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The Impact of Municipal Governments' Renewable Electricity Use on Greenhouse Gas Emissions in the United States

Rachel M. Krause¹

Abstract

Local governments are increasingly taking initiatives to reduce greenhouse gas (GHG) emissions. However, limited and inconsistent data makes evaluating the aggregate impact of relevant actions difficult. This paper focuses specifically on U.S. city governments' use of renewable electricity to power their own operations. It develops a range of rough estimates for the cumulative nationwide impact of this activity and finds that it results in an annual abatement of between 5.8 and 29.2 million metric tons of carbon dioxide equivalent (CO₂e), with the best approximation being 6.2 million tons CO₂e a year. This is about 20% of the estimated total that could be reduced if city governments used *only* renewable electricity to power their operations. Despite the considerable potential that remains untapped, even the maximum direct impact resulting from local government renewable electricity use is roughly estimated as less than 0.5% of total annual U.S. GHG emissions. Government procurement policies and "leading by example" provide opportunity for additional indirect impact.

Key Words: renewable energy, local government, climate policy

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1. Introduction

The implementation of climate protection policies in the United States is largely occurring at the state and local levels. Although subnational efforts are receiving increased attention and support, limited information is available by which to evaluate their cumulative impact on greenhouse gas (GHG) emissions. This is particularly true at the municipal level where data on greenhouse gas emissions is sporadic and inconsistent. The value of local action thus remains unclear: some experts claim that it plays a key role in any comprehensive climate strategy (Bulkeley and Betsill, 2003; Aall et al., 2007; Koehn, 2008) while others suggest that the amount of abatement that localities are capable of achieving is too small to have a meaningful impact on global climate change (Victor et al., 2005; Weiner, 2007). Arguments on both sides of the debate, however, have largely been based on logic and anecdotal evidence rather than empirical findings.

In one of the more ambitious empirical pieces on this topic to date, Lutsey and Sperling (2008) estimate that if all the U.S. cities which have made voluntary GHG abatement pledges successfully achieve their goals, by 2020, the 12 year cumulative abatement would be approximately 597 million tonnes.¹ This equates to slightly less than 9% of U.S. annual emissions (U.S. EPA, 2010). However, the Lutsey and Sperling estimate is largely hypothetical in nature. The reduction pledges considered are uniform across cities (i.e. 7% under 1990 levels) and the authors do not discuss their actual abilities to reach their stated goals. Other studies suggest that a majority of cities are not on track to meet their GHG reduction commitments (Bailey, 2007; Betsill and Bulkeley, 2007; Tang et al., 2010; Wheeler, 2008). Efforts to quantify the impact of actual, as opposed to hypothetical, climate protection initiatives are hindered by a lack of local level data, which makes straightforward

comparisons and aggregation impossible. It has thus been difficult for both critics and supporters alike to make any defensible assertions about the overall trends, impact, or importance of local climate efforts.

This paper utilizes a more modest scope to help inform this debate. Instead of attempting to quantify the cumulative impact of general municipal climate-protecting activities across the United States, it focuses on one specific mitigation activity over which cities have considerable control. Namely, it develops an estimate of the annual amount of greenhouse gas emissions abated nationwide as a result of city governments' use of renewable electricity, as opposed to conventionally produced electricity, to power their government operations. Both the abatement that *is* being achieved and the potential that *can* be achieved via this activity are considered. The resulting estimates offer initial empirical answers to several related questions, including: Does local governments' current use of renewable electricity have a meaningful impact on cumulative GHG emissions? and, What is the maximum potential impact that local governments' use of renewable electricity can have on cumulative GHG emissions? Additionally, the methodological approach developed in this paper can be adapted and used to estimate the cumulative impact of other local actions in limited data contexts.

The first section of this paper provides a brief discussion of renewable electricity and its use by municipal governments in the United States. The second section describes three estimation scenarios and introduces the data and methods used to estimate the emission reductions achieved via this action. The third section presents and discusses the range of estimated results. Despite the limited data and the inability to make definitive calculations, there is considerable confidence that the actual abatement amount falls within the range identified. The final section puts

these estimates into context and assesses their significance in terms of the larger climate change dynamic.

