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Measuring Performance Metrics of a Smart City

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Executive Summary

In 2016, the City of Columbus won a grant from Paul G. Allen Family Foundation. Ten million dollars in grant funds were used to leverage many millions more in investment in decarbonization, fleet and consumer electric vehicle (EV) adoption and charging infrastructure. The three-year program has goals of increasing the amount of renewable energy consumed in the region by over 500MWh, increasing EV adoption by almost 500% and deploying 925 public, workplace, fleet, and residential chargers. To track progress towards program goals a Performance Measurement Plan was developed. This paper addresses how decarbonization of the grid and vehicle adoption metrics were tracked and the resulting greenhouse gas (GHG) reductions were quantified.

Key Words: smart city, performance measurement, GHG, grid decarbonization, electric vehicle adoption

1 Background

On November 23, 2018, 13 federal U.S. agencies released the Fourth National Climate Assessment [1], a report mandated by the U.S. Congress. *The New York Times* said it was noteworthy, “for the precision of its calculations and bluntness of its conclusions.” In part it stated that:

> *Climate-related risks will continue to grow without additional action. Decisions made today determine risk exposure for current and future generations and will either broaden or limit options to reduce the negative consequences of climate change…*
>
> *Without substantial and sustained global mitigation and regional adaptation efforts, climate change is expected to cause growing losses to American infrastructure and property and impede the rate of economic growth over this century.*

This was precisely what the Paul G. Allen Family Foundation challenged mid-size cities in the United States to do in late 2016 with the Smart Cities Challenge [2]. Its stated goal was to “help disrupt the current climate trajectory – one of the most urgent challenges the world is facing.” The foundation granted $10 million to the City of Columbus, Ohio to answer this call to action by addressing transportation sector GHG emissions –

the new leading cause of emissions in the United States at 28.5% compared to electricity production at 28.4% (see Figure 1).

Columbus beat out 77 other cities competing in the Smart City Challenge with its five-part Smart Columbus approach to reducing GHG emissions by the transportation sector:

- Priority 1: Decarbonization of the Power Grid
- Priority 2: Fleet Electric Vehicle Adoption
- Priority 3: Transit, Autonomous and Multi-Modal Systems in the City
- Priority 4: Consumer Electric Vehicle Adoption
- Priority 5: Charging Infrastructure

This paper addresses how GHG reductions were calculated and quantified for program activities related to decarbonization of the power grid (Priority 1, see Section 3.1) and also for electric vehicle adoption (Priorities 2 and 4, see Section 3.2).

The area of study is in the Mid-Western United States (Figure 2) in the seven-county region shown in Central Ohio on Figure 3.

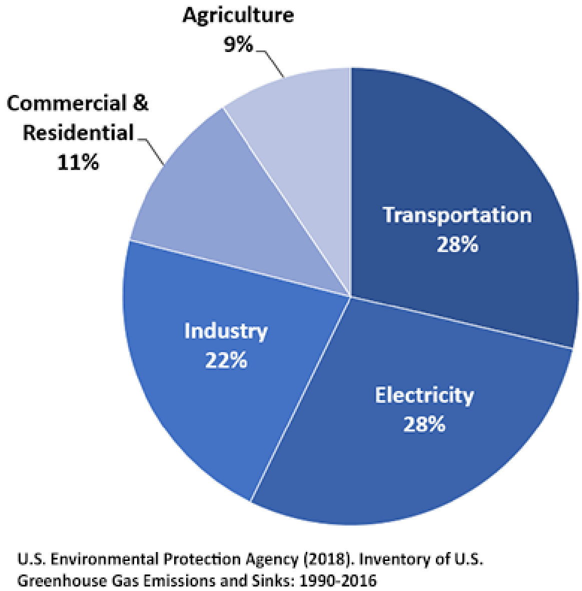

Figure 1: Total U.S. Greenhouse Gas Emissions by Economic Sector in 2016 [3]

The grant was awarded in June of 2016 and signed in April of 2017. The three-year grant officially began in April 2017 and ends in March 2020.

