Intersecting Residential and Transportation CO₂ Emissions: Metropolitan Climate Change Programs in the Age of Trump

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Abstract
This article uses a series of fixed-ratio projections and scenarios to explore the potential for local residential energy conservation mandates and compact growth programs to reduce locally based CO₂ emissions in eleven representative US metropolitan areas. Averaged across all eleven metros, residential energy conservation mandates could reduce residential CO₂ emissions in 2030 by an average of 30 percent over and above 2010 levels. In terms of implementation, residential conservation standards were found to be goal-effective, cost-effective, scale-effective, and in the case of new construction standards, reasonably resistant to local political pushback. Local compact growth programs do not perform as well. If accompanied by aggressive efforts to get drivers out of their cars, compact growth programs could reduce auto-based 2030 CO₂ emissions by as much as 25 percent over and above any emissions reductions attributable to higher fuel economy standards. Unaccompanied by modal diversion programs, the stand-alone potential for local compact growth programs to reduce auto-based CO₂ emissions falls into a more modest range of 0 to 7 percent depending on the metropolitan area. Based on past performance, local compact growth programs are also likely to have problems in terms of their goal- and scale-efficiency, and their potential to incur political pushback.

Keywords
energy conservation mandates, infill development, greenhouse gas reduction

When we first submitted this article in June 2016, our manuscript explored the potential for local governments to achieve meaningful greenhouse gas reductions by supplementing the Obama Administration’s two major climate change initiatives¹ through local planning interventions. The election of President Donald Trump makes this original subject even more important in light of his administration’s opposition to federal action on climate change.² With the federal government now on the climate change sidelines, local government initiatives have suddenly and unexpectedly become more important to any remaining US effort to reduce greenhouse gas emissions. Many cities have declared or expressed their interest in residential energy conservation and compact, transit- and pedestrian-friendly development forms as ways to continue the United States’ previous commitments to the Paris Agreement.

At first look, such initiatives would seem to have significant potential. Residential energy use accounted for 22 percent of total US energy consumption in 2014 while residential heating and cooling accounted for 5.6 percent of US CO₂ emissions in 2013; and there is believed to be room for further efficiency improvements in both (Brown 2008). Similarly, the transportation sector currently accounts for 28 percent of US greenhouse gas emissions, with private car and light truck use accounting for 62 percent of transportation-based emissions (US Environmental Protection Agency 2015). While vehicle-level fuel efficiency is mostly a matter of technology and energy prices—both of which are determined nationally and internationally—planners can try to shift local land use patterns and densities in ways that encourage people to change their travel behavior, reduce structural auto-dependency, and drive shorter distances.

This article uses a series of fixed-ratio projections to answer two overarching questions:

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**Question 1 (Q1):** What is the potential for local residential energy conservation mandates to substantially reduce residential energy consumption and related CO₂ emissions?

**Question 2 (Q2):** What is the potential for local infill and compact growth programs to reduce vehicle miles traveled (VMT) and thus transport-based CO₂ emissions?

There is no one-size-fits-all answer to either question. Rather, the answers vary locally and by metropolitan area depending on the amount of projected population growth (Q1 and Q2); the age and mix of the local housing stock (Q1); the local potential for infill development and residential densification (Q2); local travel patterns and modal preferences (Q2); the local climate (which determines heating and cooling loads) (Q1); and the local sensitivity of auto travel to urban form (Q2). Any discussion of either approach should thus consider how and why their results are likely to vary locally.

The rest of this article is organized into seven parts. Part II delves further into the modeling and empirical literature. Part III develops a simple residential energy consumption model and uses it to explore the local energy conservation and CO₂ emissions reduction benefits of four new and existing home energy conservation regimes. Part IV develops and applies a similarly configured model of auto-based CO₂ emissions based on projected population growth, rates of infill housing development, travel behavior trends, and the fact that the residents of dense neighborhoods are less likely to use their cars and more likely to walk, bike, or use public transportation.