1.1 Local Efforts at GHG Abatement

Local climate protection initiatives can be divided into two categories based on whose actions are targeted for change (Feiock et al., 2010; Krause, 2011). The first category of initiatives aims at reducing the GHG emissions that result from city government operations. The second aims to reduce the emissions from the community at large. The potential impact of policies within these two categories varies considerably. City government operations generally contribute less than 5.5% of a city's overall emissions, so the magnitude of their impact is limited.² Indeed, even if all of the emissions resulting from their operations were successfully eliminated, most cities would still not meet the seven percent reduction goal stated in the Mayors' Climate Protection Agreement. However, despite the fact that the direct impact of government-focused initiatives is limited in size, a relatively high degree of control exists over their outcomes. Leaders can directly change city governments' GHG-relevant operations through the self-administration of ordinances and internal rules (Bulkeley and Kern, 2006). Non-governmental, community-wide emissions are characterized by the opposite dynamic. Because they comprise the majority of total emissions, actions taken to influence them have the potential to be much more significant. However, because most policies aimed at altering community emissions – which result from residential, commercial, and industrial behavior – utilize non-coercive instruments like information, service provision, or incentives, the level of control or certainty that local governments have over their outcome is limited (Kaufmann-Hayoz et al., 2001; Salamon, 2002). The use of renewable electricity to

power city government operations clearly falls in the first category and, when compared to community focused efforts, is characterized by relatively high levels of control but relatively small levels of potential impact.

1.2 Electricity Use and Variation in the U.S.

Nationally, approximately 45% of electricity in the United States comes from coal, 23% from natural gas, 20% from nuclear, and 11% from clean renewables including hydro (7%) solar (1%), wind (1%), and biomass (1%) (U.S. EIA, 2009). This mix results in an average baseload rate of 606 kilograms of carbon dioxide equivalent (CO₂e) released for every megawatt hour (MWh) of electricity produced. However, the electricity mix varies regionally, resulting in baseload emission rates that range from 227 kilograms CO₂e per MWh in portions of rural Alaska to 894 across Nebraska and Missouri (U.S. EPA, 2007). The U.S. Environmental Protection Agency's Emissions and Generation Resource Integrated Database (eGRID) identifies 26 subregions with distinct electricity source mixes and carbon intensities. The relative per unit benefit from replacing conventionally produced electricity with renewable electricity – above and beyond what is already in the standard source mix – varies accordingly.

Baseload electricity consists of the output that is consistently generated to meet typical daily demand. Its sources - like nuclear power facilities and large coal plants - cannot be turned on and off easily. Non-baseload electricity is the additional electricity generated to meet peak demand. Its sources tend to be less efficient than baseload plants. Within each EPA eGRID subregion, the non-baseload rates represent the emissions from the total system, with a greater weight given to the plants that operate during peak demand. Non-baseload intensity ranges from 508 to

988 kilograms of CO₂e for every MWh of electricity produced (U.S. EPA, 2007). Although non-baseload emission rates have been specifically designed to estimate the abatement benefits resulting from renewable energy and efficiency projects (Rothschild and Diem, 2009), both baseload and non-baseload rates are utilized in this paper to develop estimates of the emission reductions from local governments' renewable electricity use.

Most electricity generated by municipal governments for their own use is done at a relatively small scale, for example by placing solar panels on public buildings or recovering methane from local landfills. It is typically consumed directly without ever entering the grid. Some cities also purchase renewable electricity from specialized commercial providers and/or purchase carbon credits to offset the emissions from the non-renewable energy that they consume. Of the 0.5 to 5.5% of total community GHG emissions that are typically attributed to city government operations, the percent of emissions resulting from electricity consumption varies considerably. This range is illustrated by the Cities of Eugene, Oregon and Arlington, Texas. In the former, only 15% of municipal government emissions are a result of electricity consumption whereas, in the latter, 70% of municipal emissions are attributed to electricity (City of Arlington, 2010; City of Eugene, 2010). The variation is due to differences in climate, the regional carbon intensity of electricity, and the relative amounts of electricity, natural gas, and other fuels used in city buildings.

2. Methods

2.1 Data Types and Sources

The cumulative abatement estimates developed in this paper consider the 665 cities in the United States with populations greater than 50,000, per the 2005 Census projections. Three main types of data provide the foundation for the estimates: the annual amount of renewable electricity used or offsets purchased to power city government operations, the annual amount of electricity consumed by governments each year, and local economic, demographic, and climatic characteristics.

Cities are not required to track and report their electricity use, and relevant information is not readily available from centralized databases. Thus, effort was undertaken to collect this information from as many cities as possible as part of this research. Data on cities' renewable electricity use was gathered from two sources: a Municipal Climate Protection survey administered by the author in April and May, 2010 and a follow-up survey administered October, 2011. Both surveys were sent to the local government official identified as in charge of sustainability, energy, or environmental issues in each of the 665 U.S. cities with populations over 50,000. The first survey yielded 329 usable responses. Responses from 90 additional cities were obtained from the second survey. This equates to information about renewable electricity use for a total of 419 city governments, which represent approximately 63% of those in the sample frame. The 419 cities for which this information was obtained are referred to as "data-rich" throughout the remainder of the paper. Cities for which no information about renewable electricity use is available are referred to as "data-poor". Of the data-rich cities, 188 stated that they produce and/or purchase renewable electricity to power some portion of their city government operations, and/or buy offsets. Figure 1 depicts the number of cities engaged in each action.