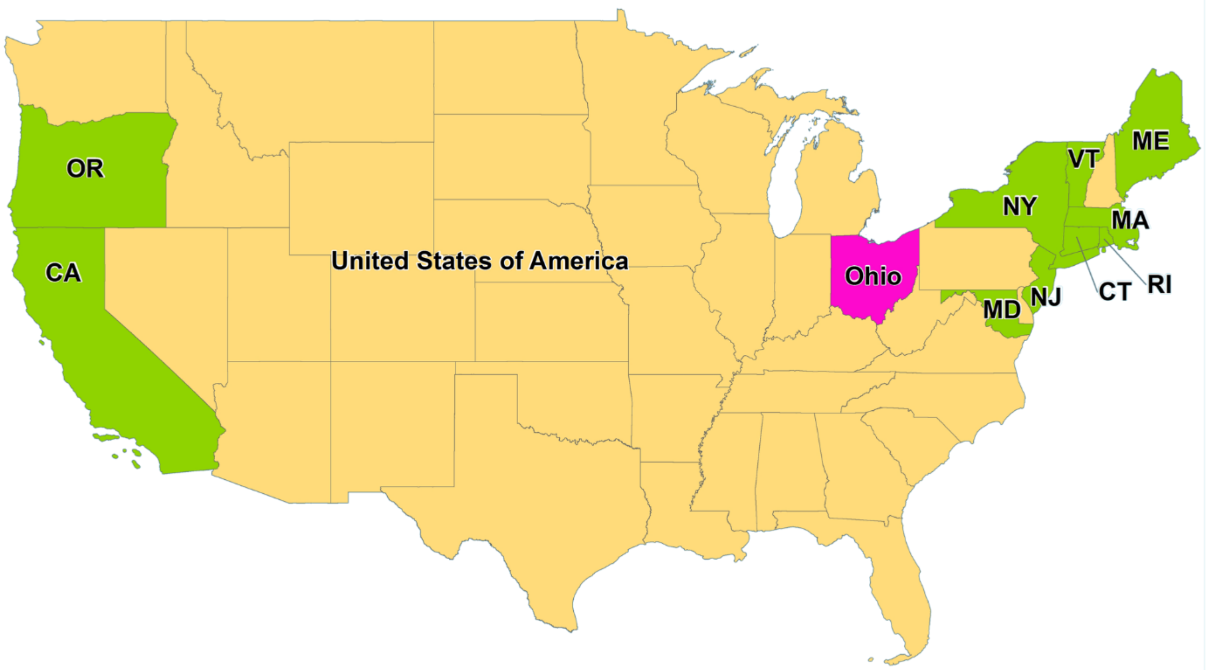

Figure 2: 10 ZEV States and Ohio

Zero emission vehicle (ZEV) states, depicted in green in Figure 2, are 10 states within the United States that require vehicle manufactures to sell electric cars and trucks. The ZEV program is considered the driving force behind the increasing number of electric vehicles available for sale in the United States [4].

Ohio is a non-ZEV state with no state or local government rebate incentives, except through this program[1]. For this reason, Columbus focused on EV adoption including public, private and transportation service provider fleets as well as consumer adoption. This focus has paid off, as in 2018, the Smart Columbus region showed stronger EV adoption than any other region in Ohio – when evaluated by population or per capita income (see Figure 4 and Figure 5).

Smart Columbus focused on decarbonizing the power grid as well, because the study area has one of the dirtier grids in the US (see Figure 6). This carbon-heavy power generation limits the benefits that can be achieved by increased EV adoption.

Figure 3: Map of Ohio and Seven-County Smart Columbus Region (Study Area)

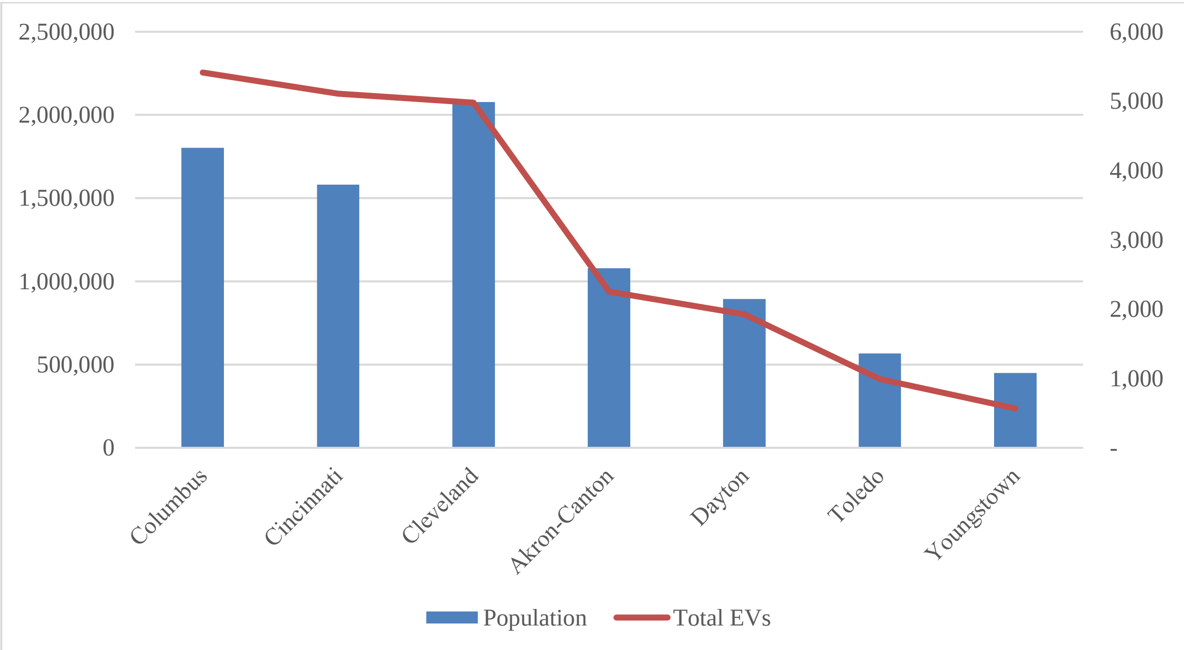

Figure 4: 2018 Ohio EV Adoption and Population by Region

[1] Incentives associated with the Smart Columbus program include a $3,000 incentive for 40 transportation service provider vehicles provided with grant funds as well as $1,000 and $3,000 vehicle incentives provided to employees of Alliance Data and American Electric Power, respectively.