The models developed in Parts III and IV are used to create baseline energy use and emissions projections for 2030; and then to simulate how different residential energy conservation and urban development policies, expressed in the form of scenarios, might lead to greater or lesser residential energy use and urban automobile travel. Both sets of projections and simulations are developed for 2030, the original target year for full implementation of the Obama Administration’s Clean Power initiative. Both are developed and tested using the same eleven metropolitan areas. These include the Atlanta, Boston, Chicago, Cleveland, Denver, Houston, Los Angeles, Miami, Philadelphia, Phoenix, and Seattle Metropolitan Statistical Areas. These eleven metro areas were chosen because they are large enough to include an adequate number of observations as reported in the US Energy Information Agency’s (2009) Residential Energy Consumption Survey (RECS), large enough to have viable public transit systems, large enough to include both core and noncore neighborhoods, and are spatially representative of different climate zones and political orientations.

Part V evaluates the various simulation results by comparing them to the results of local Climate Action Plans (CAPs). Part VI takes a more detailed look at the range of local regulatory, pricing, and investment programs available to reduce residential energy consumption and promote increased infill development, and evaluates them along four measures of implementation effectiveness. Lastly, Part VII tries to identify where and when both sets of programs would seem to make the most sense.

The simple formula-driven models at the heart of this article stand in deliberate contrast to conventional statistical models such as regression analysis. Regression models typically compare the observed pattern of variation around the average value of a designated outcome measure (i.e., the dependent variable) to corresponding variations around a series of input, or independent, variables. When used for forecasting and policy simulation, regression models work best for testing small shifts in input values, or conditions like those under which the model parameters were originally calibrated. This limitation is especially binding when the model doesn’t fit the data all that well, or, as in the current case, when testing the effects of simultaneous changes to two or more inputs. When modeling big changes from the status quo, or a combination of big changes—both of which we are doing here—it is better to follow economist John Maynard Keynes’s advice that “it is better to be roughly right than precisely wrong,” and use imprecise but robust ratio-based models rather than seemingly precise but circumstantially limited regression models.

Finally, as in many disciplines, planning researchers too often work in isolation from one another. Figuring out ways to reduce CO₂ emissions in the face of continued population growth will require that local housing planners effectively work alongside regional transportation planners. This article offers an initial step for how such collaborations might take place.

**Literature Review**

There have been several recent studies connecting urban form to carbon emissions. The usual approach taken is to connect national- or regional-level surveys of travel behavior or building-level energy use (as outputs) to similarly scaled socioeconomic or built form measures (as inputs), and then to “downscale” those relationships to the local level using small area information gathered as part of the Decennial Census or American Community Survey (US Census Bureau 2016a). Using this approach and regional-scale data from the 2009 US Residential Energy Consumption Survey (RECS), Min, Hausfather, and Lin (2010) was one of the first papers to develop zip code–level estimates of residential energy use.

For transportation-related energy use and carbon emissions, Gately et al. (2013) and Gately, Hutrya, and Wing (2015) connected fine-grained (1-km square) roadway-level traffic data for Massachusetts to US travel pattern data to construct carbon emissions inventories at the local level. Similar to the approach of Min, Hausfather, and Lin (2010), C. Jones and Kammen (2014) combined the results of national-level energy consumption surveys with known empirical relationships between energy consumption and
various geographic factors to derive household-level carbon footprints at the zip code level and further disaggregated these carbon footprints into energy, transportation, food, goods, services, and other end uses. The results in both papers are a series of statistical correlations between emissions levels and local population densities. And while these papers suggest that their results could usefully inform local planning decisions, neither says precisely how.

