Census Bureau, 2015)

2.1.3 The distribution of GDP in the NYC-MSA

As does population data, gross domestic product (GDP) data provides context for understanding the MSA and functions as proxy data in one of the estimation methods in this paper. Table 5 displays the GDP for the five sub-regions and thirty-one counties of the NYC-MSA. Those with the highest GDP are three counties within NYC, the two counties of Long Island, and the one county in the Mid-Hudson sub-region and one in the Connecticut sub-region that are closest to NYC. Those with the lowest GDP are generally the furthest distance from NYC and contain farmland and other rural characteristics. This data is projected in figure 5 (Unites States Bureau of Economic Analysis [US BEA], 2015).

Table 5: GDP values by sub-region and by county (US BEA, 2015)

Sub-region	Sub-region GDP	County	County GDP
Connecticut	119,034,000,814	Fairfield	74,432,000,000
		Litchfield	10,120,000,814
		New Haven	34,482,000,000
New Jersey	400,067,160,146	Bergen	62,319,881,052
		Essex	43,389,309,007
		Hudson	31,475,573,800
		Hunterdon	9,015,961,695
		Mercer	23,004,000,000
		Middlesex	41,586,398,510
		Monmouth	38,820,599,417
		Morris	36,412,250,347
		Ocean	25,218,412,448
		Passaic	22,652,606,030
		Somerset	24,428,228,822
		Sussex	7,848,399,186
		Union	28,866,079,751
		Warren	5,029,460,080
Long Island	177,979,638,328	Nassau	94,896,062,194
		Suffolk	83,083,576,134
Mid-Hudson	134,965,540,654	Dutchess	14,334,282,374
		Orange	16,127,694,952
		Putnam	5,740,811,451
		Rockland	17,643,411,648
		Sullivan	3,046,752,959
		Ulster	4,195,000,000
		Westchester	73,877,587,270
New York City	464,452,109,341	Bronx	46,684,636,417
		Kings	104,452,595,849
		New York	189,685,369,545
		Queens	99,405,332,398
		Richmond	24,224,175,132
		NYC-MSA Total GDP	1,296,498,449,284

Table 6 displays the NYC-MSA's GDP juxtaposed with the United States' GDP. The GDP of the NYC-MSA composes nearly 9% of the nation's GDP.

Table 6: GDP values for the NYC-MSA and the United States (US BEA, 2015)

	2010 GDP (US dollars)
NYC-MSA	1,296,498,449,284
United States	14,783,800,000,000

Figure 5 shows GDP by county, and those with the highest GDP are clustered closely in and around NYC.

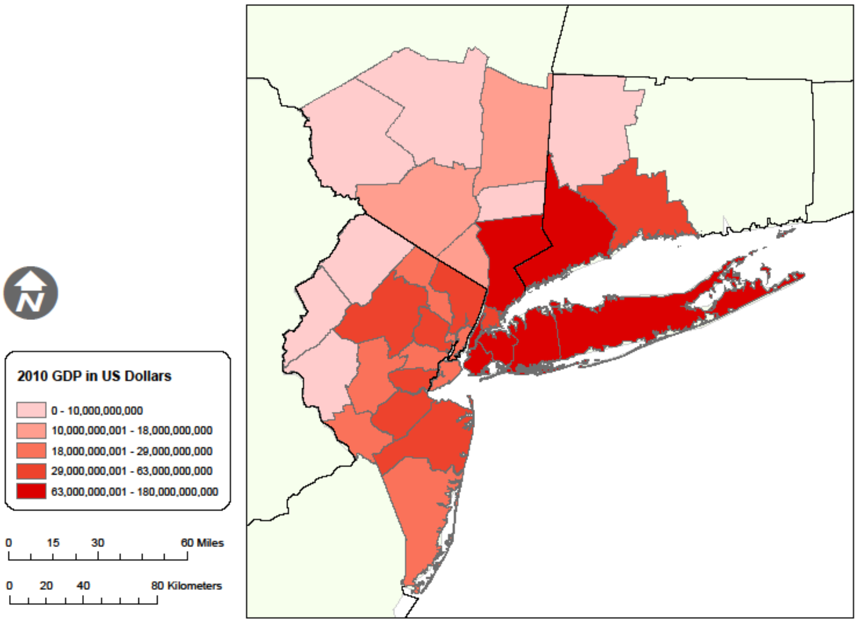

Figure 5: GDP by county, data is from (US BEA, 2015)

In figure 6, in which GDP is aggregated to the five sub-regions in table 4, NYC ranks first followed closely by the New Jersey sub-region. There is a substantial drop-off of more than 55% down to the third ranked sub-region of Long Island when aggregated to the sub-region level.

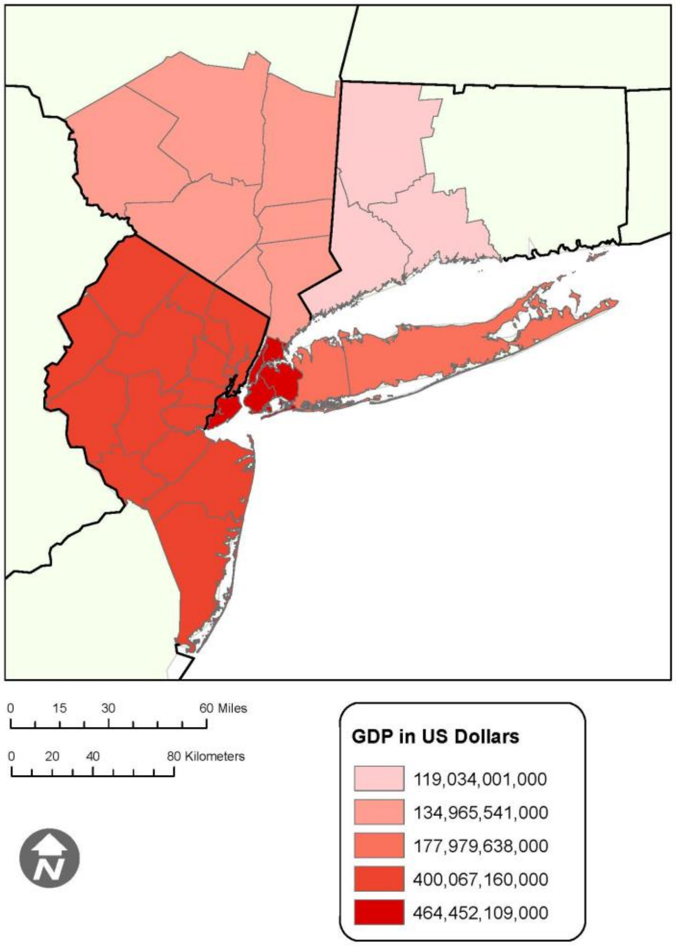

Figure 6: GDP by sub-region, data is from (US BEA, 2015)

With the sub-regional rankings of two important proxy data, population and GDP, the results are the same with NYC ranked first, followed by the New Jersey, Long Island, Mid-Hudson, and finally Connecticut sub-regions. Of interest is seeing how these rankings may or may not correlate with GHG emissions.

2.2 GHGs, ODS, and ODS substitutes

A wide variety of greenhouse gases (GHGs) are recognized as being responsible for global warming. Some have a much greater warming impact per kilogram than others. Some, such as CO2, have been accumulating in the atmosphere for hundreds of years, while others, such as ODS substitutes, are much more recent. It is important to clarify how these emissions warm the atmosphere and what distinguishes them form each other.

CO2 emissions related to combustion of fossil fuels dominate the anthropogenic GHG emissions in the earth's atmosphere. While fluorinated gases, discussed more in the next section, such as HFCs, PFCs, and SF6 are not the leading pollutants (United States Environmental Protection Agency [US EPA], 2015a), their measurement and reduction is so vital to the health of the earth's atmosphere because of their extremely high GWP relative to CO2, and in North America their emissions have grown by more than 250% between 1990 and 2010 (European Commission, 2012a).

2.2.1 The role of GHGs in global warming

The term GHGs refers to gases in the earth's atmosphere, which are believed to be responsible for heating the earth. Many of these GHGs exist naturally in the earth's atmosphere, such as water vapor, carbon dioxide, methane, and nitrous oxide.

When radiation from the sun enters the atmosphere and reaches the earth as infrared, visible, and ultraviolet light, much of that radiation is reflected back through the atmosphere as infrared radiation in the form of heat and, in a balanced system, the earth reflects nearly as much radiation back through the atmosphere and into space as originally had entered, leaving the earth's temperature relatively stable and constant. On it's way to and from the earth, as the sun's radiation passes through the atmosphere it interacts with GHGs gases such as CO2, methane, water vapor, and nitrous-oxide. GHGs have the characteristic of absorbing some of that heat on its way out. Most of the light energy from the sun is emitted in wavelengths shorter than 4,000 nanometers which is not absorbed by, in this example, CO2. The returning heat energy released by the earth, however, is released in wavelengths longer than 4,000 nanometers, some of which is absorbed by CO2 (Flannery, 2007).

When a molecule of carbon dioxide absorbs heat energy, it goes into an excited unstable state. It can become stable again by releasing the energy it absorbed. Some of the released energy will go back to the earth as heat and some will go out into space. CO2 is unfortunately not the only gas which absorbs and disperses heat energy in this way in our atmosphere. All of the classes of gases known as GHGs have this same quality, many of which absorb many times more heat than CO2 does. Essentially, these compounds let the light energy in but don't let all of the heat energy out, causing the earth's atmosphere to warm up like the inside of a greenhouse (Lallanilla, 2015).

At naturally occurring levels these greenhouse gases pose no threat to the climate. In a healthy system, these gases pass back and forth between the atmosphere, ocean, and land surfaces and are produced and consumed by flora, fauna, and micro-organisms. The gases which concern the global scientific community are those which are anthropogenic, or produced as a consequence of human activities such as food production, energy production and chemical production and use. These anthropogenic GHGs have been accumulating in the atmosphere since large-scale industrialization began over 250 years ago, and their rate of accumulation has been increasing rapidly in recent decades.

When the industrial revolution began, around the year 1750, human activity began to contribute much more CO2 to the atmosphere by burning fossil fuels, previously locked safely in the earth's crust in the form of oil, coal, natural gas, and even peat. When the carbon atoms in these fuels are heated and burned, they combine with 2 oxygen atoms to form CO2 and rise into the atmosphere. Early industrialization burned available fuels to power machinery and heat homes, and as industry and society advanced and became more sophisticated, the growing use of automotive internal combustion engines, shipping and air transportation, the large-scale production of livestock, and the industrial processes which produce cement, metals, chemicals, and consumer goods have added considerably to the concentration of CO2 and other GHGs in the atmosphere. Adding to the imbalance in the carbon cycle, the clearing of hundreds of millions of acres of forest to harvest wood and clear land for agriculture and land for towns and cities has negatively impacted the earth's natural ability to absorb CO2 and store it in plant matter.

The result of the increased levels of GHGs entering the atmosphere is more trapped heat and a gradually heating earth. Some of the consequences of this heating are the melting of polar and glacial ice which is resulting in habitat loss, sea-level rise, the flooding of coastal communities, the disruption of previously predictable climate patterns which may disrupt agricultural production and wildlife habitats, and excess carbon being absorbed into the oceans which creates a more acidic environment for marine life (Block, 2015).

With all of these environmental issues at stake, the global scientific community is working to get a handle on the volumes of anthropogenic GHGs entering the atmosphere, the sources of them, and the relative damage wrought by the wide spectrum of gases. A firm grasp of the geographies of the sources of GHGs will help with planning how to reduce them locally and globally back down to potentially sustainable levels. Knowing more about ODS and ODS substitutes will have an outsized impact on reduction efforts because of their much higher global warming potential (GWP), discussed further in section 1.3.

2.2.2 The ozone layer and the impact of ODS

Ozone is a gas in the earth's ozone layer, which is one layer of the earth's protective stratosphere. Ozone molecules (O3) are composed of three oxygen atoms. The ozone molecules in the ozone layer help keep life on earth stable by blocking about 98 percent of the ultraviolet radiation coming from the sun. Some UV radiation is needed, but too much reaching the earth can have devastating consequences, such as higher rates of sun burn, skin cancer and cataracts in humans, and reduced reproductive rates in plants and animals. The protective ozone molecules are constantly being destroyed and reformed naturally. Ozone forms when an ultraviolet photon with a particular wavelength strikes an oxygen atom (O2) and breaks it in half. Some of those single oxygen atoms then bond with an oxygen molecule to form an ozone molecule. Those ozone molecules then split back into an oxygen molecule and an oxygen atom when they are struck with an ultraviolet photon with a slightly different wavelength. In a balanced system oxygen atoms, oxygen molecules, and ozone molecules continue splitting and bonding in an endless cycle. However, when ozone depleting substances (ODS) are introduced, the cycle is broken (Rutledge et al., 2015).