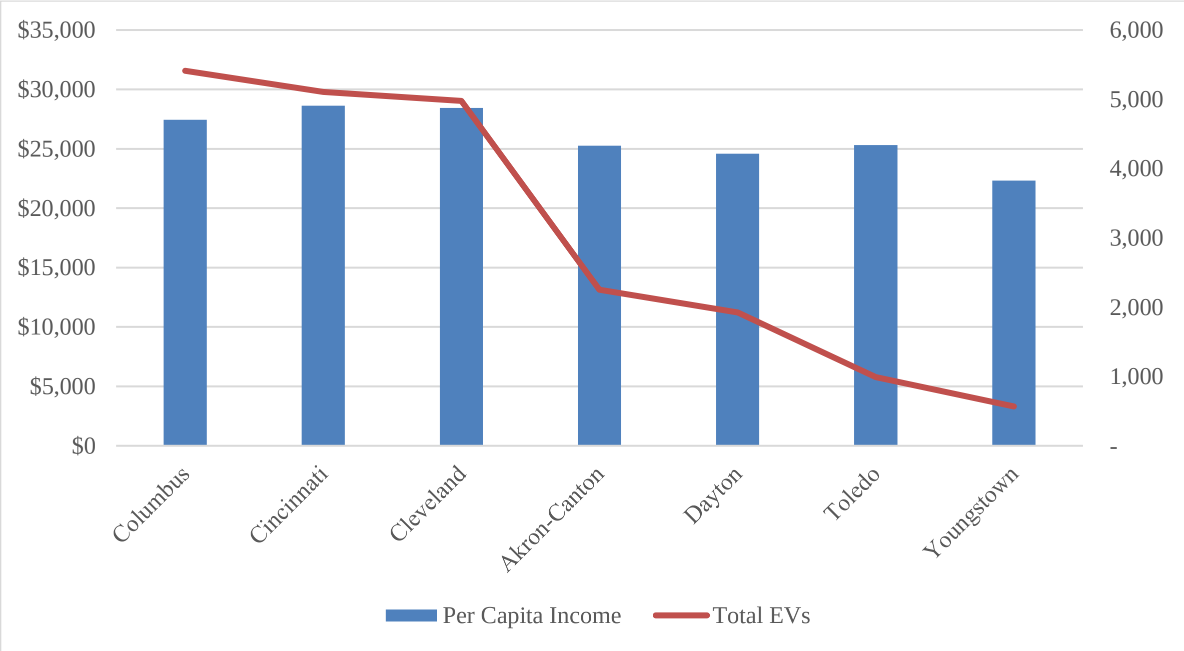

Figure 5: 2018 Ohio EV Adoption and Per Capita Income by Region

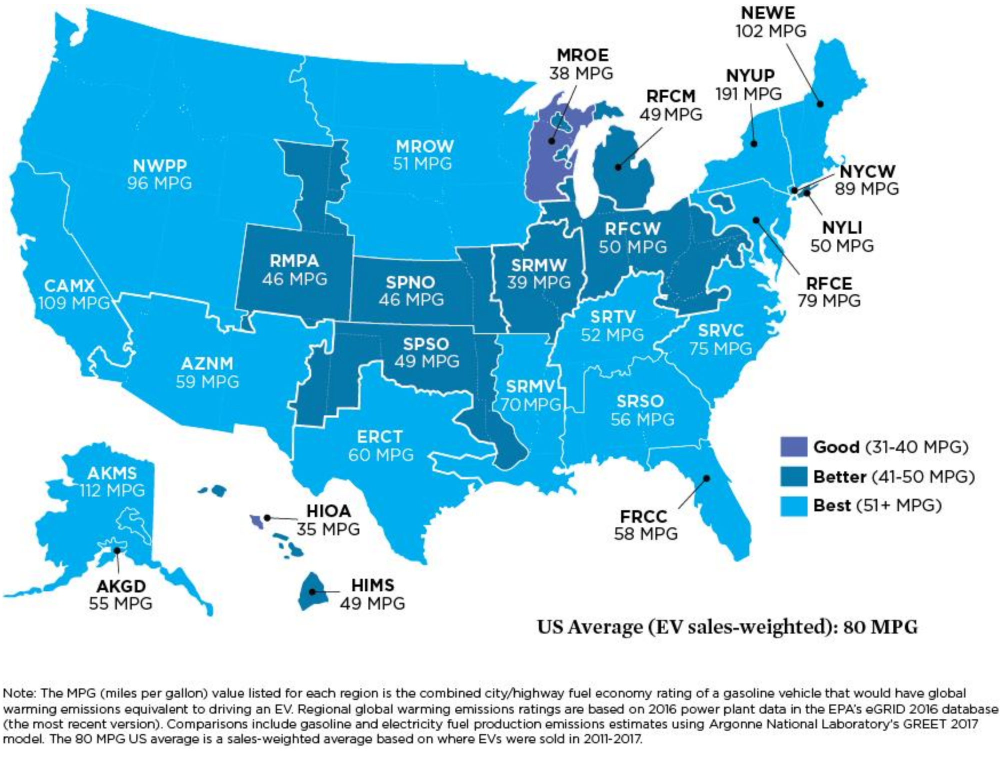

Figure 6: Average EV Efficiency by eGRID Sub Region [5]

2 Program Goal and Objectives

The overall program goal is to measurably decrease light-duty transportation GHG emissions expressed in metric tons of carbon dioxide ($MTCO_2$) as a result of grid decarbonization and EV adoption during the grant period compared to a baseline year (2015). The primary program indicators being tracked are:

- Percent GHG emission reductions from baseline year.
- Total GHG reductions/savings from baseline year measured in $MTCO_2$.

3 Metrics

Of the five program priorities, decarbonization of the power grid yields the most significant GHG savings. EV adoption by consumers and from public, private and transportation service provider fleets result in less than 1% of the GHG savings. Grid decarbonization accounts for 99%.