Downscaling assumes that national- or regional-level policies will work the same way at the community or building scale, something that is not always true. The scale differential problem is further complicated by discrepancies between preimplementation simulation studies and postimplementation audits. In the case of building-level energy conservation, an entire industry has developed to simulate how improved building design, construction, and commissioning processes—usually around the LEED standards promulgated by the US Green Building Council—can achieve meaningful gains in energy efficiency (Sentman, Del Percio, and Koerner 2008; Eames et al. 2013; Stevenson 2013). At the same time, after-the-fact audits of new LEED-certified buildings have found tremendous variability in observed energy performance, even among those designed to the same standards (Newsham, Mancini, and Birt 2009; Diamond 2011). Residents, whether they own or rent, still face a number of persistent barriers to retrofitting existing homes for energy conservation (Blumstein et al. 1980; P. Jones, Lannon, and Patterson 2013).

There is similar uncertainty about the effectiveness of compact growth policies. Using national-level travel data from the 1995 Nationwide Personal Transportation Survey, Burchell et al. (2002) estimated that shifting the locations of new housing and employment centers away from development patterns colloquially known as “sprawl,” and toward more compact development forms would reduce total person miles of travel by just 4 percent. By contrast, a more detailed study by Ewing et al. (2007), titled Growing Cooler, concluded that reductions in overall vehicle miles of travel (VMT) of 30 percent might be possible by 2050 if 60 to 90 percent of projected new urban development were to take the form of compact growth instead of sprawl. A subsequent study by a National Research Council Committee (2009) came to a more modest conclusion. It found that doubling residential densities—something that would be near impossible to achieve in the face of certain community opposition—for 75 percent of projected new housing (though 2030) would result in a 25 percent reduction in VMT, and at most, an 8 percent reduction in CO₂ emissions. More realistic scenarios, in which residential densities would be doubled for 25 to 50 percent of new housing units, resulted in CO₂ reductions in the range of just 1 to 3 percent.

The extent to which changes in density (and other related characteristics of urban form) will result in reductions in automobile travel can be expressed in shorthand form as the “elasticity of VMT with respect to density.” This elasticity summarizes the change in auto-based vehicle miles of travel (VMT) associated with a percentage increase in population densities. Summarizing the results of nine empirical studies connecting density and VMT, Ewing and Cervero (2010) identify a consensus elasticity estimate of just −0.04. In practical terms, this means that a 10 percent increase in population density would be associated with just a 0.4 percent decrease in VMT. One reason these estimates are so low is because increasing densities will only result in less automobile travel if competing modes—which, for most trips, means public transit—can offer a comparable frequency and level of service to the private car. In most American metropolitan areas, that is just not the case (Bento et al. 2005; Zhang 2006; Boarnet 2011; Brownstone and Golob 2009). Other aspects of urban form also matter: The same Ewing and Cervero meta-study found that a collective doubling of density, good urban design, land use diversity, regional accessibility, and distance to transit collectively corresponded with a 50 percent reduction in VMT across the studies reviewed. While encouraging higher densities is sometimes used as shorthand for promoting good urban form, density represents only a fraction of the potential influence of urban form on total VMT and associated emissions.

Modeling the Effects of Local Residential Energy Conservation Standards

We start by considering the potential of residential energy conservation standards to reduce local CO₂ emissions. Municipal decision makers thinking about adopting such standards must contend with four questions. First, should such standards apply to ex ante design and construction or to ex post performance? That is, should property owners be required to build or retrofit their properties using designs, materials, systems, and furnishings that have been predetermined to meet applicable preconstruction standards—this is the prescriptive approach—or should properties, once built or retrofit, be required to perform to an overall standard while in use? Second, should the relevant standards apply to both new and existing homes, or to just new ones? Third, if existing properties are to be covered, should they be required to meet the same conservation standards as new ones? And fourth, if existing properties are to be covered, should compliance be required by a particular date, or should it be tied to particular events, such as when the property sells or is leased to a new tenant?