While all GHGs are busy trapping heat in the atmosphere, ODS are impacting the atmosphere in an additional way. ODS are materials that have the quality of disrupting the formation of ozone. They are almost entirely man-made products that were extremely useful to society and thought to be quite safe for commercial and consumer use when the first generation of them, chlorofluorocarbons (CFCs), were introduced in the 1920’s under the name “freon”. Their applications included use in mechanical cooling and refrigeration systems, aerosol spray propellants, and precision cleaning of delicate electronic equipment. Halons are another class of materials that can have a similar effect to CFCs. Halons, introduced around the same time, were commonly used in agriculture, dry cleaning and fire suppression. When contained, these materials can be used responsibly. However, when released to the atmosphere, they can cause serious harm. Before they were phased out of production and use, these materials were released whenever there was a leak in an automobile’s air-conditioning system, or whenever a consumer used an aerosol product (Kettering, 1947).

Those ODS materials released into the atmosphere over the last century have been interfering with the natural ozone and oxygen cycle when exposed to incoming ultraviolet light from the sun. The ultraviolet light can split a chorine atom from an ODS, such as a CFC molecule. The chlorine atom then eagerly attracts an oxygen atom away from an ozone molecule, thus leaving the atmosphere with fewer protective ozone molecules. In the case of halons, it is a bromine atom instead of a chlorine atom which interferes with the oxygen and ozone cycle. After many decades of accumulating ODS in the stratosphere, the ozone layer had begun to suffer. The damage to the ozone layer was allowing increasingly dangerous amounts of ultraviolet radiation to reach the earth’s surface, especially at the earth’s poles (US EPA, 2010b).

These concerns were first noticed and raised by the scientific community in the 1970’s, and by the 1980’s enough was understood about the risks that the international political community saw the need to act. In 1988, the United States, and many other nations, ratified the Montreal Protocol on Substances that Deplete the Ozone Layer. By ratifying the original Montreal Protocol and its subsequent adjustments and amendments, the United States has committed to a collaborative, international effort to regulate and phase out ODS, including CFCs, hydrochlorofluorocarbons (HCFCs), halons, carbon tetrachloride, methyl chloroform, methyl bromide, and hydrobromofluorocarbons (HBFCs) among others. This international agreement led to an amendment of the U.S. Clean Air Act (CAA) in 1990 to include Title VI, Stratospheric Ozone Protection. Title VI authorizes the U.S. Environmental Protection Agency (EPA) to manage the phase-out of ODS. Among the regulations established by the EPA are requirements for the safe handling of ODS and prohibitions on the known venting or release of ODS into the atmosphere. Therefore, as ODS are phased out, surplus ODS around the world must be stored, reused (after recycling or reclamation), or destroyed (Institute for Governance and Sustainable Development, 2015).

2.2.3 The Montreal Protocol and the emergence of ODS substitutes

With the political framework for ODS phase-outs in place, the chemical industry had to begin finding replacement materials for use in industry and for the consumer market. The replacement materials which have been formulated are known as ozone depleting substances substitutes (ODS substitutes).

The ODS phase-outs took many years as new targets were set and met and the Montreal Protocol was subjected to many revisions. The original ODS were used in such a broad range of applications that there is no single replacement which would be suitable for all tasks. One of the first substitutes was a hydrochlorofluorocarbon (HCFC), named

HCFC-141b, in the late 1980s and was used as a CFC replacement as a solvent for precision cleaning of electronics. While its ozone depletion value was much lower, and thus a marked improvement, it was not zero. Because of this, the US Environmental Protection Agency (EPA) greatly restricted this new compound's use, but still permitted it for some types of precision cleaning and set a future phase-out date for the year 2003 in one revision to the Montreal Protocol (Intergovernmental Panel on Climate Change, 2006).

A second-generation introduction by the chemical industry was a class of materials called hydrofluorocarbons (HFCs) which, as the name suggests, contain no chlorine, only hydrogen, fluorine, and carbon. There are a great many HFC compounds available commercially, each with slightly different industrial applications and global warming potentials (GWPs), so selection among them can be difficult. When selecting more appropriate materials for use by industry, the key environmental concerns are their ozone depletion potential, global warming potential, contribution to smog in the lower atmosphere by the emission of volatile organic compounds (VOCs), ground water pollution, and that the molecules must be relatively non-toxic so that workplaces remain safe (Institute for Governance and Sustainable Development, 2015).

Hydrofluoroethers (HFEs) are being used as third-generation replacements for some applications in place of CFCs, HCFCs and perfluorocarbons (PFCs) because of their nearly zero stratospheric ozone depletion and relatively low global warming potential. HFEs have been developed for commercial uses as precision cleaning solvents, foam blowing agents, refrigerants, and dry etching agents in semiconductor and electronics manufacturing. As knowledge of these materials grows with continued development and testing, the use of ODS substitutes will continue to shift as safer alternatives emerge (Tsai, 2005).

While the move to the use of ODS substitute compounds is recognized as progress, as their use will permit the ozone layer to repair itself and continue protecting the earth from dangerous levels of ultra-violet radiation, this does not absolve them from their responsibility of damaging the earth’s atmosphere as they are still quite potent GHGs.

2.2.4 Explanation of GWP and atmospheric lifetimes

While all anthropogenic GHGs are a concern to climate experts, some have much greater impacts than others. Scientists have devised the metrics “global warming potential” (GWP), and “atmospheric lifetimes” to quantify the relative threat of the variety of GHGs. GWP is calculated by comparing the amount of heat that one kilogram of a certain gas will absorb relative to one kilogram of CO2. The GWP of CO2 is standardized to a value of 1 as a point of comparison for all other measured gases. Climate scientists commonly publish GWP for a gas over time intervals of 20, 100, and 500 year time horizons, as some gases will remain in the atmosphere for centuries and others will decay more quickly. Methane, for example, will usually only remain in the atmosphere for about 10 years but will absorb about 20-30 times as much heat as CO2 during that time. N2O will absorb about 300 times as much heat as CO2 and will remain in the atmosphere for about 100 years. ODS substitutes, such as HFCs and PFCs, are referred to as high-GWP gases because some of them can absorb more than ten thousand times as much heat as CO2 during their time in the atmosphere (US EPA, 2015c).

The second metric mentioned above, atmospheric lifetime, of a greenhouse gas "refers to the approximate amount of time it would take for an anthrogogenic increment to an atmospheric pollutant concentration to return to its natural level as a result of either being converted to another chemical compound or being taken out of the atmosphere via a sink" (ChartsBin, 2011). This value depends on the pollutant's sources and sinks as well as its reactivity. Average lifetimes can vary from about a week (sulfate aerosols), to more than a century (carbon dioxide), to tens of thousands of years (perfluoromethane). Materials with a particularly high atmospheric lifetime value will correspondingly have a high GWP value because their presence will continue to have negative impacts until they decay and or are otherwise rendered benign. Using CO2 as the standard unit of comparison allows policy-makers to create and compare local or national GHG inventories regardless of the gases involved.

The ODS substitutes displayed in table 7 are organized with the 'industry' in which they are used, their general 'class' name based on their chemical composition, 'industry name' which is a commercial identifier, 'chemical name' as used in science (and it should be noted that a single compound is often given multiple chemical names), chemical 'formula' representing the atomic composition of each molecule, 'atmospheric lifetimes', and 'GWP'.

Each industrial sector is listed with all of the chemicals and blends, its chemical class, name, formula, atmospheric lifetime and its global warming potential. These ODS substitutes each have a variety of trade names, scientific names and chemical names which can lead to confusion. For instance, perfluoromethane (CF4) is also known as tetrafluoromethane and carbon tetrafluoride. Perfluoroethane (C2F6) is also known as hexafluoroethane and carbon hexafluoride. To help clarify the situation for the purposes of this paper, below is a table which shows all of the ODS substitutes used in each industrial sector, their names, formulas, atmospheric lifetimes and global warming potentials. Despite the many alternative chemical names, for simplicity the table below displays just one name. In the column labelled “Class”, there are 4 acronyms used, and not all of the materials fit into one of those classes. HFC stands for hydrofluorocarbon and is a gaseous compound which contains hydrogen, fluorine and carbon. A PFC is a perfluorocarbon. A PFC is a hydrocarbon in which all hydrogen atoms have been replaced with fluorine. HFE is a hydrofluoroether. This class of ethers has very short atmospheric lifetimes and low GWP (Tsai, 2005). A PFA is perfluoroalkane, which is a carbon-flourine compound with extremely low atmospheric lifetime and GWP.

Most of the commercial products in the refrigeration sector are actually combinations of 2 or more chemical compounds. In those cases, the products (R-404a, R-410a, R-407c, R-507a) are broken down into their component parts in the table because the atmospheric lifetime and global warming potential values are only available for the components. In the column labelled “Industry Name” the letter “R” (in R-404a for example) stands for refrigerant, and the designation “404a” is determined systematically according the molecular structure.

That “Atmospheric Lifetime” column and “GWP” column contextualize the relative potency of the materials when released into the atmosphere. The values in the table below reflect the estimated GWP over 100 years.

The material with the most potential to warm the atmosphere is sulfur-hexafluoride (SF6), which is displayed as being 22,450 times as impactful per kilogram emitted relative to CO2. Because of its potential to warm the atmosphere, its use should be monitored especially closely.

Table 7: Relevant GHGs shown with their atmospheric lifetimes and GWP and aggregated by industrial sub-sector (US EPA, 2014a)

Industrial Sub-sectors	Class	Industry Name	Chemical Name	Formula	Atmospheric Lifetime (years)	GWP
Refrigeration	HFC	R-134a	Tetrafluoroethane	CH2FCF	14	1,320
	HFC	R-404a (blend of 3)	Pentafluoroethane (R-125)	CHF2-CF3	29	3,450
			Trifluoroethane (R-143a)	CH3-CF3	52	4,400
			Tetrafluoroethane (R-134a)	CF3CH2F	14	1,320
	HFC	R-410a (blend of 2)	Difluoromethane (R-32)	CH2F2	4.9	543
			Pentafluoroethane (R-125)	CHF2-CF3	29	3,450
	HFC	R-407c (blend of 3)	Difluoromethane (R-32)	CH2F2	4.9	543
			Pentafluoroethane (R-125)	CHF2-CF3	29	3,450
			Tetrafluoroethane (R-134a)	CF3CH2F	14	1,320
	HFC	R-507a (blend of 2)	Pentafluoroethane (R-125)	CHF2-CF3	29	3,450
			Trifluoroethane (R-143a)	CH3-CF3	52	4,400
Solvents	HFC	R-23	Trifluoromethane	CHF3	270	12,240
	HFC	HFC-43-10mee	Pentane	C5H2F10	15.9	1,610
	PFC	FC-72	Perfluorohexane	C6F14	3,200	9,140
	HFE	HFE-7100	Methoxy-nonafluorobutane	C4F9OCH3	5	397
	HFE	HFE-7200	Ethoxy-nonafluorobutane	C4F9OC2H5	0.77	56
Foam	HFC	R-134a	Tetrafluoroethane	CH2FCF	14	1,320
	HFC	R-152a	Difluoroethane	C2H4F2	1.4	122
	HFC	R-245fa	Pentafluoropropane	C3H3F5	7.6	1,020
	HFC	R-365mfc	Pentafluorobutane	C3H3F5	8.6	782
Aerosols	HFC	R-134a	Tetrafluoroethane	CH2FCF	14	1,320
	HFC	R-152a	Difluoroethane	C2H4F2	1.4	122
	HFC	R-227ea	Heptafluoropropane	C3FH7	34.2	3,660
Fire Protection	HFC	R-236fa	Hexafluoropropane	C3H2F6	240	9,650
	HFC	R-227ea	Heptafluoropropane	C3FH7	34.2	3,660
Aluminum	PFC	R-14	Perfluoromethane	CF4	50,000	5,820
	PFC	R-116	Perfluoroethane	C2F6	10,000	12,010
HFC-22	HFC	R-23	Trifluoromethane	CHF3	270	12,240
Semiconductors		Sulfur Hexafluoride	sulfur hexafluoride	SF6	3,200	22,450
		Nitrogen Trifluoride	nitrogen trifluoride	NF3	740	10,970
	PFC	R-14	Perfluoromethane	CF4	50,000	5,820

	PFA	TFE	Tetrafluoroethylene	C_2F_4	1.9 days	0.27
Magnesium		Sulfur Hexafluoride	sulfur hexafluoride	SF_6	3,200	22,450
Electrical Systems		Sulfur Hexafluoride	sulfur hexafluoride	SF_6	3,200	22,450
Photovoltaic Cells		Nitrogen Trifluoride	nitrogen trifluoride	NF_3	740	10,970
	PFC	R-14	Perfluoromethane	CF_4	50,000	5,820
	PFC	R-116	Perfluoroethane	C_2F_6	10,000	12,010
Flat Panel Screens	PFC	R-14	Perfluoromethane	CF_4	50,000	5,820
	PFC	R-116	Perfluoroethane	C_2F_6	10,000	12,010
	HFC	R-23	Trifluoromethane	CHF_3	270	12,240
		Sulfur Hexafluoride	sulfur hexafluoride	SF_6	3,200	22,450
		Nitrogen Trifluoride	nitrogen trifluoride	NF_3	740	10,970

2.3 How and why ODS substitutes are used

As stated in section 1.1, the protocol that the EPA provides for municipalities to use for allocating emissions simply uses population and GDP values with no regard for the geographies of where the relevant emissions are generated or what gases are involved. To propose any alternative method for creating an estimate, it would be useful to know more about the materials, such as what they are and for which industrial activities they are used.