Several stakeholders, noted in the acknowledgements, collaborated to develop the methodology used to quantify GHG savings that is presented in the following sections.

3.1 Grid Decarbonization

Various efforts are underway to increase the utility-scale renewable energy capacity and promote energy efficiency throughout the region. Of the 11 power providers in the seven-county region American Electric Power[2] (AEP) supplies the largest amount of power. Approximately 50% of their generation is from coal. The Columbus Division of Power (DOP) also serves as a significant power provider within the region.

Both power providers have begun plans for future renewable energy capacity to be installed. In addition to the renewable grid efforts, AEP and DOP have implemented energy efficiency efforts to reduce the power demand for the region. Initiatives under this priority include distributed energy programs, green power purchase plans, advanced metering infrastructure programs, energy efficient product promotions, and LED streetlight conversions, all of which contribute to a reduction in GHGs.

3.1.1 GHG Reductions

The power generated by renewable sources is considered emissions saved since fossil-fuel power production methods would no longer be used. The U.S. Environmental Protection Agency (EPA) releases the Emissions & Generation Resource Integrated Database (eGRID) biennially as a comprehensive source of environmental characteristics of electric power generation by region. The retrospective report is based on plant-level data reported by all U.S. generating plants that provide power to the electric grid. Emissions from the electric power grid for the seven-county region can be estimated using the GHG Annual Total Output Emission Factor for the RFC West sub region. This factor can be applied to estimate the $MTCO_2$ saved by installing and generating electricity from renewable sources.

$$MTCO_2\ saved = MWh\ generated\ using\ renewables \times eGRID\ regional\ emission\ factor^3 \quad (1)$$

The grid decarbonization efforts for the first two years of the grant period are shown in Table 1. The table includes estimated values for year 3. The GHG reduction total in the bottom line of the table is calculated by adding the renewable energy consumed and the energy saved and then applying the eGRID regional emission factor to convert from MWh to $MTCO_2$.

Table 1: Grid Decarbonization GHG Reductions

	Year 1 Actual	Year 2 Actual	Year 3 Projected	Total
Renewable Energy Capacity Installed (MW)	4.77	6.40	TBD	11.17
Renewable Energy Consumed (MWh)	47,881	213,974	242,860	504,715
Energy Saved (MWh)	211,122	331,601	160,000	702,723
GHG Reduction ($MTCO_2$)	146,673	307,703	227,212	681,588

[2] AEP has the largest electricity transmission network in the United States with 26GW of generation capacity provided to 5.4 million customers in 11 states. [6]

[3] 1243.4 lbs. CO_2/MWh, 2016 eGRID GHG Annual Total Output Emission Rate for the RFC West sub region.

3.1.2 Assumptions

To ensure the GHG calculations are tailored to the seven-county region it was important to use carbon intensity values specific to the local grid. The EPA's eGRID Report is based on national, state, North American Electric Reliability Corporation (NERC), and eGRID sub region inputs (Figure 7). The study area comprised of the seven-county region is located within the Reliability First Corporation (RFC) West eGRID sub region market.

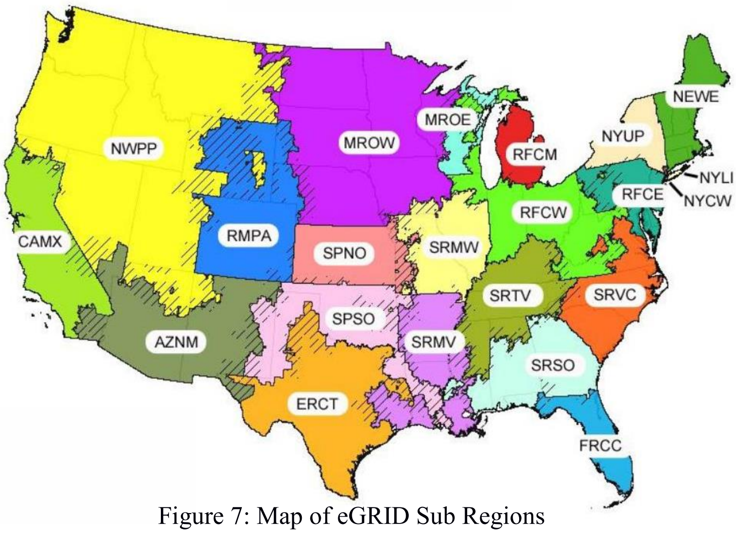

Figure 7: Map of eGRID Sub Regions

The grid emission factors for these regions are released every two years, generally with a two-year time delay for the reported values. eGRID2016 was released in February 2018 but uses data from 2016. To project grid emissions for the current year and into the future, the U.S. Energy Information Administration (EIA) Annual Outlook data tables project how the electricity grid power sources change over time.

The electricity generation grid mix directly impacts the emission factor used in the EV calculations. As shown in Table 2, both the U.S. average and RFC West sub region had a significant reduction in the use of coal for power generation from 2014 to 2016. The eGRID2016 data indicates the lowest CO_2 emission factor to-date for this sub region. This decrease in fossil fuel use supported the national decrease in emission factors. Still, the RFC West generation mix has an almost 20% higher share of coal power generation than the U.S. average mix. This is due to the coal-heavy Appalachian region located in the RFC West sub region.