Together, approximately 40.4 million people, or 13.6% of the entire U.S. population, live in one of these 188 cities.

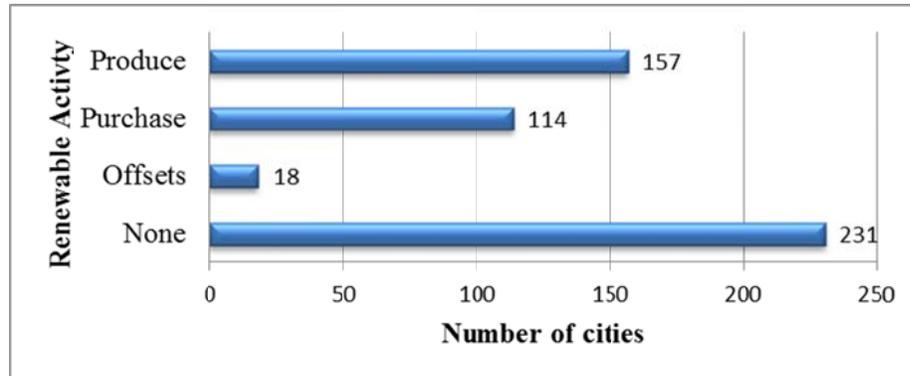


Figure 1: Number of City Governments Engaged in Various Renewable Electricity Activities (n=419)

Of the 188 city governments known to utilize renewable electricity, 45 provided the number of kWh of renewable electricity that they use each year, 106 provided the percent of total government electricity use covered by renewables (95% meet under 25% of their total electricity with renewable), and 37 did not indicate the amount of renewables.

The second main type of data used in these estimations is the total amount of electricity that city governments consume each year to power their own operations. This was obtained for 89 cities and comes from several of sources. The state of Texas requires that all local governments located in air quality non-attainment areas report their electricity usage to the State Energy Conservation Office (SECO) each year. This law (SB12) applies to 21 Texas cities in the sample and resulted in the publication of their 2007 electricity consumption data (Combs, 2008). Data for the other 68 cities comes from individual greenhouse gas emissions inventories. A significant number of cities have taken the voluntarily initiative to inventory local

GHG emissions in order to establish a baseline for their reduction. These inventories sometimes contain an accounting of the electricity consumed by all city departments in a year. Most city inventories were completed between 2005 and 2010.

The third main type of data includes relevant city demographic, economic, and climatic characteristics and was obtained for all 665 cities from public databases.

A description and source of relevant variables is provided in Table 1.

Table 1: Description and Source of Variables used in Estimations

Renewable Electricity	The amount of renewable, non-GHG emitting electricity (in kWh) that cities purchase or produce annually to power their own government operations, over and above what is included in the conventional electricity mix. Potential sources include: solar, wind, methane capture, and small-scale hydro. The purchase of carbon credits or “offsets” are included. Nuclear is not included because it is not within cities’ abilities to produce nor is it typically included in “green electricity” packages. <i>Source:</i> Municipal Climate Protection Survey 2010; 2011.
Total Electricity	The total annual amount of electricity used to power city government operations (in kWh). <i>Source:</i> Texas State Energy Conservation Office 2008; Various city GHG inventory reports.
Population	The population of each city in 2005. <i>Source:</i> County and City Data Book: 2007.
Political Leaning	The percent of each county’s total votes that supported the Democratic candidate in the 2000 presidential election. <i>Source:</i> CQ Voting and Elections Collection.
Income	Median household income in \$1000s. <i>Source:</i> U.S. Census Bureau, American Community Survey 2006-2008.
Education	Percent of population over the age of 25 with a BA or higher. <i>Source:</i> U.S. Census Bureau, American Community Survey 2006-2008.
Per Capita General Revenue	Per capita general revenue for each city in 2001-2002. <i>Source:</i> County and City Data Book 2007, Department of Housing and Urban Development’s State of Cities data source.
Renewable Portfolio Standard	A dichotomous variable indicating whether the state each city is located in has a renewable portfolio standard specifying a minimum percentage of electricity that must come from renewable sources. <i>Source:</i> U.S. Department of Energy, Energy Efficiency and Renewable Energy.
Heating Degree Days	Number of heating days: one heating degree day is accumulated for each whole degree that the mean daily temperature is above 18.3 degrees Celsius. <i>Source:</i> City and County Databook: 2007.
Cooling Degree Days	Number of cooling days: one cooling degree day is accumulated for each whole degree that the mean daily temperature is below 18.3 degrees Celsius. <i>Source:</i> City and County Databook: 2007.