This section organizes these options into a sequence of five residential energy conservation scenarios, and then tests each of them in the eleven metropolitan case study areas identified above. (This approach assumes that all the municipalities in each metropolitan area adopt the same standards.) These scenarios draw on information on the current composition and age of the housing stock as obtained from the 2010
Decennial Census, on current residential end-use energy consumption as reported in the Energy Information Administration’s 2015 Residential Energy Consumption Survey (RECS), and on 2030 metropolitan population projections as prepared by local metropolitan planning organizations (MPOs). The five scenarios are as follows:

- **The 2030 Baseline Scenario** assumes that the mix of new dwelling units (one-family detached, one-family attached, dwelling units in buildings with two to four units, and dwelling units in buildings with five or more units) built between 2010 and 2030 will mirror the 2010 mix; and that these new homes will consume energy at the same levels as homes constructed between 2000 and 2009. Because the mix of housing types and energy consumption rates both vary by metro area, similar increments of population growth and new home construction may be associated with very different energy consumption outcomes.

- **The R1, Tougher New Construction Standards, Scenario** again assumes that the mix of housing types does not change between 2010 and 2030, but that the introduction of mandatory construction energy standards for new homes would reduce heating, cooling, and refrigeration-based energy consumption by 30 percent (over comparable 2009 levels) and lighting and appliance-based energy consumption by 25 percent. While arbitrary, these reductions are certainly within the realm of technical possibility, and could be achieved through a combination of increased mechanical or electrical energy efficiency and the use of price- and demand-responsive HVAC, lighting, and appliance control systems.

- **The R2, Multifamily Shift, Scenario** takes scenario R1, above, as its starting point, but shifts the mix of new units away from one-family detached homes and toward multifamily structures. Specifically, it posits a 25 percent reduction in the construction of one-family detached homes (compared to the Baseline Scenario) and a corresponding increase in the construction of one-family attached and multifamily homes. This shift among structure types is likely to manifest itself as a partial shift among locations and densities, away from lower-density suburban neighborhoods and toward higher-density urban neighborhoods.

- **The R3, New Construction + Retrofit Standards, Scenario** is like scenario R2 (above) with respect to newly constructed homes, but adds additional energy conservation requirements for homes built prior to 2000. For owner-occupied homes, these retrofit mandates would trigger at the time of first sale. For investor-owned or rental units, they would trigger by some combination of tenant turnover and scheduled mandate. In this scenario, the annual rate of residential turnover in all eleven case study metro areas is assumed 5 percent for both single-family and multifamily homes. Regardless of when the retrofit process occurs, newly retrofit units would be required to reduce their annual energy use (for all purposes) by 25 percent over comparable pre-retrofit levels. Although also arbitrary, these reductions, like the 30 percent new construction reductions specified in scenarios R1 and R2, have the advantage of being in the range of technical possibility.

- **The R4, Retrofit w/Local Residential Turnover Rates, Scenario** is similar in every respect to the previous one except that single-family turnover rates can vary locally and in accordance with residential turnover rates as reported in the 2010 Census.

### Modeling and Data Notes

We estimated total 2030 residential energy consumption for each of the eleven case study metropolitan areas using the following model:

$$\text{CO}_2 \text{emissions attributed to the residential sector in 2030 for each metro area}_k = \left[ \sum \left( 2030 \text{ Res Units}_ijk \right) * \left\{ \begin{array}{l} \left( \text{EnergyHC}_{ijk} * (1 - \text{HCCS}) \right) + \\ \left( \text{EnergyLA}_{ijk} * (1 - \text{LACS}) \right) \end{array} \right\} \right] * \text{CO}_2/\text{BTU}_k$$

where 2030 Res Units is the number of occupied housing units in 2030 as calculated by dividing forecast population by average household size; EnergyHC indicates energy use per dwelling unit (in millions of BTU) for heating and cooling purposes; HCCS indicates the percentage reduction in energy use for heating and cooling associated with a particular conservation mandate; EnergyLA indicates energy use per dwelling unit (in millions of BTU) for lighting and appliance (including computers and entertainment) use; LACS indicates the reduction in lighting and appliance energy use associated with a particular conservation mandate; and CO2/BTU is the weight (in kilogram) carbon dioxide emissions per million BTU of heating, cooling, or electricity (equivalent).