Table 2: eGRID Electricity Generation Mix*

	U.S. Average Mix (eGRID2014) [7]	U.S. Average Mix (eGRID2016) [8]	RFC West Mix (eGRID2014)	RFC West Mix (eGRID2016)
Coal	38.7%	30.4%	60.0%	49.8%
Oil	0.7%	0.6%	0.5%	0.4%
Gas	27.5%	33.8%	9.3%	16.7%
Other Fossil	0.5%	0.3%	0.7%	0.7%
Nuclear	19.5%	19.8%	25.7%	27.6%
Hydro	6.2%	6.4%	`0.6%	0.9%
Biomass	1.6%	1.7%	0.6%	0.6%
Wind	4.4%	5.6%	2.4%	3.2%
Solar	0.4%	0.9%	0.0%	0.1%
Geothermal	0.4%	0.4%	0.0%	0.0%
Other	0.1%	0.1%	0.1%	0.1%

* Percentages may not sum to 100 due to rounding

Whereas eGRID data only tracks actuals, the EIA publishes projections. The projected electricity grid emission factors published by EIA for the RFC West sub region anticipate an overall decrease in grid emissions from 2016 to 2025. So, the benefits realized from driving an EV instead of an internal combustion engine vehicle (ICEV) are expected to continue to increase during the course of the grant (Figure 8).

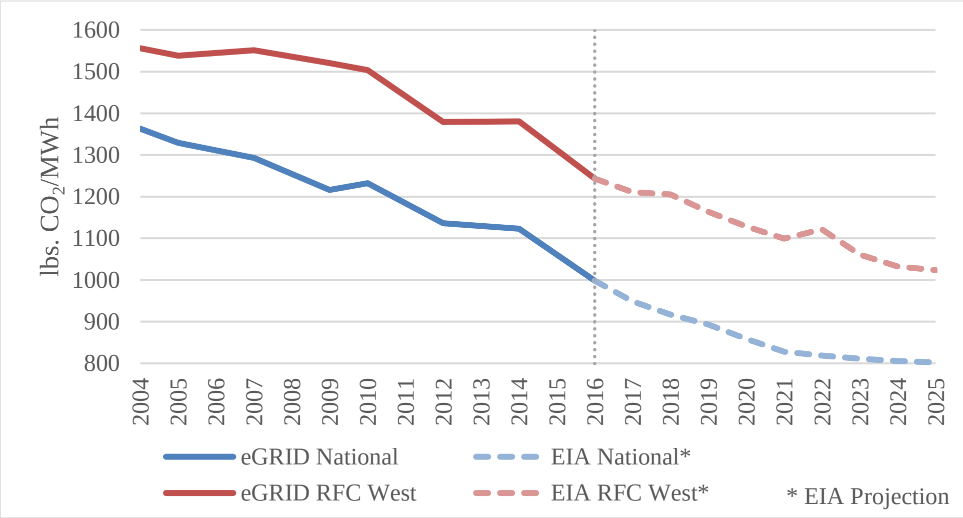

Figure 8: Electricity Grid Emissions Factor

3.2 EV Adoption

EV adoption for this program is comprised of electric fleet vehicles and electric consumer vehicles. The program is tracking three separate types of fleet vehicles: public, private and transportation service providers. New fleet vehicles purchased are reported by Smart Columbus partners on a quarterly basis. Information obtained is checked against the vehicle registration data obtained from the Ohio Bureau of Motor Vehicles (BMV) each month. Then, when partners report that the EVs are in operation they are recorded as such and GHG savings begin to accrue.

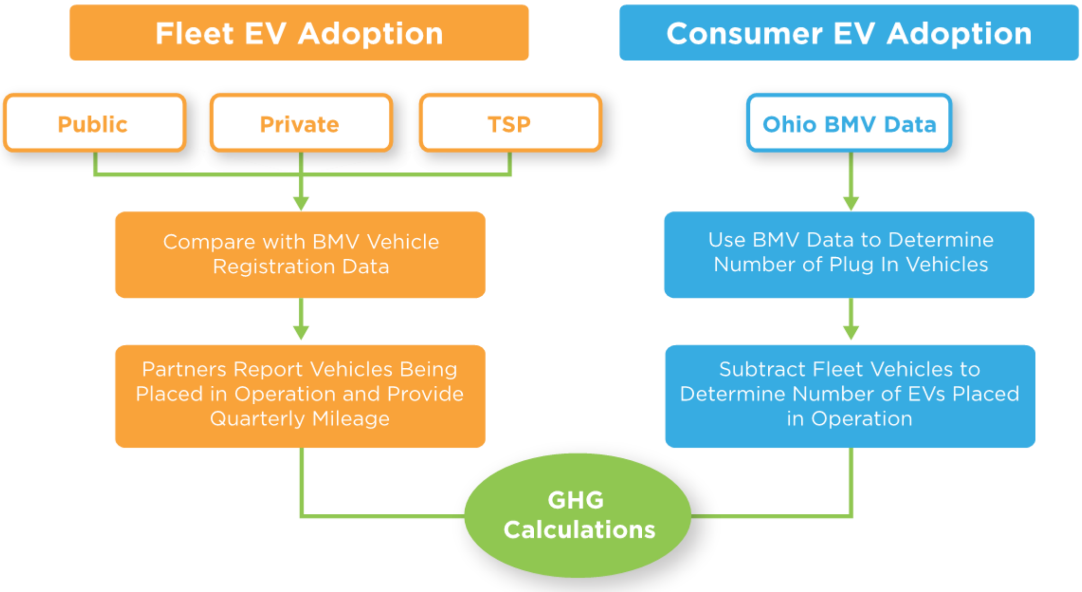

Figure 9: EV Adoption Flow Chart

In the case of consumer purchased EVs, the team uses IHS Markit data obtained from the Ohio BMV, to quantify the number of plug-in vehicles purchased. Ohio BMV vehicle registration data includes all vehicles registered in Ohio, so the team sorts out the plug-in vehicles and removes the fleet vehicles registered during the same period so as not to double count them. The resulting number of vehicles are then used to determine GHG savings.