2.2 Estimation Scenarios

The sparse and uncoordinated availability of relevant data prevents the precise calculation of the cumulative impact that municipal governments' use of renewable electricity has on GHG emissions. The development of a single specific estimate would therefore imply a false sense of certainty. Therefore, this study develops a range of three estimates, each of which makes a different assumption about cities' electricity use behaviors:

- a) The low-bound estimate quantifies only the emissions offset by city governments that are *known* to purchase and/or produce renewable electricity to power their own operations. It assumes that cities with missing data use no renewable electricity.
- b) The middle estimate considers all cities in the sampling frame. It uses information from data-rich cities to establish parameters for data-poor cities and includes them in the overall estimate of renewable electricity use.
- c) The high-bound estimate is a hypothetical maximum and quantifies the total potential emissions that could be offset if U.S. cities met 100% of their local government's electricity use with renewable electricity.

The middle scenario (b) provides the "best guess" of the amount of emissions abated via the production or purchase of renewable electricity or the purchase of offsets by city governments. However, the true amount is no less than the low-bound and no greater than the high-bound estimate.

2.3 Methodology for Low-Bound Estimate

The low-bound estimate assumes that *only* the 188 city governments that are known to use renewable electricity in fact use it. The actual aggregate amount of GHG emissions abated annually as a result of U.S. city governments using renewable electricity to power their operations is likely no less than the number

estimated here. The low-bound estimate is obtained in three basic steps: (1) for each city government known to use renewable electricity, estimate the annual kWh of renewable electricity consumed; (2) convert these values into the metric tonnes of CO₂e abated; and (3) sum all cities' CO₂e abatement estimates to calculate the cumulative abatement amount.

First, the number of kWh of renewable electricity consumed by the 188 city governments in the sample that are known to purchase or produce renewable electricity is estimated. Cities provided this information in survey responses by: (a) stating the exact amount of renewable electricity used in kWh/year (n = 45); (b) indicating the percent of total government electricity use met by renewables (n = 106); or (c) simply stating that it is used, but giving no indication of quantity (n=37).

The values for the cities in group (a) are obtained directly from their survey responses. The values for the cities in group (b) are estimated by multiplying the stated percentage of renewables by the total amount of electricity used annually by the city government. If the latter is not known it is estimated via a regression run on factors that influence local governments' electricity use. Variables theorized as influencing the amount of electricity used by city governments to power their own operations include city population size, the financial resources available, and the climates in which they are located. The governments of large cities, with greater financial resources, located in areas of extreme heat or extreme cold, are hypothesized as consuming a larger amount of electricity. Equation 1 operationalizes these factors, where e is the stochastic error term:

$$\text{Equation 1: } Total\ kWh_i = \alpha + \beta_1 population_i + \beta_2 general\ revenue_i + \beta_3 heating + \beta_4 cooling + e$$

However, as the results in Table 2 show, only city population size and general revenue are significant. These two variables alone explain 93% of the variation in amount of electricity used by city governments. Thus, Equation 2 represents the final equation used to estimate electricity consumption in the cities for which there is no direct data.

$$\text{Equation 2: Total kWh}_i = -3.21e^7 + 404.8\text{population}_i + 5.35e^4 \text{ general revenue}_i + e$$

Each city government's total electricity use total is calculated by directly substituting in its corresponding independent variable values. This result is then multiplied by the stated percent of renewables it uses.

Table 2: OLS Regression of Total Electricity used by City Governments (kWh)

	Full	Final
Population	403.6*** (12.7)	404.8*** (12.7)
Gen revenue	5.71e^3***(1.73e^4)	5.35e^4*** (1.69e^4)
Cooling days	2.71e^5 (4.28e^5)	--
Heating days	-7.32e^4 (2.70e^5)	--
Constant	-4.17e^7 (5.08e^7)	-3.21e^7* (1.79e^7)
	F= 294.0 (0.000)	F=583.2 (0.000)
	R ² = 0.934	R ² = 0.933
	Adj R ² = 0.931	Adj R ² = 0.931
	n= 89	n = 89
OLS regression. Standard errors in parenthesis. Significant <i>p</i> values are represented by *<0.10, **<0.05, ***<0.01		

The estimates for the 37 city governments in group (c), which state only that they use renewable electricity but do not indicate any amount, are based on the outcome of a regression run on the number of kWh of renewable electricity used by the cities that did quantify their own use. The factors that influence a city government's decision to invest in renewable electricity include the city's population size, its fiscal health, and resident's demographic characteristics such education,

political leaning and income. The presence of a state-level energy renewable portfolio standard (RPS), which establishes minimum requirements for the percentage of renewables that must be used, is also potentially influential. The hypothesized relationship is shown in Equation 3.