Table 8 displays the industrial activities which the EPA associates with industrial emissions. The utility to industry and to the public is included as well as the chemicals and blends, which they commonly emit into the atmosphere. Further discussion of these activities is included in Appendix A. Using the data assembled in this table, the problem of estimating GHGs in the NYC-MSA can be approached from either the "Activity" column or the "Emissions" column. By identifying the geographies of where those activities take place, and the geographies of where those chemicals and blends are reported as being used, two alternate methods of estimating ODS substitutes can be compared to the method which is recommended in the EPA’s *Draft Regional Greenhouse Gas Inventory Guidance.* These methods will be discussed in section 2.

Table 8: Relevant industrial activities, their utility to society, and their related emissions (US EPA, 2013b)

Industrial Activity	Utility	Emissions
Refrigeration & AC system recharge and collection and recycling stations	stationary systems such as residential and commercial buildings, mobile systems such as trucks and cars	HFC-134a, HFC-404a, HFC-410a, HFC-407c, and HFC-507a
Solvents Usage	precision cleaning applications and electronics cleaning applications, primarily solder flux residues, from electronics or circuit boards.	HFCs, HFEs, and PFCs
Foam production, use, disposal, and even following disposal (e.g., in landfills) if the foam substance is not specially treated	insulation in equipment including refrigerated appliances and transport systems, buildings, and to produce other consumer products	HFC-134a, HFC-152a, HFC-245fa, and HFC 365mfc
Aerosol Usage	consumer products such as spray deodorant, hair spray, freeze spray, dust removal products and pharmaceutical products, primarily metered dose inhalers	HFC-134a, with lesser amounts of HFC-152a and HFC-227ea
Fire protection equipment leakage, accidental discharges, and use during fire extinguishing	residential and commercial portable fire extinguishers and total flooding applications	HFC-236fa, HFC-227ea
Aluminum Production Emissions of the PFCs are generated during brief process upset conditions in the aluminum smelting process	wide variety of consumer and commercial products	perfluoromethane CF4 perfluoroethane C2F6
HCFC-22 Production	HCFC-22 is used both in emissive applications (primarily air-conditioning and refrigeration) and as a feedstock for production of synthetic polymers.	Trifluoromethane HFC-23
Semiconductor Manufacturing	A semiconductor is a substance that can conduct electricity under some conditions but not others, making it a good medium for the control of electrical current	sulfur hexafluoride SF6, nitrogen trifluoride NF3, carbon tetrafluoride CF4, perfluoroethane C2F6, HFC-23, nitrous oxide N2O
Photovoltaic cell manufacturing - during etching and chamber cleaning processes some of the F-GHGs not used are released to the atmosphere	solar panels collect convert solar radiation and convert it into electricity	nitrogen trifluoride NF3, carbon tetraflouride CF4, perflouroethane C2F6
Flat Panel Display - etching and chamber-cleaning processes commonly used in electronics manufacturing	television screens and computer monitors	sulfur hexafluoride SF6, nitrogen trifluoride NF3, and carbon tetrafluoride CF4

2.4 Three emissions estimation methods

There are no methods to accurately measure all anthropogenic GHG emissions in the atmosphere, but that doesn't keep interested parties from trying to estimate them. Some of these efforts are made by targeting the activities that contribute to global warming, while others use proxy data to help with estimates. As the world's scientists and policy makers grapple with this challenge, they search for ways to estimate at the global, national, regional, and facility levels. Below are three recommended methods for approaching the task.

2.4.1 2006 IPCC Guidelines for National Greenhouse Gas Inventories

These guidelines, published by the International Protocol on Climate Change (IPCC), are proposed for national level emissions estimation and consider such data as domestic production, imports, and exports of chemicals and the products and processes for which they are used. While such data may be available at the national level, it can be nearly impossible for local and regional policy makers and municipalities to collect and use at appropriate scales for analysis. Part of the challenge stated in this publication is that chemical manufacturers and consumers often protect their data due to confidentiality concerns. For instance, a manufacturer of foam products or air conditioning systems may not want its competitors knowing how much HFC-134 or HFC-410 they are using because it may reveal too much about their industrial processes. To overcome such concerns and protect fine-grained industrial secrets, databases for public use are often developed and maintained at the broad regional level. Because regional data is more geographically vague than data made available at perhaps the scale of a square mile grid or even at the county scale, this helps to protect the industrial confidentiality of individual firms (Intergovernmental Panel on Climate Change, 2006). This reference is used throughout section 1.4.1.

Some additional challenges proposed in this publication revolve around whether to generate estimates based on actual emissions or potential emissions, prompt emissions or banked emissions, and the fact that some materials only function when they are contained, while others function only when they are emitted.

Actual emissions may occur when solvents are used to manufacture semi-conductors while potential emissions may be the refrigerants stored in an air-conditioning unit which may leak out slowly over 10 years, be released due to appliance malfunction, or, more optimistically, be responsibly recaptured at the time of disposal. Prompt emissions can be described as the use of an aerosol product by a consumer shortly after purchase, while an example of banked emissions may be the propellant in a home fire extinguisher which sits in a kitchen cabinet for 10 years. An example of a contained product is the refrigerant which must stay in a refrigerator’s system to work versus emitted products, such as canned air used to clean photography equipment, which must be ejected from its canister in order to serve its function.

The IPCC outlines what it calls tier 1 and tier 2 approaches for making estimates which both take into account lag times of the emissions, which may be many years in the case of refrigerants and closed cell foams. Tier 1 datasets are aggregated at the application level while the tier 2 approach estimates each sub-application separately. An example of the distinction between application and sub-application is that foam manufacturing is an application, while open-cell and closed-cell foam are sub-applications. If both sub-applications use similar chemical blends, have similar emission patterns, and data gathering methodologies, then their emissions data can be aggregated in a tier 1 approach. Another example, fire protection, also has two major sub-applications, but each has unique emission characteristics and a disaggregated tier 2 method will produce better emission estimates.

While the IPCC provides useful insight into many of the challenges of emissions accounting, the data needed for this protocol is not publically available at the scale required for analysis within a single MSA.

2.4.2 World Resources Institute - GHG Protocol HFC Tool

The HFC tool was developed by the World Resources Institute (WRI) and the World Businesses Council on Sustainable Development (WBCSD). It is for use by companies for calculating and reporting direct hydrofluorocarbon emissions from the refrigeration and air-conditioning equipment which they own and operate. That equipment would have, before the Montreal Protocol took effect, been using CFCs and HCFCs which are ozone depleting substances, but are now using the HFCs which have been deemed suitable replacements. Despite their more benign impact on atmospheric ozone, their global warming potential is still hundreds of times more impactful than carbon. In the case of refrigeration and AC usage, the detrimental GHG’s find their way into the atmosphere during manufacturing of the equipment, leakage during use or servicing, and at the time of disposal, both from the refrigerant gases and those stored in their insulating foams.

This protocol suggests a “sales based approach” for equipment manufacturers and owners who service their own equipment. In those cases, accounting is done by recording the volume of refrigerants installed in the new equipment, the volume and frequency of additional refrigerants added during servicing of equipment, and how much refrigerant they safely recover at the time of disposal (World Resources Institute, 2005). This reference is used throughout section 2.4.2.

The "lifecycle stage approach" is recommended for equipment owners who use a third party to service their equipment. The process is similar to the sales based approach except that it involves the manufacturers, owners, and those who service the equipment to act as a team to account for how much refrigerant is used to fill new equipment during installation, how much is needed to top-off equipment during servicing, and how much is safely recovered at the time of disposal. In both cases, the refrigerant which cannot be accounted for is assumed to have been emitted into the atmosphere. If the owner of the equipment determines that their leak rates between servicing are high, it can quantify the resulting GWP based on provided tables listing GWP for common gases and blends of gases.

While this protocol provides accounting guidance for companies to track and report their data, such data is rarely made publicly accessible. Such close accounting at all the billions of potential locations of intentional or accidental emissions would be extremely helpful in getting closer to an accurate accounting at all geographic levels of aggregation, however that may have to wait until there is broad public belief that such close data measuring, reporting and accounting is worth the effort and expense.

2.4.3 EPA's *Draft Regional Greenhouse Gas Inventory Guidance*

The Draft Regional Greenhouse Gas Inventory Guidance document was prepared by the EPA in 2010 to assist municipalities and planning organizations in calculating their local and regional contributions to global climate change. The EPA protocol breaks down emissions activities into six categories and seventeen sub-categories, and provides an equation for each to facilitate the estimation of GHG emissions.

Table 9 highlights the emissions categories and sub-categories identified by the EPA (US EPA, 2010). This reference is used in the text and tables throughout section 2.4.3.

Table 9: The six GHG source categories and their seventeen sub-categories (US EPA, 2010a)

Source	Sub-category
Direct Fuel Use and Electricity	Residential
	Commercial
	Industrial
	Electric Power
Transportation	Highway Vehicles
	Aviation
	Marine
Industrial Processes	Ozone Depleting Substitutes
	Iron and Steel
	Cement
Agriculture	Agricultural Soils
	Manure Management
	Enteric Fermentation
Waste	Solid Waste Management
	Wastewater
Land Use, Land-Use Change, and Forestry	Forest Carbon
	Urban Trees

The relevant category for this paper is industrial processes with the three sub-categories of ozone depleting substitutes, iron and steel production, and cement production. These top three sub-categories compose approximately 65% of industrial GHGs, and this protocol leaves out the remaining nineteen sub-categories because each, on its own, is such a small fraction of the total and so varied that they are too hard to estimate at regional levels. The percentage of industrial emissions allocated to each of those sub-categories is displayed in table 10.

Table 10: The main components of the industrial processes sector of GHG emissions and their values, as estimated by the EPA for 2007 (US EPA, 2010a)

Source/Sector	2007 US Emissions MMTCO2E	Percent of Gross US Emissions	Percent of Industrial Process Sector Emissions
Industrial Processes	**350.9**	**4.90%**	**100%**
Substitution of Ozone Depleting Substances	110.1	1.50%	31.40%
Iron, Steel and Metallurgical Coke Production	73.5	1.00%	20.90%
Cement Production	45.2	0.60%	12.90%
All Others (19 total)	20.5	0.30%	34.60%

Of the three primary contributors to industrial sources of GHGs, ODS substitutes is the largest within the United States. Its five sub-sectors are refrigeration and air conditioning, aerosols, foams, solvents, and fire protection. Table #10 displays those five industrial sub-sectors and their annual volumes in millions of metric tons of CO2 equivalence (MMTCO2E).

Table 11: The five sub-sectors within the ODS substitutes sector of industrial emissions, as estimated by the EPA for 2010 (US EPA, 2014b)

United States EPA values for the year 2010	
Sub-sectors within ODS substitutes	Emissions of ODS Substitutes (MMTCO2E)
Refrigeration/Air Conditioning	120.5
All others	17.9
Aerosols	9.3
Foams	5.4
Solvents	1.3
Fire Protection	0.9

The EPA protocol states that because the uses are widespread and the methods and data needed to estimate the emissions are complex, a detailed analysis of where the materials are used and emissions occur is not possible. At the national level the EPA tracks more than fifty use categories, but has no recommended model for doing this accurately at the regional or state level. Instead, they recommend that municipalities allocate the national figures for ODS substitutes to their geographies based on their local populations and GDPs. To help accomplish this, the protocol provides an equation to use which allocates national values for refrigeration and A/C emissions based on local population and national values for the remaining four sub-categories based on local GDP. Using this protocol, a municipality of any size (village, city, county, state, region) can generate an estimate for ODS substitute emissions as long as population and GDP values are available.