3.2.1 GHG Reductions

The following are examples of GHG calculations associated with EVs, applicable for fleet and consumer EV adoption (Priorities 2 and 4). This method for determining GHG reductions from replacing miles travelled by an ICEV with an EV or PHEV uses the EPA Greenhouse Gas Emissions from a Typical Light Duty Passenger Vehicle [9] calculation to determine the tailpipe emissions. The general method is as follows:

$$EV\ savings\ (MTCO_2) = (ICEV\ emissions) - (EV\ emissions) \quad (2)$$

$$PHEV\ savings\ (MTCO_2) = (ICEV\ emissions) - (PHEV\ emissions) \quad (3)$$

Where,

$$ICEV\ emissions = fuel\ production\ emissions + tailpipe\ emissions \quad (4)$$

$$EV\ emissions = charging\ grid\ emissions \quad (5)$$

$$PHEV\ emissions = fuel\ production\ emissions + tailpipe\ emissions + charging\ grid\ emissions \quad (6)$$

For tailpipe emission during vehicle operation, an ICEV produces GHGs for every gallon of motor fuel combusted, while an EV has zero tailpipe emissions during vehicle operation. There are however GHG emissions produced from charging an EV. The electricity that is generated to power an EV (energy production) has its own GHG emissions which could be considered as upstream emissions. The GHG savings from an EV and PHEV are averaged to come up with an overall yearly value to be used in calculations.

Table 3 includes the EV adoption progress to date as well as the projected year 3 values for fleet EVs, consumer EVs, and charging infrastructure installed.

Table 3: EV Adoption GHG Reductions

		Year 1 Actual	Year 2 Actual	Year 3 Projected	Total
Fleet Vehicles	Fleet EVs Placed in Operation	9	153	445	607
Consumer Vehicles	EV Market Penetration	0.77%	1.21%	1.80%	1.80%
	Estimated number of EVs purchased	613	719	1,639	2,971
	GHG Reduction (cumulative, $MTCO_2$)	345	749	1,686	1,686
Charging Infrastructure	Number of EVSE ports installed	213	254	624	1,091

3.2.2 Assumptions

The sources used for data assumptions to calculate vehicle emissions in the state of Ohio for 2016-2018 are shown in Table 4 below.

Table 4: Data Assumption Sources for Emissions Calculations

Parameter	Assumption
Average annual vehicle mileage (miles)	Calculated using Table 40 and 42 of the U.S. EIA Annual Energy Outlook 2018 Report using 2016 values. Assumed one-to-one vehicle replacement, such that electric vehicles replace vehicles with similar annual miles travelled at this level.
New vehicle efficiency (mpg)	From the EIA Annual Energy Outlook 2018 Table 41 using year-specific values. Adjusted using factor of 0.74.[4]
All electric range (miles)	Using year-specific national sales weighted averages from EPA's 2017 Carbon Dioxide Emissions and Fuel Economy Trends Report.
EV efficiency (kWh/mile)	Using year-specific national sales weighted averages from EPA's 2017 Carbon Dioxide Emissions and Fuel Economy Trends Report.

[4] The basis for new vehicle fuel economy data after 2016 comes from the US EIA's Annual Energy Outlook data tables. These projected fuel efficiency regulations are unadjusted and do not represent real world driving estimates. To make these values consistent with the EPA Trends Report, the mpg ratings were adjusted by a factor of 0.74.

Percent of miles electric	Using utility factor from SAE J2841 based on RCD of 41 miles in 2016, 36 miles in 2017, and 37 miles in 2018.
Pounds of CO_2 per gallon of E10	Includes upstream production emissions and combustion emissions.
Grid emissions (lbs. CO_2/kWh)	Year 2016 calculations use eGRID2016 for RFC West sub region. Subsequent years are calculated using Table 55.11 of the EIA Annual Energy Outlook 2018 Report using projected values.

As many parameters are updated on an annual basis, the assumptions are also updated annually. The following table offers a snapshot of new vehicle emissions assumptions for year 2018. While there is an increasing trend of electrifying light trucks, passenger cars currently make up around 80% of the EV market. The following tables are specifically for passenger cars (i.e. Tesla Model X, BMW X5, Chrysler Pacifica PHEV, Volvo XC90, etc.) and do not include other vehicle classes such as light trucks.

Table 5: Assumptions for Annual Emissions per New Car in Ohio in 2018

Parameter	Gasoline Car	Gasoline Hybrid Electric Car	PHEV Car	Battery Electric Car
Average annual vehicle mileage (miles)	11,630	11,630	11,630	11,630
New vehicle efficiency (mpg)	28.2	40.7	43.5	-
All electric range (miles)	-	-	37.0	-
Electric vehicle efficiency (kWh/mile)	-	-	0.32	0.30
Percent of miles electric	-	-	59%	100%
Pounds of CO_2 per gallon of E10[5]	25.2	25.2	25.2	-
Grid emissions (lbs. CO_2/kWh)	-	-	1.33	1.33
Annual emissions per vehicle (lbs. CO_2/year)	10,385	7,197	5,653	4,680
Annual emissions per vehicle ($MTCO_2$/year)	4.71	3.26	2.56	2.12

The above assumptions are meant as a way to estimate the annual benefits for each year of the grant period and do not consider lifetime vehicle benefits. Considering the vehicle benefits over the average life of a vehicle, which for some fleets could be ten years or more, would account for considerably more emission savings after the grant period. Future phases of the program could change from an annual accounting benefits model to vehicle stock-turnover model to more fully demonstrate the full benefits of the Smart Columbus program.