$$\text{Equation 3: } Renewable\ kWh_i = \alpha + \beta_1 population_i + \beta_2 general\ revenue_i + \beta_3 education + \beta_4 political\ leaning + \beta_5 income + \beta_6 RPS + e$$

As with the estimate of total electricity consumed, only city population and general revenue significantly influence the amount of renewable electricity that these city governments use (see Table 3). Corresponding independent variables are inserted into Equation 4 to calculate each city government’s renewable use.

$$\text{Equation 4: } kWh_i\ Renewable = 104.7 population_i + 3.52e^4 general\ revenue_i + e$$

Table 3: OLS Regression of Cities’ Renewable Electricity Consumption (kWh)

	Full	Final
Population	102.7*** (16.4)	104.7*** (15.9)
General Revenue	3.05e ⁴ *** (1.16e ⁴)	3.52e ⁴ *** (1.06e ⁴)
Percent Democrat	4.64e ⁴ (5.48e ⁵)	--
Median Income	-323.2 (429.1)	--
Education	3.10e ⁵ (5.21e ⁵)	--
RPS	6.32e ⁶ (1.71e ⁷)	--
Constant	-1.93e ⁷ (3.18e ⁷)	2.39e ⁶ (9.67e ⁶)
	F= 10.26 (0.000)	F=30.55 (0.000)
	R ² = 0.300	R ² = 0.292
	Adj R ² = 0.270	Adj R ² = 0.283
	n= 151	n = 151
Tobit regression. Standard errors in parenthesis. Significant <i>p</i> values are represented by *<0.10, **<0.05, ***<0.01		

The second step in the low-bound estimate involves converting the amount of cities’ renewable electricity into the metric tonnes of carbon dioxide equivalent (CO_{2e}) abated through its use. The estimated amount of renewable electricity (in

kWh) that is purchased and/or produced by each of the 188 city governments, is converted into an emissions value (tonnes of CO₂e). This is done by using a conversion factor of X tonnes CO₂e per kWh, where X represents the eGRID emissions value associated with each city's corresponding subregion. Separate estimates are developed using both baseload and non-baseload conversion terms.

The final step in generating the low-bound estimate simply involves adding together the CO₂e abatement estimates generated for each city in Step 2.

2.4 Methodology for Middle Estimate

The mid-range estimates calculate the amount of renewable electricity used to power city government operations in all 665 cities in the U.S. with populations over 50,000. It provides the best estimate of the actual impact that city government investments in renewable electricity have on cumulative GHG emissions. Unlike the low-bound estimate, it does not automatically assume that all cities with missing electricity data do not purchase or produce any electricity from renewable sources.

As described above, data was obtained for 419 city governments via surveys of local officials. Of these “data-rich” cities, 188 are known to use renewable electricity and 231 are known to use none. No information regarding renewable electricity use is available for the other 246 cities in the full sample. The middle estimate uses data from the 419 data-rich cities to predict whether the data-poor cities also use renewable electricity and in what amounts. A multi-step procedure is again used, although when compared to the low-bound estimate, the key differences lie in the first step.

The mid-range estimate is based on the assumption that certain economic and demographic factors influence whether, and to what extent, local governments invest

in renewable electricity. The hypothesized relationship is the same as that depicted in Equation 3. A regression analysis is run on the 419 data-rich cities and subsequent calculations assume that the relationship estimated between the independent variables and renewable electricity for the data-rich cities also hold for the data-poor ones. A large number (n=231) of the data-rich cities do not use renewable electricity and have a dependent variable with a value of zero. A corner solution Tobit analysis is therefore employed.

The second column of Table 4 shows the results of the full model represented in Equation 3. The third column contains the results of a second model which, despite being more parsimonious, provides nearly as good a fit. The final Tobit model utilized is thus represented as:

$$\text{Equation 5: } kWh_i \text{ Renewable} = \alpha + \beta_1 \text{population}_i + \beta_2 \text{general_revenue}_i - \beta_3 \text{income}_i + \beta_4 \text{education}_i + e$$

Table 4: Tobit Analysis of Cities' Renewable Electricity Production

	Full	Final
Population	29.8*** (10.4)	30.8*** (10.4)
General Revenue	3.35e^4*** (3.35e^4)	3.74e^4*** (1.18e^4)
Percent Democrat	5.73e^5 (4.44e^5)	--
Median Income	-772.3** (356.4)	-715.2** (353.5)
Education	1.25e^6*** (4.72e^5)	1.27e^6*** (4.73e^5)
RPS	5.72e^5 (4.25e^7)	--
Constant	-8.13e^7* (1.33e^4)	-5.44e^7*** (1.77e^7)
	LRX ² = 39.45 (0.000)	LRX ² = 37.73 (0.000)
	n = 419	n = 419
Tobit regression. Standard errors in parenthesis. Significant <i>p</i> values are represented by * < 0.10, ** < 0.05, *** < 0.01		