In table 10, after ODS substitutes, the next two sectors are iron, steel and metallurgical coke production, at 31.4%, and cement production, at 20.9%. In the next section, Section 3 Research Design, it will be demonstrated that production activities in those two industrial sectors are not present in the NYC-MSA.

3. Research Design of three GHG estimation methods

Section 3 describes the three methods used to calculate emissions estimates for the NYC-MSA using the EPA's recommended protocol, using the BLS's data on employment by county, and using the EDGAR database on global emissions allocated over a global grid.

3.1 Method #1: Using the EPA's *Draft Regional Greenhouse Gas Inventory Guidance*

The Draft Regional Greenhouse Gas Inventory Guidance document, as described above in section 1, provides formulas for generating baseline GHG emissions estimates for industrial contributors as well as all other sectors of the economy.

As displayed in Table 10, above, within the Industrial Processes section of the protocol document, the three contributors to greenhouse gas emissions that are considered substantial enough to be tracked are Ozone Depleting Substitutes, Iron and Steel Production and Cement Production. Figure 7 reveals that there is only one mini-mill steel mill in the NYC-MSA and the mini-mill designation means that it produces steel from scrap metal. Mini-mills are distinct from integrated steel mills which incorporate coke-making, iron-making, and the heating of iron-ore, coal, and limestone in the steel production process. As with cement manufacture, the process of heating limestone at an integrated steel mill releases a lot of CO2. It is this CO2 which ranks steel production and cement production at numbers two and three on the industrial processes sector emissions list in table 10. As mini-mills are essentially just processing scrap metal, and there is only one of them in the entire NYC-MSA, steel and iron production are really not a factor in the industrial processes sector in this region. Figure 7, showing a single mini-mill location in New Jersey, effectively discounts emissions from iron and steel manufacture from the NYC-MSA region.

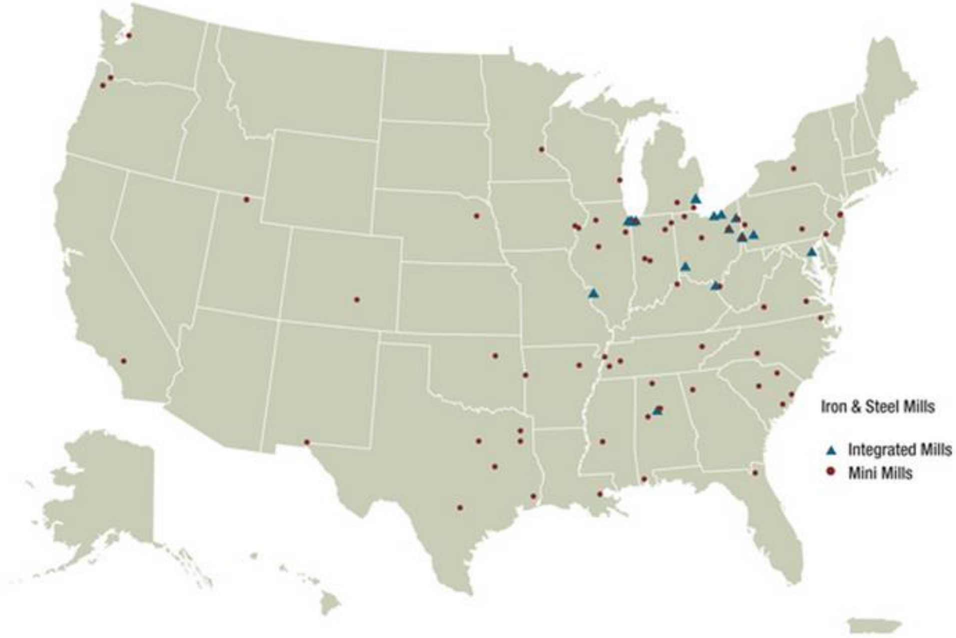

Figure 7: Iron and steel mills and mini-mills within the United States (US EPA, 2013a)*[1]

Figures 8, 9, and 10 show the locations of cement production business offices, production plants and shipping terminals in the region. Figures 8 and 9 reveal that, while there are a few offices and distribution terminals, there are no cement manufacturing plants within Connecticut or New Jersey. Figure 10 reveals that while there is one plant very near to the NYC-MSA, in Cementon, NY, it is actually located in Greene County, which is just outside of the study area (Portland Cement Association, 2015).

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[1] This map was created by the US EPA

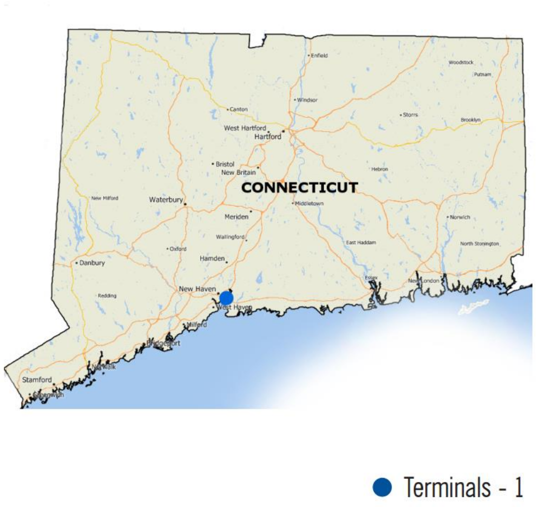

Figure 8: Connecticut cement facilities (Portland Cement Association, 2015)*[2]

Figure 9: New Jersey cement facilities (Portland Cement Association, 2015)

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[2] Figures 8, 9, 10 were created by the Portland Cement Association

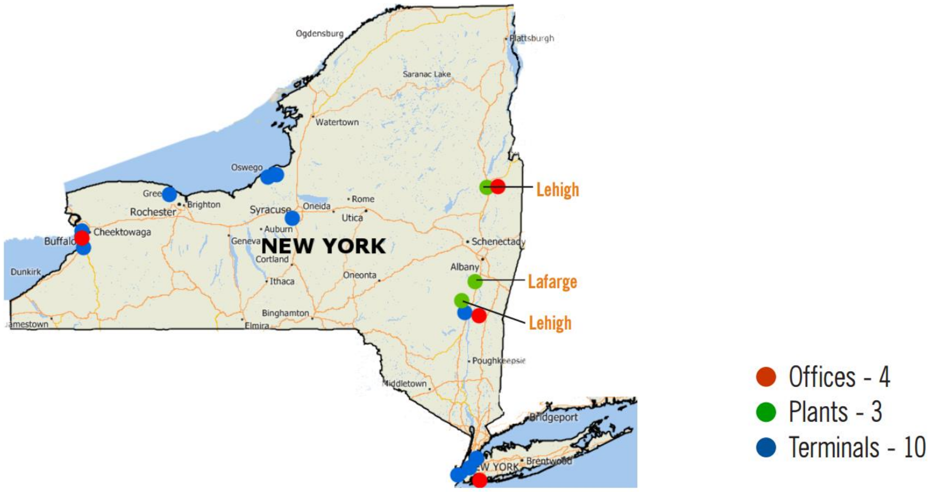

Figure 10: New York cement facilities (Portland Cement Association, 2015)

With iron, steel, and cement manufacture having such negligible or no presence within the NYC-MSA, that leaves ODS substitutes as the sole source of estimable emissions using the EPA's protocol (US EPA, 2010a). The following steps us the same EPA reference and work through the EPA's guidance document for ODS substitutes:

Step 1 – Set the geographic boundaries for the analysis

The boundaries for the NYC-MSA are shown in figure 1, in Section 2.1.1, and are composed of the thirty-one counties identified by RPA.

Step 2 – Identify the equation

For this study, because ODS substitutes is the only sector being analyzed, the following equation provided by the EPA is all that is needed for allocating emissions to each of the five sub-regions:

$$
\begin{aligned}
&ODS\ Substitute\ Emissions \\
&= National\ Emissions\ from\ Refrigeration\ AC\ (MTCO2E)\ x\ \left(\frac{Population(region)}{Population(nation)}\right) \\
&+\ National\ Emissions\ from\ All\ Other\ ODS\ Substitute\ Subsectors\ (MTCO2E) x\ \left(\frac{GDP(region)}{GDP(nation)}\right)
\end{aligned}
$$

Step 3 – Find the components to complete the equation for each sub-region

The equation for estimating ODS substitutes requires the discovery of six variables for the year 2010:

1. National Emissions from Refrigeration: The EPA has a published value of 120.5 terra-grams of CO2 equivalence (TgCO2E) contributed by the Refrigeration/Air Conditioning subsector of Industrial GHG Emissions for the US for the year 2010. The value of 120.5 terragrams equal is 120.5 million metric tons of carbon dioxide equivalence (MMTCO2E), shown in table 11(US EPA, 2014b).

2. Population (region): The US Census Bureau has published population levels for each county in the United States. In this study the counties are aggregated to the five sub-regions and their populations are shown in table 2.

3. Population (nation): The US Census Bureau has a published population level for the United States, shown in table 4.

4. National Emissions from All Other ODS Substitute Subsectors: The EPA has a published value of 17.9 TgCO2E, or 17.9 MMTCO2E, contributed by the other four sub-sectors (Aerosols, Foams, Solvents, and Fire Protection) within the Industrial GHG sector, shown in table 11 (US EPA, 2014b).

5. GDP (region): While most of the variables required for the equation are available directly at the required administrative level, Gross Domestic Product values at the county level are not. However, the BEA does publish GDP for all MSA's in

the United States, so to allocate GDP values at the county level, it is necessary to do some interpolation and extrapolation. Accomplishing this for all thirty-one counties is done in steps A, B, and C, below.

Step A – The Bureau of Economic Analysis publishes a GDP value for what they define as the New York Metropolitan Statistical Area, including twenty-five counties, which is not perfectly aligned with the thirty-one counties used in this paper as the NYC-MSA, but is similar. The difference is that the BEA excludes two New York counties, two New Jersey counties and all three Connecticut counties which are needed for the MSA defined for this paper. The BEA also includes one county in Pennsylvania which is not needed. Allocating GDP values to the BEA's twenty-five counties was done by portioning the GDP among the twenty-five counties based on their relative Total Incomes (available from the BEA at the county level). The GDP allocated for the single Pennsylvania County can be left out of the final equation. Step one yields the GDP allocation for twenty-four counties, leaving seven counties without GDP values.

Step B - Four of the seven remaining counties comprise their own MSA's and, since the BEA publishes GDP values for all MSAs, those GDP values can be used directly without interpolation. This brings the total to twenty-eight counties with assigned GDP values.

Step C – GDP for the remaining three counties can be extrapolated by adding up all the GDP values for the first twenty eight counties, using all of the Total Income values for the thirty-one counties, and then assigning GDP values to the final three counties based on each county’s relative Total Income value. GDP values are listed for all thirty-one counties, and aggregated to all five sub-regions, in table 5.

6. GDP (nation): The BEA has a published GDP value of $1,296,498,449,284 for the United States in 2010, shown in table 6.

A strength of this protocol is that it does provide a method for calculating an estimate for any geographic area, be it city, state, county, etc. for which GDP and population are known. As those are generally publically available data, this does seem to be a good protocol for estimating GHGs for the five sub-regions of the NYC-MSA. One drawback however, is that for a metropolitan area like New York, the population and GDP tend to be quite centrally located while a lot of manufacturing and other industry, which may be contributing the GHGs, is generally located outside of the city center. The equation utilized in this protocol does not account for the geographies of the industrial activity, at least at the sub-regional scale. The results of this equation and corresponding maps are displayed in section 3.1.

Once the calculations are completed for industrial GHG emissions, the question remains: Do population levels and GDP provide enough information to produce an accurate representation of relative ODS substitute emissions in the NYC-MSA at the sub-region level?

After establishing the allocation of industrial GHG emissions in the NYC-MSA using the EPA Protocol, and mapping that allocation as a baseline, the next task is to find alternative methods of allocation by looking more closely at the industries involved, by understanding exactly which ODS substitutes they use, how they use them, and to what degree the related activities are conducted in each of the five sub-regions of the NYC-MSA.

The following are descriptions of two alternate methods for estimating the ODS substitutes in the NYC-MSA. The first will approach the problem from the left side of table 8, using the Bureau of Labor Statistics' (BLS) data to examine the industries that use and produce the relevant chemicals, and the second will approach the problem from the right side of table 8, examining data that is collected, organized, and maintained in a project of the European Commission's Joint Research Centre and the Netherlands Environmental Assessment Agency. The database is called the Emissions Database for Global Atmospheric Research (EDGAR) and makes the data publically available with longitude and latitude values so that it can be mapped and analyzed.