4 Lessons Learned

Through the process of developing the performance measurement plan, measuring progress, and adjusting our methodology, our team identified the following items that may assist others undertaking similar efforts.

Table 6: Smart Columbus Lessons Learned

Topic	Lesson Learned	Example
General	Seek out the best expertise you can find, ask for their perspective and listen.	There was no how-to manual for calculating GHG emissions savings for EVs in our region. We received support from National Renewable Energy Laboratory, American Electric Power (AEP), International Council on Clean Transportation and the Mid-Ohio Regional Planning Commission. All provided important contributions in terms

[5] Includes emissions from upstream fuel production and combustion.

		of what assumptions or calculations were most appropriate in a given scenario.
Approach to Metrics	Evaluate whether refining assumptions is worth the time necessary to do so. Consult others to make an accurate assessment of the time/value trade off.	Using Ohio BMV vehicle registration data we can calculate emissions based on the specific vehicle make and model data for the seven-county region. Instead we are using average light duty vehicle make and model efficiency. This average efficiency is updated annually. Having very refined make and model data may move the calculations a percent or two at most. Without the ability to refine other assumptions, such as the mileage, refining the make and model is less valuable.
Assumptions	There are several sources available for some assumptions. Select a primary source that can be used consistently throughout the analysis.	For grid and vehicle emission projections we are using the U.S. EIA Annual Energy Outlook instead of the GREET model or working with AEP to develop region-specific projections. The EIA information is well-vetted and a heavily used model that offers new vehicle (car, light truck), stock vehicle, and vehicle miles travelled assumptions. The Annual Energy Outlook also includes future-year projections (e.g., average stock vehicle removed from road in 2019, 2020, etc) that will prove to be useful as the PfMP is updated.
Decarbonization	Utility regulatory practices are unique for every circumstance investigated. Complexities around asset ownership and maintenance require thoughtful deliberation and consideration when designing a utility program. Realize that full engagement in this process is necessary, but still can be unpredictable and outside of your control.	Renewable energy projects must go through a rigorous process with consumers, stakeholders, and approval from the Public Utilities Commission (PUCO). The proposed 400MW solar project included considerable customer and stakeholder input before and after the Request For Proposal to perform the work. During the PUCO review process, it has been important for local government, supporting non-profits and industry partners to remain engaged to provide stakeholder input.
EV Adoption	Complications and challenges with obtaining vehicle registration data.	The Smart Columbus agreement with IHS Markit provides for data every quarter. The data is received 45 days from the end of the quarter. This means we wait 4 months for data to know if our interventions are having a positive impact. By obtaining vehicle registration data directly from the Ohio BMV we were able to estimate the likely vehicle

		adoption numbers for the month within a couple weeks of the end of each month.
Tracking Performance	Define specific details for data collection for each project element and establish the GHG baseline early as soon as possible in the program.	Our program is complex and has needed to evolve to incorporate new learnings and capitalize on opportunities. That said, retroactively quantifying the indicators that have evolved/changed since grant initiation presents more of a challenge than if these items were tracked at the time of occurrence.

When Columbus received funding from the Paul G. Allen Family Foundation the importance of using this program to learn and grow the industry was made clear. Loreana Marciante, Paul G. Allen Family Foundation Program Manager, said she expected some of the projects would not play out as expected, but all should be documented and shared in order for others to learn from the successes and struggles. The result is the Smart Columbus Playbook [10]. New articles are continually added.

5 Conclusions

As noted in the Fourth National Climate Assessment, "Communities, governments, and businesses are working to reduce risks from and costs associated with climate change by taking action to lower greenhouse gas emissions and implement adaptation strategies." [1]

Thanks to a jumpstart from the Paul G. Allen Family Foundation, combined with considerable additional investment from partners such as AEP, Columbus has realized the following reductions in GHGs:

Table 7: Overall Program GHG Reductions

Overall Program Goals	Year 1 Actual	Year 2 Actual	Year 3 Projected	Total
Grid Decarbonization GHG Reduction ($MTCO_2$)	146,673	307,703	227,212	681,588
EV Adoption GHG Reduction (cumulative, $MTCO_2$)	345	749	1,686	1,686
Total GHG reductions/savings ($MTCO_2$)	147,018	308,452	228,898	683,274
% GHG emission reductions from baseline year	0.57%	0.63%	0.89%	2.09%

Over 99% of the projected GHG reductions will be from the decarbonization (Priority 1) effort which includes various energy efficiency programs and the conversion of coal power production to wind, solar, and hydroelectric power production.

This grid decarbonization savings equates to over 3,700 railcars worth of coal not being burned and the number of EVs placed in operation will prevent about 190,000 gallons worth of gasoline from being consumed.

Figure 10: Greenhouse Gas Reduction Equivalencies

Grid decarbonization efforts are expected to continue. The Columbus DOP has begun construction on a 5MW hydroelectric plant and a co-generation plant. American Electric Power is in the approval process of installing 400MW solar generation capacity and 500MW of wind generation capacity. Once operational, their projected annual GHG reduction is anticipated to be over 1 million metric tons of carbon dioxide.