In order to estimate the renewable electricity use for each of the 247 data-poor cities, the marginal effects associated with the Tobit results are used. The first set of marginal effects (Table 5, column 2) is used to determine the probability of a 0 outcome (i.e. no renewable electricity use). The second set (Table 5, column 3)

provides the marginal effects for the expected value of the dependent variable conditional on it being above zero.

Table 5: Tobit Analysis Estimate of Marginal Effects

	Probability outcome is > 0	Marginal effects if outcome > 0
Population	1.32e ⁻⁷ *** (0.000)	9.43*** (3.19)
General Revenue	1.60e ⁻⁴ *** (0.000)	1.15e ⁴ *** (3.63e ³)
Median Income	-3.05e ⁻⁶ ** (0.002)	-219.03** (108.07)
Education	5.44e ⁻³ *** (0.000)	3.90e ⁵ *** (1.44e ⁵)
Tobit marginal effects. Standard errors in parenthesis. Significant <i>p</i> values are represented by * < 0.10, ** < 0.05, *** < 0.01		

Each city's independent variable values are inserted into Equation 6 to determine the probability that its use of renewable electricity is greater than zero. The highest resulting probability for any city is 0.62. A probability cut-off must be identified to determine which cities qualify for the conditional marginal effects analysis. The selected cut-off is based on the corresponding probabilities of the data-rich cities. When run through the same calculations, the 188 cities that are known to consume renewable electricity have an average probability of 0.15 and the 231 that are known not to use any have an average probability of 0.11. Therefore, the data-poor cities which emerge from Equation 6 with a probability of 0.15 or higher are assumed to utilize some amount of renewable electricity. Fifty-six of the 247 data-poor cities meet this threshold. Equation 7 is then employed to estimate the actual number of kWh of renewable electricity used for this subset of cities.

$$\text{Equation 6: Probability Renewable} = 1.32e^{-7}population_i + 1.60e^{-4}general\ revenue_i - 3.05e^{-6}income_i + 5.44e^{-3}education_i + e$$

$$\text{Equation 7: kWh}_i \text{ Renewable} = 9.43population_i + 1.15e^4general\ revenue_i - 219.03income_i + 3.90e^5education_i + e$$

To further illustrate the procedure used to generate the middle estimate, consider the example of Tucson, Arizona. The City of Tucson did not respond to the surveys administered for this project and it is unknown whether it uses renewable electricity to power government operations, or how much. However, many characteristics about Tucson are known, including that its 2005 population was approximately 515,526, its per capita general revenue equates to approximately \$501.94, its median household income is \$37,936, and 24.5% of its adult residents have bachelor degrees or higher. The calculations below show that Tucson has a 0.17 probability of renewable electricity use, which is above the stated threshold of 0.15. Thus, the Tucson City government is assumed to utilize some renewable electricity.

$$\begin{aligned}
 \text{Probability Renewable} &= 1.32e^{-7}\text{population}_i + 1.60e^{-4}\text{general revenue}_i - 3.05e^{-6} \\
 &\quad \text{income}_i + 5.44e^{-3}\text{education}_i + e \\
 0.166 &= 1.32e^{-7}(515,526) + 1.60e^{-4}(501.94) - 3.05e^{-6}(37,936) + 5.44e^{-3} \\
 &\quad (24.5) + e
 \end{aligned}$$

The amount of renewable electricity is calculated by substituting its independent variables values into Equation 7. As shown below, the Tucson City government is estimated as using approximately 9.1 million kWh of renewable electricity each year.

$$\begin{aligned}
 \text{kWh}_i \text{ Renewable} &= 9.43\text{population}_i + 1.15e^4\text{general revenue}_i - 219.03\text{income}_i + \\
 &\quad 3.90e^5\text{education}_i + e \\
 9099990 &= 9.43(515,526) + 1.15e^4(501.94) - 219.03(37,936) + 3.90e^4(24.5) \\
 &\quad + e
 \end{aligned}$$

Although this approach may not yield accurate results for any individual city, it has the potential to yield approximate results *on average*. The same procedure is followed for all 247 of the data-poor cities.

Steps 2 and 3 – where renewable electricity use is transformed into metric tonnes of CO₂e abated and abatement values are summed across cities – are performed in the same manner as described for the previous low-bound estimate. The only difference is that now all 665 cities in the sample are considered.