3.2 Method #2: Using the BLS's employment data

One fairly comprehensive, publicly available data source to use for understanding the geography of industrial activity is the United States BLS. Understanding the geography of employment levels in activities such as foam, semiconductor, or flat screen manufacturing will perhaps provide a more accurate picture of the sub-regions in which the ODS substitutes are being used and entering the atmosphere.

The BLS provides data on employment by occupation and by industry. The distinction between occupation data and industry data is explained in the following example: If a researcher is looking for employment levels in foam manufacturing using *occupation* data for a specific geographic location, he/she will find the number of factory workers who work in foam manufacturing plants and therefore directly involved with the activities responsible for emissions; however, if he/she is looking for employment levels in foam manufacturing using *industry* data for a specific geographic location, the result may include lawyers, accountants, janitors, and security guards who work for foam manufacturing firms, and that data might just be reflecting the location of a headquarters for a foam manufacturing company, providing no information of where the ODS substitutes are actually being used.

While occupation data would serve as a much more accurate proxy than industry data, the occupation data is only made available by the BLS at the state level, and consequently is too geographically vague to be used in this study. County level data is, however, available for *industry* data. While industry data is the less preferable of the two, it can be aggregated at the sub-region level, and so it is this data which will form the basis for this method of analysis.

The Bureau of Labor Statistics uses a classification scheme known as the North American Industry Classification System (NAICS). In this scheme, a two-digit code is the broadest category. For instance all manufacturing activities are encoded with numbers 31, 32, or 33. Mapping employment levels using data from those three codes would produce a map displaying all manufacturing activity in the counties of interest. A three-digit code goes one step deeper: 334 is for Computer and Electronic Manufacturing. Deeper still is 3341 for Computer and Peripheral Equipment Manufacturing. The finest grain data is represented by six-digit codes, such as 334112 for Computer Storage Device Manufacturing. (United States Bureau of Labor Statistics [US BLS], 2015)

By pouring over the long list of NAICS codes, those codes most closely associated with the activities listed in table 8 can be selected to yield the proxy data for this method of estimating the emissions of ODS substitutes. Table 12 displays the relevant NAICS codes and groups them using the same five industrial sub-sectors as the EPA uses in its protocol (refrigeration and A/C, aerosols, foams, solvents, and fire protection). For aerosol and fire protection there are no relevant NAICS codes which are good enough matches to include in the analysis.

NAICS data is made available in tables by county code, so each county is populated with data for each industry. The data includes “employment level”, which is the number of workers, “annual wages”, which are the wages paid in that sector for that county, and “number of firms”, which is the number of companies for that sector in that county. However, once downloaded for initial analysis, a vast majority of the data for employment level and annual wages were found to be left empty, rendering those categories nearly useless for analysis. In contrast, for almost all of the counties, the number of firms data were populated. Staff from the BLS explained that industrial firms often have an interest in keeping their employment levels data private from competitors and consequently request that the BLS does not release it to the public. The BLS believes that in most cases the number of firms data is adequately vague to protect industrial privacy. While the actual number of workers would serve as a better unit for proxy data, the number of firms data is much more universally complete in the industries and counties of interest and consequently is used in this study. Further descriptions and discussion of the codes for each of the five sub-sectors are available in Appendix B.

Table 12: The NAICS employment codes which are most relevant to the industrial sub-sectors within the ODS substitutes sector (US BLS, 2015)

Industrial sub-sectors	NAICS Category	Employment Codes
Refrigeration and Air Conditioning	Air-Conditioning and Warm Air Heating and Commercial and Industrial Refrigeration Equipment Manufacturing	333415
	Household Refrigerator and Home Freezer Manufacturing	335222
	Food and Beverage Retail Stores	445
	Refrigerated Warehousing and Storage	49312
Aerosol	Aerosol Usage	none
Foam	Polystyrene Foam Product Manufacturing	32614
Solvents	Semiconductor and Other Electronic Equipment Manufacturing	3344
	Photovoltaic Cell Manufacturing	334413
	Computer and Peripheral Equipment Manufacturing	3341
	Flat Panel Display Manufacturing	334119
	Audio and Video Equipment Manufacturing	3343
	HCFC-22 Production	325120
Fire Protection	Fire protection equipment leakage, accidental discharges, and use during fire extinguishing	none

Once the relevant employment data is collected and aggregated to the refrigeration and A/C, foam, and solvent industrial sub-sectors for the thirty-one counties in the NYC-MSA, it is then aggregated to the five sub-regions and projected, using a GIS, to three maps, one for each industrial sub-sector. No maps for aerosol or fire protection need to be created as they have no usable employment data. One additional map is also created aggregating all of the employment data together. The maps provide a clear ranking of the five sub-regions.

The same employment data is displayed in pie chart in figure 15, in section 3.1, by sub-region to provide a visual ratio of the data relative to the other estimation methods.

3.3 Method #3: Using the EDGAR Database of emissions distribution

The EDGAR project collects, compiles, and provides data for twenty-four GHGs and provides the data in a format that can easily be projected in a GIS in the form of gridded maps at the resolution of 0.1x0.1 degrees. In addition to data for CO2, CH4, and NO2, there is map-able data for twenty-one fluorinated GHGs including eleven HFCs, eight PFCs, SF6, and NF3. Each gas is provided in a separate file with the unit “metric tons” of emissions for that chemical. Since each of those gases has its own GWP value, each emissions value needs to be multiplied by the GWP value in order to standardize the outcomes as CO2 equivalence.

The EDGAR data are compiled from emissions data for area, line and point sources. An example of area data would be for agricultural pollutants in a farming region; an example for line data would be exhaust emissions over a road network; an example of point sources would be manufacturing locations, which likely compose the majority of the industrial emissions data. The emissions are then aggregated at the national level and allocated to each point on the mapped grid based on proxy data chosen by the research team. The proxy data library for EDGAR clarifies that industrial source emissions are distributed to each grid cell based on the presence or absence of production facilities and also by using some urban population threshold value. The provided documentation stresses that there is a lot of uncertainty about accuracy in the dataset, especially for fluorinated gases, due to the challenges of choosing emissions factors for the variety of industrial activities (European Commission, 2012a).

Table 7, in section 2.2.4, includes nineteen distinct fluorinated GHGs across the five industrial sub-sectors, with some gases in the table being repeated in multiple industries. Of those nineteen gases associated with the five target industries, sixteen gases have data provided by EDGAR. Of the sixteen gases, only twelve are found on the geographic grid within the five geographic sub-regions of the NYC-MSA.

Because several of the gases span more than one industrial sub-sector, decisions had to be made in a few cases about to which sub-sector some of the gases would be allocated to prevent double counting. For instance HFC-134 is identified as being used in the refrigeration and A/C and the foams manufacturing sub-sectors, and consequently it was assigned to refrigeration and A/C.

For this study, these data were projected in a GIS using latitude and longitude assignments over a vector base layer of the five sub-regions of the NYC-MSA. The emissions data points for each of the twelve chemicals were aggregated to their respective sub-regions and then re-projected onto their own maps by sub-region. Once the twelve maps were created, the data was then exported and each of the chemicals was multiplied by its GWP value, shown in table 13. The gases, now with their CO2 equivalence values, were aggregated to their most relevant sub-sector and projected again. One chloropleth map was created for each of the five industrial sub-sectors. This provided five visual ranking maps of the emissions sums. Table 13 shows the twelve relevant chemicals, their industrial sectors, their volumes, GWPs and CO2 equivalence within the NYC-MSA as per the EDGAR database.

Table 13: ODS substitutes from the EDGAR database which are in the NYC-MSA, expressed in CO2 equivalence (European Commission, 2015)

Industrial Sub-sector	Chemical	Reported Volume (tons)	GWP	Emissions in Tons (CO2 Eq.) per Chemical	Emissions in Tons (CO2 Eq.) per Sub-sector
Refrigeration and AC	HFC134	2684	1320	3,542,416	3,542,416
Aerosols	HFC152	462	122	56,341	533,012
	HFC227	130	3660	476,671	
Foams	HFC245	81	1020	82,978	109,800
	HFC365	34	782	26,823	
Solvents	CF4	6	5820	32,154	801,011
	C6F14	2	9140	14,368	
	C2F6	6	12010	74,591	
	NF3	1	740	690	
	SF6	30	22450	666,469	
	HFC23	1	12240	12,738	
Fire Protection	HFC236	4	9650	42,923	42,923

4. Results and Discussion

The results discussed in section 3.1 will be the total emissions estimates mapped for each of the three methods. For these maps, all five industrial sub-sectors are aggregated within their sub-regions. Section 3.2 will take a closer look at some of the finer grained emissions' details.

4.1 Total industrial GHG maps, tables, and charts for each of the three estimation methods

While the EPA's recommended method is a well-considered approach to the goal of estimating ODS substitutes, it is perhaps an oversimplification of the complete picture, as it only utilizes population levels and GDP as the variables, without considering the geographies of the relevant activities or geographies of the relevant chemical materials. It comes as no surprise that, as a sub-region, New York City is displayed as having the highest emissions in the NYC-MSA with all industrial sub-sectors aggregated in figure 11, below. NYC ranks first, followed closely by the New Jersey sub-region. There is then a substantial drop-off of over 58% down to the Long Island, Mid-Hudson, and Connecticut sub-regions.

As with the results of the EPA data analysis, when using the BLS data for the number of emissions related firms as proxy data, the NYC sub-region also sits at the top of the rankings followed closely by New Jersey before a drop-off of over 55% down to the bottom three sub-regions substantially below them. Figure12, below, displays that data.

The results from the mapped EDGAR data look nothing like those from the EPA or BLS data. The biggest difference is that not only does the NYC sub-region not lead in the rankings, but rather it is allocated zero industrial GHG emissions along with nearly zero for the Connecticut sub-region. Instead, the Mid-Hudson sub-region leads in the rankings, which is in stark contrast to the methods using EPA data and BEA data. The drop-off from the Mid-Hudson sub-region down to the second ranking sub-region, Long Island, is a huge jump of over 83%. In contrast, using the EPA and BEA data methods, Mid-Hudson had ranked at the bottom. Since the EDGAR data uses a combination of urban population and industrial production sites as its proxies for distribution of emissions, it seems that either there are no industrial production facilities in the NYC sub-region and nearly none in the Connecticut sub-region that meet its threshold for accounting, or there is incomplete data. The EDGAR data is displayed in figure 13, below.

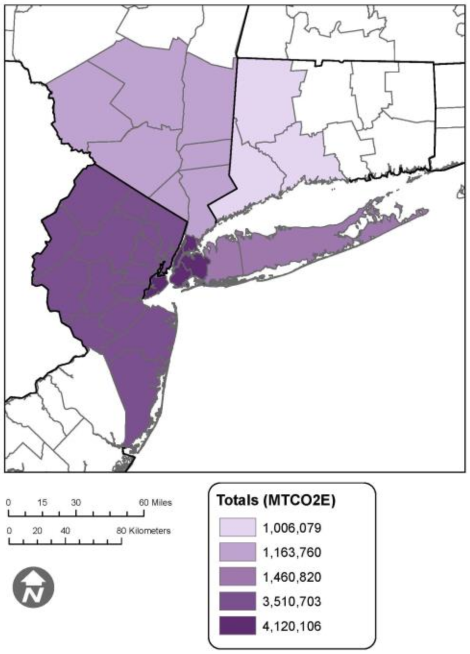

Figure 11: Emissions distribution totals using the EPA's protocol

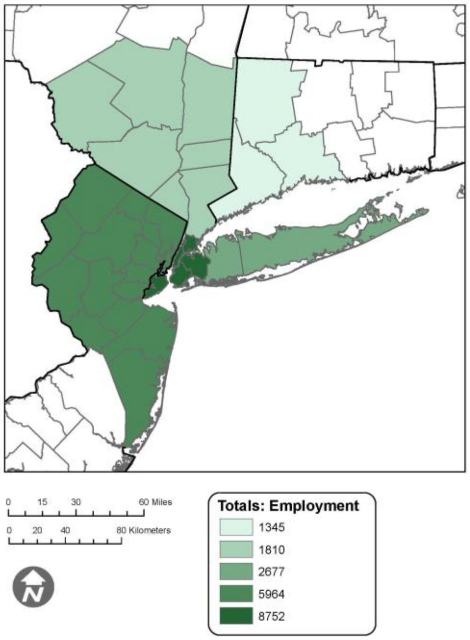

Figure 12: Emissions distribution totals using the BLS data method

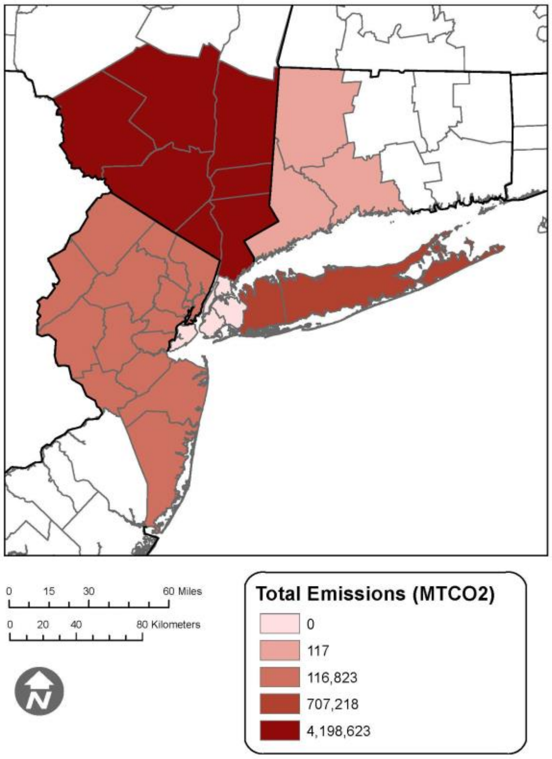

Figure 13: Emissions distribution totals using the EDGAR database method

While figures 11, 12, and 13 for the emissions totals display a clear ranking of each sub-region, tables 14 and 15 provide side-by-side values, and figures 14, 15, and 16 show the sub-regions' relative emissions estimates.