Over the last five years, there has been an average year over year grown in EVs registered in Ohio of 120%[6]. Positive EV adoption trends seem to be even more pronounced in the seven-county Columbus region since the grant work began in April of 2017. From 2013 to 2017 the Columbus region's new EV registrations matched those of the Cleveland and Cincinnati, Ohio, regions (Figure 11). In 2018, Columbus broke away from the others and experiences higher EV adoption rates.

This adoption trend is expected to continue as Smart Columbus program momentum builds. The Paul G. Allen Family Foundation's initial challenge to Columbus was that they use the $10 million in grant funds to leverage other funding and partnerships to collectively accelerate GHG reductions. Early indications are that they are accomplishing their goal of creating an inflection point and future benefits will compound.

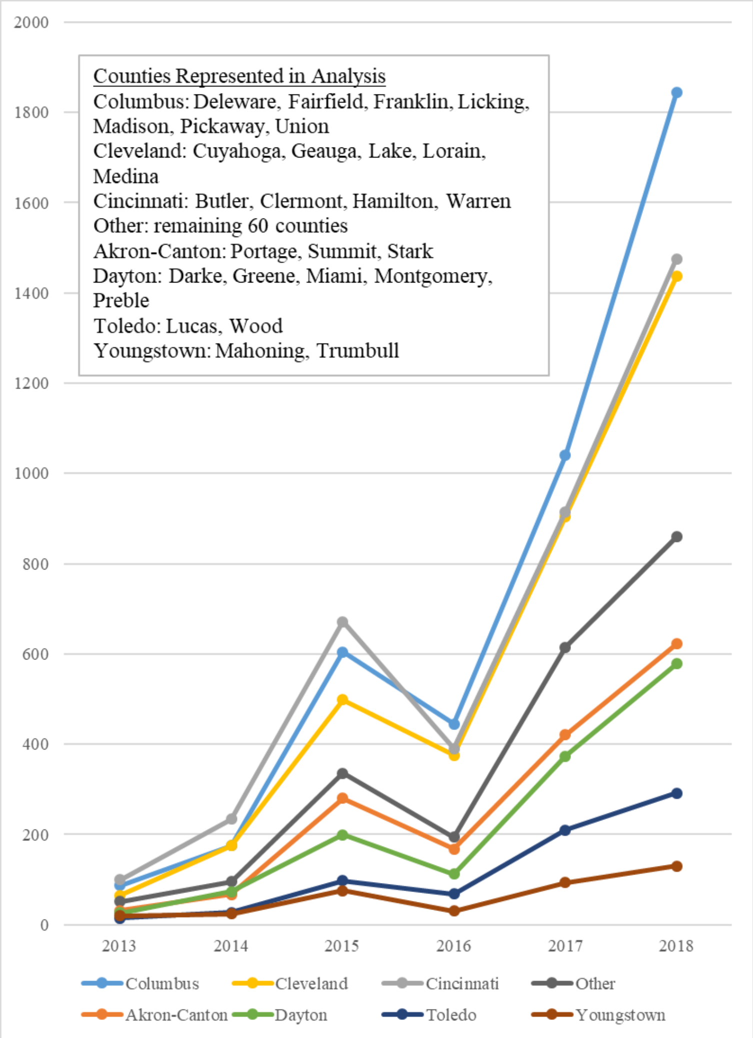

Figure 11: New Plug-in Vehicle Registrations in Ohio

Acknowledgments

Smart Columbus' program is notable for the number of partners that contributed time, equipment and funding to achieving the metrics discussed. American Electric Power, the City Division of Power and Division of Fleet Management, The Columbus Partnership and several of their corporate members, the National Renewable Energy Lab, Ohio Dominican University, DC Solar Freedom and others contributed to Smart Columbus reaching most of the targets they set out to achieve.

We would like to thank Nic Lutsey, Program Director / Regional Co-Lead, International Council on Clean Transportation for his guidance on this paper.

Thank you also to the Ohio Bureau of Motor Vehicles for providing endless data and guidance as we worked through how to measure and track progress.

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Authors

Scott Lowry, PE is an engineer with HNTB. He's experienced in ITS design and has been working the past couple years on performance measurement for the City of Columbus Paul G. Allen Family Foundation Smart Cities Grant. This involves calculating the greenhouse gas (GHG) emissions reductions associated with each of the 40+ grant projects. Scott also recently drafted a Zero Emissions Vehicle strategy document for the San Francisco International Airport. He has a geomatics engineering and a civil engineering degree from The Ohio State University, Columbus, Ohio.

Katherine Zehnder, PE, PTOE, AICP has twenty years of experience with HNTB on large infrastructure and technology projects. She led a team the City of Columbus hired to prepare the technical application that won Smart City's Grants from USDOT and Paul G. Allen Family Foundation. Katie moved to Ohio to join HNTB after graduating with honors in civil engineering from Union College, Schenectady, NY in 1998. She has an MBA in Management Information Systems from Case Western Reserve University in Cleveland, Ohio.

Norman L. (Bud) Braughton, PE serves as Program Manager for the $10m Paul G. Allen Family Foundation's Smart City grant to the City of Columbus. For the past 16 years he's overseen the planning, design, and construction of major downtown projects including over $100 million in projects in preparation for the 2012 City Bicentennial celebration. Prior to working at the city, he spent twenty-seven years with Conrail and CSX railroads improving and modernizing railroad signal systems and training employees in order to provide for better safety and reliability. He has an electrical engineering degree and MBA from Franklin University, Columbus, Ohio.