- **i** indicates housing structure type (one-family detached, one-family attached, two- to four-unit buildings, five-plus-unit buildings)
- **j** indicates housing vintage (built prior to 1970, built between 1970 and 2000, built after 2000)
- **k** indicates each metropolitan area

The model terms and parameters vary widely across the case study metropolitan areas (Table 1). The number that
| Source | Characteristic | Atlanta | Boston | Chicago | Cleveland | Denver | Houston | LA and Orange Counties | Greater Miami | Philadelphia | Phoenix | Seattle |
|--------|----------------|---------|--------|---------|-----------|--------|---------|-----------------------|--------------|-------------|----------|--------|
| Baseline population and housing data (Decennial Census) | Metro area population | 5,226,888 | 4,478,644 | 9,455,664 | 1,992,798 | 5,972,036 | 12,789,034 | 5,276,004 | 5,894,521 | 4,117,935 | 3,439,809 |
| | Average household size | 2.7 | 2.5 | 2.7 | 2.4 | 2.5 | 2.8 | 3.0 | 2.6 | 2.5 | 2.7 |
| | Occupied dwelling units (DU) | 1.870,000 | 1.590,000 | 3.100,000 | 0.460,000 | 0.979,000 | 1.967,000 | 0.420,000 | 0.202,000 | 0.498,000 | 1.501,000 |
| | Percentage detached 1-unit dwelling units | 67.1 | 48.0 | 52.1 | 65.0 | 59.7 | 62.4 | 50.0 | 42.5 | 44.6 | 64.8 |
| | Percentage attached 1-unit dwelling units | 5.0 | 5.7 | 7.4 | 5.6 | 7.6 | 3.4 | 7.8 | 9.6 | 29.3 | 5.1 |
| | Percentage 2-4-unit multifamily dwelling units | 4.2 | 2.1 | 6.8 | 10.3 | 4.3 | 8.3 | 7.2 | 9.0 | 4.8 | 6.6 |
| | Percentage 5+ multi-family dwelling units | 20.7 | 23.4 | 24.7 | 17.9 | 26.6 | 25.6 | 32.0 | 38.7 | 15.7 | 18.6 |
| | Share (%) of dwelling units built prior to 1970 | 15.5 | 63.0 | 54.4 | 65.0 | 30.9 | 19.7 | 56.2 | 28.7 | 59.7 | 14.3 |
| | Share (%) of dwelling units built between 1970 and 2000 | 53.9 | 28.8 | 33.6 | 27.3 | 30.3 | 51.3 | 36.6 | 57.0 | 31.7 | 56.5 |
| | Share (%) of dwelling units built after 2000 | 27.3 | 8.3 | 12.1 | 7.6 | 18.8 | 26.2 | 7.0 | 143 | 8.7 | 28.3 |
| Baseline Energy Use Data (Source: 2009 Residential Energy Consumption Survey) | Average annual heating degree days, 2011-2015 | 2,667 | 5,533 | 6,309 | 5,881 | 6,132 | 3,366 | 1,372 | 124 | 4,149 | 1,046 |
| | Average annual cooling degree days, 2011-2015 | 2,050 | 898 | 1,100 | 1,011 | 1,130 | 3,366 | 809 | 4,684 | 1,551 | 5,207 |
| | Average (per DU) annual lighting and appliance electricity consumption (mBTU-equivalent, 000) | 30 | 23 | 34.9 | 28.8 | 23 | 27 | 24 | 27 | 24 | 26 |
| | Average HVAC energy use (per DU in mBTU-equivalent, 000): homes built before 1970 | 19 | 27 | 31 | 21 | 31 | 21 | 21 | 19 | 21 | 21 |
| | Average HVAC energy use (per DU in mBTU-equivalent, 000): homes built 1970-2000 | 6 | 35 | 20 | 20 | 11 | 6 | 11 | 6 | 35 | 11 |
| | Average HVAC energy use (per DU in mBTU-equivalent, 000): homes built after 2000 | 6 | 53 | 31 | 31 | 17 | 6 | 17 | 6 | 53 | 17 |
| | HVAC factor: 1-unit detached units | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 |
| | HVAC factor: 1-unit attached units | 1.00 | 0.79 | 0.81 | 0.81 | 0.8 | 1.00 | 0.8 | 0.79 | 0.8 | 0.8 |