2.5 Methodology for High-Bound Estimate

Unlike the previous two estimates, the high-bound estimate does not attempt to calculate the *actual* impact that cities' current renewable electricity use has on cumulative GHG emissions. Rather, it estimates the *hypothetical maximum* that this initiative could have if local governments met 100% of their electricity needs with renewable electricity. The 665 cities in the U.S. with populations over 50,000 are again the sample of focus. The objective is to estimate the cumulative amount of electricity consumed annually to power the operations of these city governments and transform it into an estimate of GHG emissions. Assuming all of these emissions are offset by the use of renewable electricity, this quantity represents the upper-most possible impact.

The upper-most estimate is based on the model represented in Equation 2 and the regression results shown in Table 1. As previously described, data quantifying electricity use by municipal governments is not readily available. In all, electricity use data for 89 city governments was obtained from two sources. These observations provide the basis for the remaining cities' electricity estimates.

The estimate for the total amount of electricity that each city government uses is generated by directly substituting the corresponding independent variable values for each of the other 576 cities into Equation 2. Those results, plus the electricity values for the 89 cities for which data is directly available, can be summed to obtain a cumulative estimate of electricity used by U.S. city governments. The

resulting electricity estimates for each city are converted into tonnes of CO₂e via the process described for the low and middle estimates. Values are summed across cities to obtain cumulative impact.

3. Results and Discussion

Table 6 presents the results from the low, middle, and high estimates, both for the amount of renewable electricity used (in MWh) and the tonnes of CO₂e offset through that use. The values of CO₂e arrived at using baseload and non-baseload emission rates are both presented. Because non-baseload rates were specifically developed to assess the impact of energy efficiency or renewable energy projects, those estimates receive focus in this discussion. The low estimate considers only the 188 cities in the U.S. that are known to purchase or produce renewable electricity to power their government operations. Together these cities use an estimated 8.9 million MWh of renewable electricity and offset approximately 5.8 million tonnes of CO₂e annually. The middle estimate considers all 665 cities in the U.S. that have populations over 50,000. Renewable electricity use values were statistically estimated for the cities where relevant information could not be directly obtained. Based on the outcome of a Tobit regression, 56 additional cities are predicted to utilize renewable electricity and their inclusion raises the annual estimated amount of renewable electricity used by U.S. city governments to 9.5 million MWh and CO₂e abated to 6.2 million tonnes. This represents the “best guess” of the annual cumulative impact of this action. Finally, the high estimate represents the maximum potential impact that *could* be generated if city governments were only to use renewable electricity to power their operations. If this were the case, an estimated

43.7 million MWh of renewable electricity would be used annually and 29.1 million tonnes of CO₂e would be abated. The considerable difference between the high and middle estimates suggests that approximately 20% of the potential GHG reductions from this initiative are currently being tapped.

Table 6: Estimated Renewable Electricity Used by City Governments and Corresponding CO₂e Reduced

	Renewable electricity used (million MWh)	CO ₂ e abated (million metric tonnes)	
		Baseload	Non-baseload
Low Estimate	8.90	4.80	5.81
Middle Estimate	9.54	5.14	6.23
High Estimate (hypothetical maximum)	43.67	23.47	29.16

It is helpful to consider the CO₂e reduction estimates in the context of cumulative emissions. In 2008, the U.S. released the equivalent of 6,956.8 million metric tonnes of CO₂e (U.S. EPA, 2010). Thus, when considered as a percent of the U.S. total, the amount of emissions offset through this activity is inconsequential. The middle estimate equates to 0.07% of the U.S. total. The high estimate, which represents the maximum achievable through this initiative, equates to less than 0.5%. Viewed another way, the estimated annual amount of emissions currently offset through city government’s renewable electricity use is equivalent to taking approximately one million passenger vehicles off of the road for a year. If all 665 city governments used only renewable electricity to power their operations, it would have the equivalent effect of taking over 5.5 million cars off the road for a year (U.S. EPA, 2011).

Data quantifying the renewable electricity consumed by local governments in other countries is likewise scarce, making international comparisons difficult. Studies of municipal climate action in several European nations find that the GHG

emissions attributable to local government operations typically account for between 1 and 5% of a community's total (Bulkeley and Kern, 2006). This is similar to the ratio presented for U.S. cities in this study. Further, in their study of cities in Germany and the United Kingdom, Bulkeley and Kern (2006) find that self-governance is the most frequently employed policy tool to reduce GHG emissions. Numerous local governments in both countries voluntarily purchase portions of their electricity from green sources and/or have developed renewable energy demonstration projects. Although it does not use a representative sample, a review of 210 global cities conducted by the Renewable Energy Policy Network (REN21) identifies a significant number of cities whose governments either purchase renewable electricity or have invested in infrastructure to produce it. Out of 45 European cities profiled, 23 are engaged in one or both of these activities. Comparatively, 11 out of 19 Canadian cities, 12 out of 41 Japanese cities, 4 out of 11 Chinese cities, and 4 out of 10 Latin American cities are similarly engaged (REN21, 2011). However, like much of the relevant data collected thus far, this review does not provide the representativeness or detail needed to develop aggregate estimates of the impact that local government actions have on GHG emissions.