In table 14, the only direct comparison that can be made based on emissions estimate volumes is between the EPA and EDGAR because they are normalized to the same units. In this comparison, one clear detail is that total volumes for EDGAR data are only about 45% of the totals generated using the EPA's recommended protocol. That is a substantial difference but at least still within the same order of magnitude.

Table 14: Side by side comparison of the distribution of emissions by sub-region, using each of the three estimation methods and expressed in absolute terms

	EPA (MTCO2E)	BLS data (Firms)	Edgar (MTCO2E)
Connecticut	1,006,079	1,345	117
New Jersey	3,510,703	5,964	116,823
Long Island	1,460,820	2,677	707,218
Mid-Hudson	1,163,760	1,810	4,198,623
New York City	4,120,106	8,752	0
Totals	11,261,468	20,548	5,022,781

In table 15, one striking detail is seen when comparing EPA results with those of the BLS. For four of the five sub-regions, the results are within two percentage points. For the fifth sub-region, NYC, the results are within 6 percentage points. When comparing two methods that use such completely different data, those GHG emissions distributions are startlingly similar. In contrast, the EPA and EDGAR data methods produce emissions distributions which are quite dis-similar.

Table 15: Side by side comparison of the distribution of emissions by sub-region, using each of the three estimation methods and expressed in percent

	EPA (Percent)	BLS (Percent)	EDGAR (Percent)
Connecticut	9	7	0.0023
New Jersey	31	29	2
Long Island	13	13	14
Mid-Hudson	10	9	84
New York City	37	43	0
Totals	100	100	100

Figures 14 and 15 below further highlight how similar the ratios are for EPA and BLS data. A look at figure 16 makes the EDGAR data results seem quite out of step with the others, at least at this sub-regional scale. In the case of the EDGAR data, the Connecticut and NYC sub-regions do not even register on the pie chart.

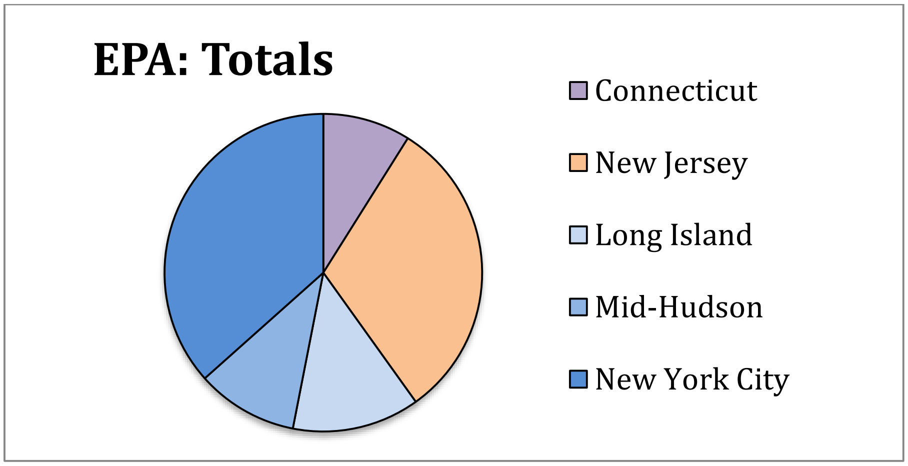

Figure 14: Emission distribution totals using the EPA's protocol

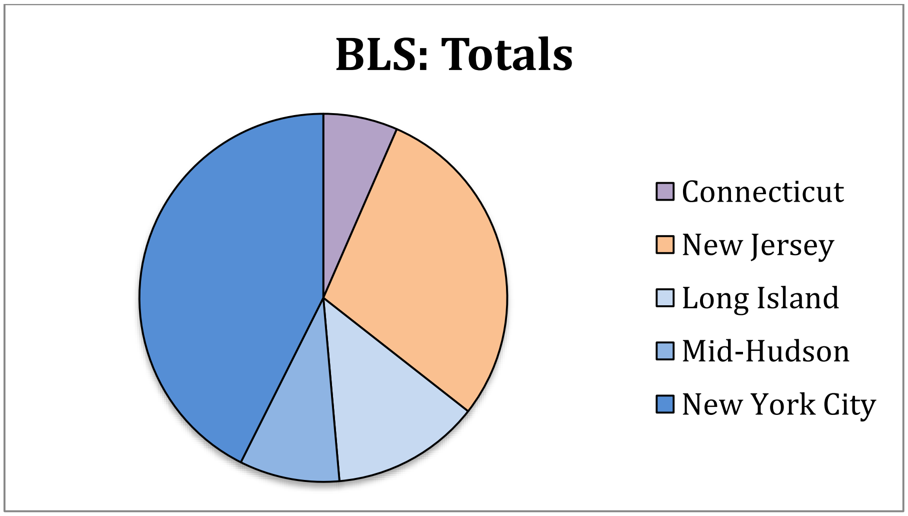

Figure 15: Emission distribution totals using the BLS employment data method

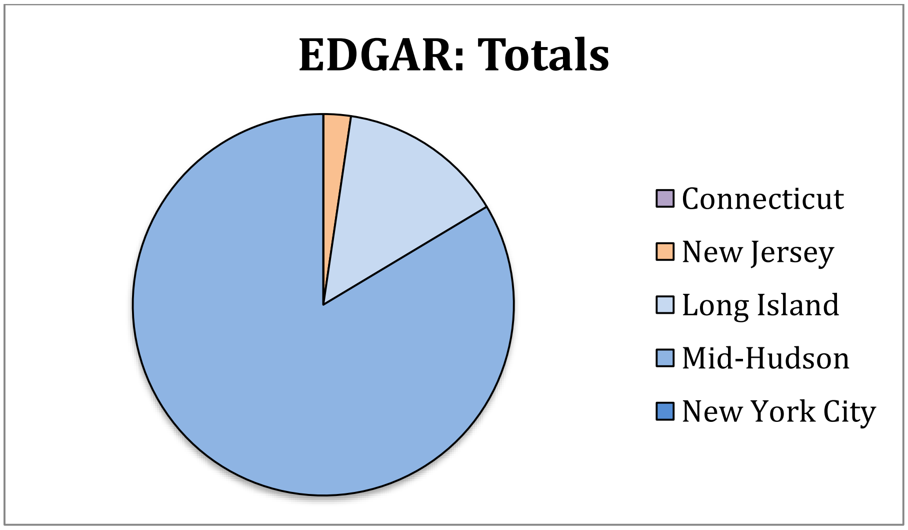

Figure 16: Emission distribution totals using the EDGAR database method

4.2 A closer look at some of the industrial sub-sectors

While the above maps, tables, and charts show the aggregated totals for GHG estimates, a closer look at some of the industrial sub-sectors reveals a slightly different story.

4.2.1 A closer look at some EPA data by sub-sector

While the intent here is to look at each sub-sector separately, because the EPA's equation for applying the proxy data is so simple, there is no variation in the ranking of sub-regions. Whether looking at the refrigeration and A/C, aerosols, foams, solvents, or fire protection sub-sectors, the sub-region rankings are all the same: NYC ranks first, the New Jersey sub-region ranks a close second, the Long Island sub-region ranks a distant third, followed by the Mid-Hudson and then Connecticut sub-regions.

Mathematically, the EPA's protocol treats the refrigeration and A/C sub-sector differently than the other four subsectors. As proxy data, refrigeration and A/C uses the sub-regional population/national population equation and the other four sub-sectors use the sub-regional GDP/national GDP equation. While applying two different equations could result in two different ranking sequences, in this case it doesn't. The reason it doesn't is because population and GDP are distributed among the five sub-regions in an almost identical manner, and so, consequently, the data for all five sub-sectors is distributed almost identically as well.

When viewed at the county level, there are great differences. For instance, Bronx County has 6.2% of the regional population but only 3.6% of the GDP, while, just across the Harlem River, the much wealthier New York County has 7.1% of the regional population and 14.6% of the GDP. But when population and GDP are aggregated at the sub-regional level, their percentages are nearly identical, within 1% point for all five sub-regions. Table 16 shows how the distribution of the two proxy values, population and GDP, are nearly identical to one another, and as a result, so are the resulting emissions estimates.

Table 16: Population and GDP by sub-region

Sub-regions	Population percent (used for Ref.& A/C)	GDP percent (used for all other sub-sectors)
Connecticut	8.9	9.2
New Jersey	31.3	30.9
Long Island	12.7	13.7
Mid-Hudson	10.3	10.4
New York City	36.8	35.8
Totals	100	100

Values for all five sub-sectors are displayed in tables 17 and 18, refrigeration and A/C using population as its proxy data and all other four sub-sectors using GDP.

Table 17: Allocation of refrigeration and A/C emissions by mass and also expressed in percent

Sub-regions	Refrigeration and A/C (MTCO2E)	Percent
Connecticut	769,360	8.9
New Jersey	2,715,103	31.3
Long Island	1,106,878	12.7
Mid-Hudson	895,360	10.3
New York City	3,196,466	36.8
Totals	8,683,167	100

Table 18: Allocation of all other industrial sub-sectors emissions (besides refrigeration and A/C) by mass and also expressed in percent

	All Others (Volumes)				
Sub-regions	Aerosols (MTCO2E)	Foams (MTCO2E)	Solvents (MTCO2E)	Fire Protection (MTCO2E)	Percent
Connecticut	74,880	43,479	10,467	7,246	9.2
New Jersey	251,669	146,130	35,180	24,366	30.9
Long Island	111,961	65,010	15,650	10,835	13.7
Mid-Hudson	84,902	49,298	11,868	8,216	10.4
New York City	292,171	169,648	40,841	28,275	35.8
Totals	815,583	473,565	114,006	78,938	100

4.2.2 A closer look at some BLS sub-sector data

The BLS data analysis uses firms (workplaces) as its unit of measure, and as its proxy data for where industrial GHG emissions are likely being released as part of industrial production, because of negligence, or simply because of the use of leaky equipment. While figure 12, above, shows the aggregated value of all industrial sub-sectors, looking at each sub-sector on its own, unlike with the EPA protocol's results, tells its own story.

4.2.2.1 BLS refrigeration and A/C sub-sector data

The refrigeration and A/C subsector map #14 displays the NYC sub-region as being the top ranked, but breaking it down into its component parts is instructive.