The current impact of cities' renewable electricity use on cumulative U.S. GHG emissions is negligible and even the maximum potential impact of this activity is small. However, additional indirect impacts may accompany the direct effect on emissions. First, municipal governments may "lead by example." By taking visible climate protecting actions, cities may send the message that GHG reduction is a worthy goal and, moreover, one that can be pursued within the local community. Although challenging to quantify, "leading by example" is an explicit part of the rationale behind some municipal leaders' engagement in climate protection (Selin

and VanDeveer, 2007). A second indirect impact of policies which focus on governments' own behavior is based on purchasing power. Governments often intentionally structure their procurement policies to push the market in a pro-environmental direction and spur innovation. The idea that purchasing power should be leveraged to promote environmentally-friendly products and technologies has been formalized in the federal government by a number of executive orders (E.O. 12873; E.O. 13514). Numerous state and local governments have similar self-imposed "green procurement" policies, some of which mandate the increased use of renewable energy (Rabe, 2007). These purchase commitments provide renewable energy producers some certainty about demand, expand the market, and can help make the technology economically competitive. In sum, the use of renewable electricity by U.S. city governments to power their own operations is, and can only be, negligible in terms of the direct impact it has cumulative national emissions. However, the indirect effects that this action may precipitate have the potential to be more significant.

4. Qualifications of Cumulative Impact Estimates

The lack of local level data makes it difficult to estimate the cumulative effect that local initiatives have on GHG emissions nation-wide. The values presented in Table 6 thus need to be qualified. First, the estimates of renewable electricity used by city governments and the subsequent emissions abated are based on a relatively small number of data points. It is possible that the cities from which electricity use values were able to be obtained are systematically different from those for which data was unavailable, resulting in skewed simulated values. A second concern is based on the fact that most of the renewable electricity use values were

obtained from surveys. The estimates assume that the cities that quantified their electricity use provided correct amounts. Although mistakes may have been made by some cities, they are unlikely to be systematic, allowing potential under-reports to balance out over-reports. The analysis also assumes that the respondents did not claim credit for purchasing renewable electricity if it is simply included in the standard commercial electricity mix. Although imperfect and limited in scope, the estimates presented in this article join a very small number of attempts to approximate the cumulative impact that local actions have on GHG emissions. Until local level electricity use and emissions data is made both more available and standardized, rough estimates, like the one developed here, are among the best and only options available.

5. Conclusion

Because of the challenges involved in obtaining data about local-level greenhouse gas emissions, this article focuses on one specific municipal abatement action and estimates its nation-wide impact. In doing so, it develops an approach that can be adapted and applied to estimate the cumulative impact of other local abatement actions for which there is limited data, including those that focus on local policies aimed at residential or commercial behavior. The overall impact of city governments' use of renewable electricity on nation-wide emissions is negligible: roughly estimated as between 5.2 and 29.1 million metric tonnes CO₂e annually. Indeed, the maximum direct potential of this activity is roughly estimated as less than half of one percent of total U.S. emissions. However, this empirical result should not be interpreted as a normative conclusion that relevant renewable energy actions should not be pursued by local governments. Indeed, any such conclusion would require the consideration of monetary costs and benefits and would likely

need to be assessed on a city by city basis, since electricity costs and carbon intensities differ among them. Additionally, the indirect effect that local climate-oriented leadership and procurement have on facilitating the adoption of GHG-reducing policies by others in the community warrants consideration in an overall assessment of this activity's value.

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¹ This estimate is based on 2007 data and includes pledges associated with the U.S. Conference of
Mayors' Climate Protection Agreement from 684 cities which cover 26% of the U.S. population.
There are currently 1,044 cities that have made this pledge, covering 30% of the population. This
updates the estimate to roughly 620 million tonnes of CO₂ by 2020 that would be reduced by the
fulfillment of pledges.

² As the result of an extensive online search of local greenhouse gas emissions inventories, separate
estimates of annual emissions released by city government operations and the community as a whole
were obtained for 88 cities. The portion of total community emissions coming from city government
operations ranged from 0.2% to 16.1% with a mean of 2.8% and a standard deviation of 2.4.