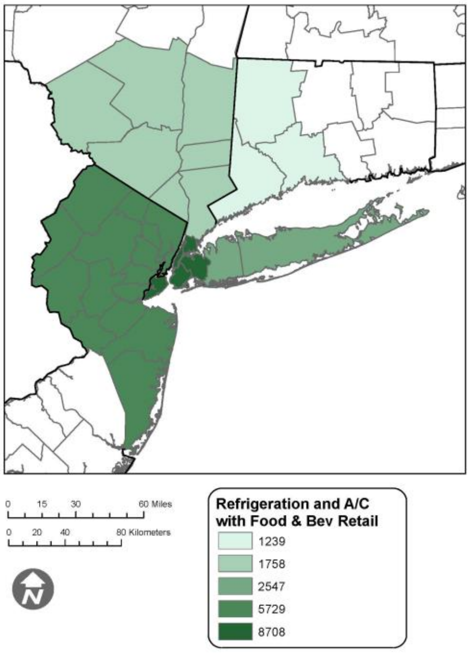

Figure 17: Refrigeration and A/C including Food & Beverage Retail

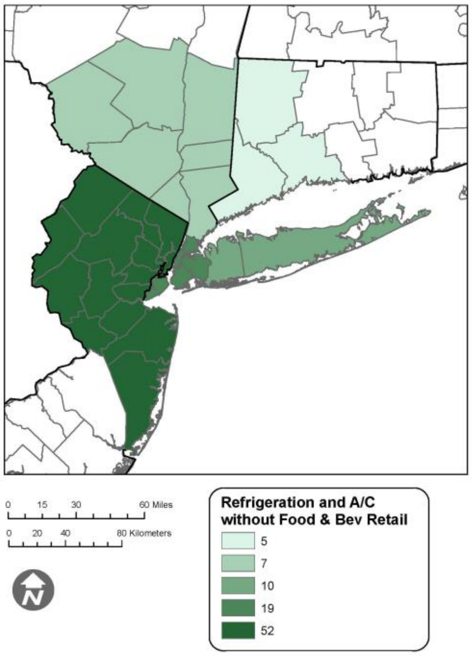

Figure 18: Refrigeration and A/C without Food & Beverage Retail

The four components of the refrigeration and A/C sub-sector are displayed in tables 19 and 20, below. It can be noted that home A/C and refrigeration manufacturing has zero presence within any of the five sub-regions. Table 19 shows the quantity of firms for each component, and table 20 shows their totals and their percent splits by sub-region, both with food and beverage stores, and without them. What is revealed is that the food and beverage store component completely dominates the sub-sector with 99.5% of all the firms counted for this refrigeration and A/C subsector. The components' names are abbreviated in table 19, but provided in their full form in the caption.

Table 19: Allocation of refrigeration and A/C emissions estimated using numbers of related firms

The abbreviated heading names are provided in full form here: Commercial Air Conditioning and Refrigeration Manufacturing, Home Air Conditioning and Refrigeration Manufacturing, Refrigerated Warehousing, and Retail Food and Beverage Stores

	All Refrigeration and A/C (Firms)			
Sub-Regions	Comm AC Rfr Manu	Home AC Rfr Manu	Rfr Wareh	Food & Bev Retail
Connecticut	3	0	2	1239
New Jersey	27	0	25	5729
Long Island	6	0	4	2547
Mid-Hudson	3	0	4	1758
New York City	9	0	10	8708
Totals	48	0	45	19981

Table 20: Allocation of refrigeration and A/C emissions estimated by number of related firms and also expressed as percent by sub-region, both with and without food and beverage retail stores

	Refrig & A/C with Food & Bev Stores		Refrig & A/C excluding Food & Bev Stores	
Sub-Regions	Firms	Percent Split	Firms	Percent Split
Connecticut	1244	6	5	5
New Jersey	5781	29	52	56
Long Island	2557	13	10	11
Mid-Hudson	1765	9	7	8
New York City	8727	43	19	20
Totals	20074	100	93	100

When just three components are aggregated, excluding food and beverage retail stores, the New Jersey sub-sector ranks at the top with 56% of the total followed by NYC at 20%. When the fourth component, food and beverage stores, is included, the NYC sub-region jumps up to the top of this ranking with 43% followed by New Jersey at 29%. Figures 17 and 18 show how the rankings shift when food and beverage retail store locations are removed from the data.

Food and beverage store locations have such a large impact because they make up over 99.5% of all the data in this sub-sector. It is no surprise that this one component swings the top ranking to NYC when the density of the population, figure 3 in section 1.1.2, is considered. Due to NYC’s unparalleled population density within the NYC-MSA, many neighborhoods in NYC can have as many as ten food and beverage stores on a single block. In light of these differences, is it realistic to think that one corner deli store could be as big an emitter of GHGs as one refrigerated warehouse or one refrigeration manufacturing plant?

What makes using the BLS data about firms so challenging is the uncertainty inherent in the data. For instance, while there may be dozens or even hundreds of grocery markets, delis, and beer distributors that keep some sort of records on how much and what blends of refrigerant gases their equipment leaks on an annual basis, for the purposes of this study it has to be assumed that all 8708 stores in the NYC sub-region leak the same amount. Additionally, it has to be assumed that each of the twenty-five refrigerated warehousing facilities in the New Jersey sub-region have the same emissions as those 8708 food and beverage stores in NYC. As mentioned earlier, another assumption that is required is that none of the three firms in the Connecticut sub-region associated with commercial refrigeration and A/C manufacturing are just sales or accounting offices for a company whose production takes place far away from the NYC-MSA.

While the study requires the assumption that all the firms in this dataset have equal emissions, it is tempting to believe that commercial activities are bigger individual polluters than thousands of the tiny corner deli stores in NYC, and that the presence of the delis greatly skews the top ranking for this refrigeration and A/C sub-sector to NYC, when it might more accurately belong to potentially much larger commercial activities in New Jersey. It should be noted that New Jersey leads the rankings in every other component of the industrial emissions profile.

Another weakness of using this data is that there is no good BLS data available for the aerosol or the fire protection sub-sectors, so only the foams and solvents data are discussed in the following sections.

4.2.2.2 BLS solvents sub-sector data

A look at each of the four employment components of the solvents sub-sector shows New Jersey as the top ranked sub-region in the solvents sub-sector. Table 21 shows the four components of the solvents sub-sector, which is dominated by semiconductor manufacturing with 402 firms, equaling 74% of the sub-sector. Aside from the dominance of the semiconductor manufacturing component among the data, there are no real surprises in table 21, and the New Jersey sub-region ranks first in three of the four component categories, all except audio visual equipment manufacturing. The components' names are abbreviated in table 21, but provided in their full form in the caption.

Table 21: Allocation of solvents emissions by sub-region, estimated by number of related firms

The abbreviated heading names are provided in full form here: Semiconductor Manufacturing, Computer Manufacturing, Audio Visual Equipment Manufacturing, HCFC-22 Manufacturing

	Components of Solvents Sub-sector (Firms)			
Sub-Regions	Semi Manu	Comp Manu	AV Eqiup Manu	HCFC-22 Manu
Connecticut	79	9	9	0
New Jersey	168	33	10	14
Long Island	100	18	11	0
Mid-Hudson	35	10	3	2
New York City	20	11	11	1
Totals	402	81	44	17

Table 22 displays the top-ranking of the New Jersey sub-region which is home to 41% of all the solvents related firms in the NYC-MSA. Notable is the fact that NYC sits at the bottom of the rankings in the solvents sub-sector.

Table 22 - Allocation of all solvents emissions by sub-region, estimated by number of related firms and also expressed as percent

	All Solvents	
Sub-Regions	Firms	Percent Split
Connecticut	97	18
New Jersey	225	41
Long Island	129	24
Mid-Hudson	50	9
New York City	43	8
Totals	544	100

4.2.2.3 BLS foams sub-sector data

Foams manufacturing data, in the BLS data set, are conveniently organized in a single NAICS code. Table 23 shows the number of firms related to foams manufacturing and the percent split by sub-region. With 56% of the foams data in the New Jersey sub-region, 22% in the Connecticut sub-region and just 6% in NYC, New Jersey emerges clearly as the top ranked emissions sub-region.

Table 23: Allocation of foams emissions by sub-region, estimated by number of related firms and also expressed as percent

	Foams	
Sub-Regions	Firms	Percent Split
Connecticut	4	22
New Jersey	10	56
Long Island	1	6
Mid-Hudson	2	11
New York City	1	6
Totals	18	100

4.2.2.4 All sub-sectors, excluding food and beverage retail stores

Revealed in the sections above is the fact that for all BLS sub-sectors in this analysis, and almost all components of those sub-sectors, the New Jersey sub-region ranks first in the number of emissions related firms. Table 24 shows the dominance of the New Jersey sub-region in all sub-sectors when the single component, food and beverage retail, is excluded.

This casts some doubt on the relevance of food and beverage retail stores as a component in estimating GHGs because, without that single component, table 24 has the New Jersey sub-sector consistently ranking first at 56%, 41% and 56% for the three sub-sectors.

Table 24: Allocation of all emissions sub-sectors by sub-region, estimated by number of related firms for each sub-sector that has relevant data, and also expressed as percent

	Foams		Solvents		Refrig & A/C excluding Food & Bev Stores	
Sub-Regions	Firms	Percent Split	Firms	Percent Split	Firms	Percent Split
Connecticut	4	22	97	18	5	5
New Jersey	10	56	225	41	52	56
Long Island	1	6	129	24	10	11
Mid-Hudson	2	11	50	9	7	8
New York City	1	6	43	8	19	20
Totals	18	100	544	100	93	100

It is worth repeating that, within its own sub-sector, food and beverage retail composes 99.5% of all refrigeration and A/C related firms. Additionally, among all BLS data analyzed, food and beverage retail dwarfs all other data and composes 96.8% of all firms. With such a massive impact on the analysis, some important issues rise to the top.

1. Do food and beverage retail stores belong in such analysis?
2. If they do belong, there needs to be a better way to understand their emissions impact.

Section 4.2.3 A closer look at some EDGAR sub-sector data

The EDGAR data totals stand out as being distributed to the five sub-regions quite distinctly from the EPA and BEA distributions, as displayed in tables 14 and 15, in section 3.1. Looking more closely at each of the five component sub-sectors reveals an interesting pattern. What is revealed is that the percent split of EDGAR data distributed to each sub-region is nearly identical in all cases. That is to say, the Mid-Hudson sub-region is allocated approximately 84% of the emissions from each sub-sector, the New Jersey sub-region is allocated approximately 2% for each sub-sector, and the other three sub-regions mirror this pattern.

Closer examination of the projected EDGAR data provides another insight. For the chemicals in the refrigeration and A/C, aerosols, foams, and fire protection sub-sectors, the emissions data in the EDGAR dataset is distributed to the same five grid cells; two grid-cells in New Jersey, two in Long Island, and one in the Mid-Hudson. The only sub-sector that differs is solvents. For that sub-sector, there are one hundred and thirty grid cells with data, and each of the materials in the solvents sub-sector has an extremely high GWP, as displayed in table 13. The surprise is that all the solvents grid cells only total to 16% of emissions in the NYC-MSA after being adjusted to CO2E, while refrigeration and A/C, with only five grid cells, totals 71% of the emissions. Another detail unique to the solvents sub-sector is that it is the only one with data for the Connecticut sub-region. For that reason, the allocation to sub-sectors is slightly different. This is shown in tables 25 and 26, which show the values and percent splits by sub-region and sub-sector.

Table 25: Allocation of emissions for each sub-sector by mass

	Five Sub-sectors (MTCO2E)				
Sub-Region	Refr & AC	Aerosols	Foams	Solvents	Fire Protection
Connecticut	0	0	0	117	0
New Jersey	82,123	12,359	2,545	18,800	995
Long Island	496,444	74,574	15,386	114,799	6,015
Mid-Hudson	2,963,849	446,079	91,869	660,914	35,913
New York City	0	0	0	0	0
Totals	3,542,416	533,012	109,800	794,630	42,923

Table 26: Allocation of emissions for each sub-sector, expressed as percent by sub-region

	Five Sub-sectors (percent split)				
Sub-Region	Refr & AC	Aerosols	Foams	Solvents	Fire Protection
Connecticut	0.00	0.00	0.00	0.01	0.00
New Jersey	2.32	2.32	2.32	2.37	2.32
Long Island	14.01	13.99	14.01	14.45	14.01
Mid-Hudson	83.67	83.69	83.67	83.17	83.67
New York City	0.00	0.00	0.00	0.00	0.00
Totals	100.00	100.00	100.00	100.00	100.00

For the refrigerant HFC-134, Dutchess County, and for that matter all of the Mid-Hudson sub-region, has data in only one grid cell. The area is fairly rural in nature with a county population of only 297,772. However, that grid cell is assigned 2245 tons of HFC-134 emissions. In contrast, Suffolk and Nassau Counties, the two components of the Long Island sub-region, each have one grid cell of HFC-134 data and they are much more populated, with a combined population nearly ten times as high of 2,836,048. If urban population and the presence of industrial production facilities in a grid cell are the two proxy criteria, then Nassau and Suffolk would certainly combine to have a higher emissions value. However, their combined assigned value is only 376, and table #25 displays that the Mid-Hudson sub-region is estimated to produce 84% of the emissions while Long Island only registers at 14%. Clearly the EDGAR emissions distribution method is using other proxy methodology which is not documented on their web-site.

4.3 Comparing the five sub-sectors

The discussion up to this point has centered on comparing how the five sub-regions compare to one another using the three methods. Table 27 turns the question on its side to compare how the five sub-sectors compare using the three methods. While the

EPA and BLS data had provided such similar results among the five sub-regions, in figures 14 and 15, and the EDGAR data in figure 16 seemed like such an outlier, table 27 reveals that perhaps the EDGAR and EPA methods may be in closer agreement.

In the results from each of the three analysis methods, the refrigeration and A/C sub-sector rank first, each with at least 70% of emissions, but the BLS employment data is so dominated by this sub-sector that it appears to be the outlier in this NYC-MSA analysis. Among the remaining four sub-sectors, the EPA and EDGAR data are reasonably close in the aerosols and fire protection sub-sectors as well, and, as stated earlier, there are no relevant aerosols or fire protection BLS data with which to compare. One final point of agreement with the EPA and EDGAR analysis methods is that they can be compared using the same CO2E units, whereas the BLS data is expressed in numbers of firms.

Table 27: Allocation of estimated emissions for each sub-region expressed as percent

	Percent Split		
Sub-sector	EPA	BLS	EDGAR
Refrig & A/C	77	97	70
Aerosols	7	0	11
Foams	14	0.01	2
Solvents	1	2.99	16
Fire Protection	1	0	1
Totals	100	100	100

5. Conclusions

While it is not possible to conclude whether the best data source for MSAs to use for emissions estimation is population and GDP with the EPA's recommended protocol equation, locations of firms maintained by the BLS, EDGAR data for point sources, or some other publically accessible data, there are some interesting questions and concerns worth raising as a result of this analysis. Perhaps equally interesting are some of the similarities and disagreements between the three methods.

If it could be made available, the following BLS data could make understanding the geographies of emissions more accurate:

1. More complete data about employment levels (numbers of workers) at the county level would be very helpful, because currently the only complete data is for numbers of firms by county. Employment level data is missing in so many cases that it is unusable.
2. Data at the county level for occupation levels (as opposed to employment levels) woul aid greatly in this type of analysis, because currently this is only available at the state level. The occupation data used in this analysis includes workers who may have nothing to do the actual industrial activities of each firm.

While being able to see the geographic distribution of industrial workers and firms will not reveal actual quantities of emissions, it can help to support or challenge any other estimation methods. However, as long as industrial secrecy is of great importance to those reporting, an increased level of detail available to the public will not be forthcoming.

Perhaps more valuable than transparent labor statistics would be more transparency surrounding how the EDGAR data is collected and distributed. A better understanding of the EDGAR database could be more useful than BLS data because EDGAR provides actual measurement values of GHGs. Clarity of the following would be useful:

1. An explanation of the sources of reported and collected data that the EDGAR database uses would aid in understanding the results of analysis.
2. An improved data proxy library that explains how the collected emissions data is redistributed over its geographic grid would also be valuable.

The fact that the EDGAR database allocated zero emissions to NYC and only 2% to New Jersey makes the current proxy seem suspect and difficult to trust in comparison to the EPA's model. Equally concerning is that for four of the five sub-sectors, there were only five grid cells which were allocated values, and in each of those four cases they were the same five grid cells. Repeated inquiries to the EDGAR administrators went unanswered.

While many questions remain, there was some data agreement which lends support to the EPA's protocol. The two strongest pieces of data are the fact that the EPA and BLS methods produce identical rankings of all five sub-regions for GHG emissions and that the EDGAR method produces values for the refrigeration, aerosol, and fire protection sub-sectors which are rather close to those produced by the EPA method. Though the EPA's method is seemingly so straight-forward and perhaps too simplistic, it seems to produce relevant results. However, for those who are conducting sub-regional analysis using publically accessible data, the questions of exactly where the industrial sources for GHG emissions are located and how much each source emits will remain until much better records are kept and made available.

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Appendix A: Discussion of industrial activities associated with ODS substitutes

Below is a breakdown of the twelve activities which are most closely associated with using ODS substitutes. There is a short description of each, its value to society, how it uses the ODS substitute chemicals, and the specific gases which are emitted. The following reference is used throughout the remainder of Appendix A (United States EPA, 2013b).

1. Refrigeration and Air Conditioning Systems

The activities in this sector which are identified as emissions sources are refrigeration and A/C system manufacturing, servicing, collection and recycling stations for old equipment, use of these systems and appliances in private homes and vehicles, use of these systems in commercial spaces and vehicles, use of these systems in transportation, and storage and retail sale of perishable food items. Accidental emissions can occur during the manufacturing process when the systems are initially filled with refrigerant gases, during servicing when existing systems are being emptied of their gases, refilling of refrigerant gases when those levels become too low for the equipment to work properly, because of leakage during equipment lifespan, because of component failure, and at the time of disposal if the gases are not properly recovered and recycled or destroyed.

The ODS Substitutes which can be emitted by these activities are hydrofluorocarbons (HFCs) and include R-134a, R-404A, R-410A, R-407C, and R-507A. Further discussion of these materials and all other ODS substitutes, listed among the industrial activities below, will be included at the end of this section.

2. Precision Cleaning Solvents

The activities in this sector which are identified as emitting ODS substitutes are the use of solvents for precision cleaning during the manufacturing process of products such as circuit boards for computers, medical equipment, and other electronic devices. Precision cleaning requires a high level of cleanliness to remove materials like solder flux residues to ensure the satisfactory performance of the product being cleaned.

The ODS substitutes which are used and emitted are HFCs, hydrofluoroethers (HFEs) and perfluorocarbons (PFCs).

The first series of volatile non-flammable solvents developed were HCFCs. These compounds suffer from the drawback that they are low, but non-zero, ozone depleting. Thus, they can be considered transitional substitutes. Perfluorocarbons are another class of substance used for precision cleaning, but they have a relatively high global warming potential. These materials therefore may also be transitional substitutes. HFEs are the most advanced of these materials in that they were developed to deplete no ozone when in the atmosphere, but they may not be suitable for all industrial activities (Basu, Kenny-McDermott & Murphy, 1994).

3. Foams

The activities in this sector which are identified as emitting ODS substitutes are production, use, disposal, and even following disposal (e.g., in landfills) if the foam substance is not specially treated. Foams are commonly used for food packaging and take-out containers, insulation in equipment including refrigerated appliances, transport systems, and buildings, and protective packaging of fragile items being shipped. HFCs have replaced the ozone depleting CFCs which were traditionally used in these applications, thanks to the Montreal Protocol which organized the CFC phase-out.

The ODS substitutes which are emitted are the HFC blowing agents R-134a, R-152a, R-245fa, and R-365mfc.

4. Aerosols

The activities in this sector which are identified as emitting ODS substitutes are the use of consumer products such as spray deodorant, hair spray, freeze spray, dust removal products and pharmaceutical products, primarily metered dose inhalers.

The ODS substitutes which are emitted are HFC R-134a, with lesser amounts of R-152a and R-227ea.

5. Fire Protection Equipment

The activities in this sector which are identified as emitting ODS substitutes are equipment leakage, accidental discharges, total flooding system discharge during fire extinguishing in residential and commercial buildings and use of portable fire extinguishers.

The ODS substitutes which are emitted are the HFCs R-236fa and R-227ea.

6. Aluminum

The activity in this sector which is identified as emitting ODS substitutes is aluminum production. Emissions of the PFCs are generated during brief process upset conditions in the aluminum smelting process. At such times, carbon combines with flourine instead of with alumina. Aluminum is used in a wide variety of consumer products such as food packaging and automobiles, and in commercial products such as airplanes and electric power lines.

The ODS substitutes which are emitted are perfluoromethane (CF4) and perfluoroethane (C2F6).

7. HCFC-22

The activity in this sector which is identified as emitting ODS substitutes is the production of HCFC-22 is used both in emissive applications (primarily air-conditioning and refrigeration) and as a feedstock (raw material) for production of synthetic polymers. Synthetic polymers are used to create plastics and synthetic fibers.

The ODS substitute which is emitted is HFC-23.

8. Semiconductors

The activity in this sector which is identified as emitting ODS substitutes is semiconductor manufacturing. A semiconductor is a substance that can conduct electricity under some conditions but not others, making it a good medium for the control of electrical current in circuit boards and other electronic equipment. It is generally a multi-layered wafer of silicon. Dry and wet etching are the processes of masking parts of the semiconductor material during fabrication, and then exposing the unmasked areas to fluorocarbons to chemically remove one or more layers of the unwanted material and leave the desired material in place. Electronic grade solvents are used extensively throughout the semiconductor industry for cleaning equipment, drying wafers, and substrate deposition and removal. (Aldrich Chemistry, 2015)

The ODS substitutes which are emitted are sulfur hexafluoride (SF6), nitrogen trifluoride (NF3), carbon tetrafluoride (CF4), perflouroethane (C2F4) and the HFC R-23.

9. Photovoltaic Cells

The activity in this sector which is identified as emitting ODS substitutes is the manufacture of photovoltaic (PV) cells, also known as solar panels. PV cell manufacturing may use fluorinated GHGs, including CF4, C2F6, and NF3, for etching and chamber cleaning processes. Etching is done on various substrates, including crystalline silicon, amorphous silicon, and other thin-films. CF4 and C2F6 are used during the manufacture of some crystalline silicon PV cells, and NF3 is used during the manufacture of amorphous silicon PV cells.

The ODS substitutes which are emitted are nitrogen trifluoride (NF3), carbon tetrafluoride (CF4) and hexaflouroethane (C2F6).

10. Flat Panel Display Screens

The activity in this sector which is identified as emitting ODS substitutes is the manufacture of flat panel display screens for use as televisions and computer monitors. As with the manufacture of semiconductors and photovoltaic cells, the process involves precision etching and chamber cleaning processes for thin-film transistors on glass substrates, which switch the pixels of liquid crystal displays and organic light-emitting diode displays.

The ODS substitutes which are emitted are perfluoromethane (CF4), perfluoroethane (C2F6), trifluoromethane (CHF3), sulfur hexafluoride (SF6) and nitrogen trifluoride (NF3).

Appendix B: NAICS codes and descriptions

Below are the five ODS substitute sub-sectors, the NAICS codes with which they are most closely associated, and a description of each code. The following reference is used throughout the remainder of Appendix B (US BLS, 2015).

Refrigeration and A/C

In table #9, within the refrigeration and air-conditioning sub-sector, four codes were found which seemed to be most precisely representative of the relevant employment data. 333415 is the code for commercial and industrial refrigeration and A/C manufacture and 335222 is the code for home refrigerator and freezer manufacture. Code 445, for food and beverage stores, includes all locations which likely use commercial sized refrigeration units with the potential to leak during daily use or regular servicing. Code 493120 is for refrigerated warehousing and storage and is included because refrigerated warehousing of perishables has similar potential to leak refrigerant gases.

Aerosols

Within the NAICS code hierarchy, aerosol manufacturing is listed within the 325998 code, however it shares that code with at least 60 other manufacturing process as broad as cat litter manufacturing and baby oil manufacturing. Consequently, this employment code is not nearly precise enough to provide a good proxy for aerosol emissions, and so aerosols emissions are not included in the analysis of employment data.

Foams

The foam manufacturing sub-sector has its very own NAICS code of 32614 which makes this sub-category much more precise. It would have been useful if foam waste recycling and processing had a code, but there is nothing available in the NAICS code structure which would provide that data.

Solvents

The solvents sub-sector is more complex in that the relevant materials are used so broadly in many industries. In some cases they are used for cleaning delicate electronics and in some cases they are used for silicon chip etching. The 3341 code includes computer components manufacturing and includes a nested code of 334119 for flat-panel displays; the 3343 code is for the manufacture of audio and video equipment; the 3344 code is for semiconductors and electronics and includes a nested code of 334413 for solar panels; and the 325120 code captures HFC-22 production which is known for emitting HFC-23 gas. The nested codes for flat-panel displays and solar panels are not analyzed separately from their parent codes, but simply included in table #9 separately because the EPA identifies them as target activities. Their parent codes actually aggregate dozens of other related manufacturing activities which are analyzed together. The codes in table #9 serve as a fairly comprehensive proxy for solvents emissions.

Fire Protection

In the NAICS code hierarchy, code 238220 contains fire sprinkler system installation, however it is buried in that code among about 80 other industries including things like chimney liner installation and lawn sprinkler installation. Consequently, code 238220 is simply not precise enough to include in this study.