| | HVAC factor: 2-4-unit buildings | 0.76 | 0.79 | 0.85 | 0.85 | 0.5 | 0.76 | 0.5 | 0.76 | 0.79 | 0.5 |
| | HVAC factor: 5+ unit detached units | 0.55 | 0.53 | 0.48 | 0.43 | 0.4 | 0.55 | 0.4 | 0.55 | 0.53 | 0.4 |
| | Non-HVAC factor: 1-unit detached units | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 |
| | Non-HVAC factor: 1-unit attached units | 0.69 | 0.75 | 0.66 | 0.66 | 0.61 | 0.69 | 0.61 | 0.75 | 0.61 | 0.61 |
| | Non-HVAC factor: 2-4-unit buildings | 0.49 | 0.56 | 0.66 | 0.66 | 0.50 | 0.49 | 0.50 | 0.49 | 0.56 | 0.50 |
| | Non-HVAC factor: 5+ unit detached units | 0.40 | 0.38 | 0.33 | 0.33 | 0.36 | 0.40 | 0.36 | 0.40 | 0.38 | 0.36 |
| CO₂ emissions intensity (Source: US Energy Information Administration) | Kilogram of CO₂ emissions per million BTUs—2013 baseline | 23.7 | 28.7 | 25.3 | 34.3 | 32.7 | 18.6 | 10.7 | 27.3 | 28.0 | 32.8 |
| | Kilogram of CO₂ emissions per million BTUs—Clean Power Plan | 18.1 | 26.7 | 19.4 | 27.9 | 21.8 | 13.8 | 9.6 | 20.9 | 23.1 | 22.6 |
| 2030 projections and scenario parameters | Projected population, 2030 (from MPO) | 6,780,000 | 4,780,000 | 10,800,000 | 2,326,000 | 3,420,100 | 8,676,100 | 13,707,000 | 6,387,400 | 6,240,000 | 7,387,700 |
| | Projected population growth, 2010-2030 | 1,553,112 | 301,356 | 1,344,336 | 333,202 | 885,820 | 2,749,064 | 917,966 | 345,479 | 3,269,765 | 1,073,780 |
| | Projected (annual) housing renovation rate (national average), % | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 |
| | Annual renovation rate based on local turnover, % | 9 | 6 | 6 | 5 | 9 | 6 | 7 | 6 | 10 | 8 |
| | Potential energy consumption reduction mandates (%, compared to baseline) | 30 | 25 | | | | | | | | |
| | New residential construction: HVAC systems | 25 | | | | | | | | | |
| | New construction: non-HVAC systems | 25 | | | | | | | | | |
varies most is anticipated population growth between 2010 and 2030. It ranges from a low of just 0.3 million in metropolitan Cleveland to a high of 3.3 million in metropolitan Phoenix. On the one hand, because new homes are more energy-efficient than older ones, adding more homes that are new has the potential to boost average energy efficiency. On the other hand, growth is growth, so 3.3 million new residents will consume a lot more total energy than 0.3 million.4

The mix and age of the housing stock also varies. According to the 2010 Census, of the eleven case study metro areas, Atlanta has the highest share of detached homes (which, all else being equal, tend to use more energy for heating and cooling than attached homes, and much more energy for lighting, appliances, and consumer electronics), while Miami has the lowest.5 Cleveland and Philadelphia have the highest shares of homes built prior to 1970, while Atlanta, Houston, and Phoenix have the highest percentages of homes built since 2000. In Atlanta and Houston, new homes are slightly more energy-efficient than older homes. In Phoenix, by contrast, new homes are less energy-efficient than older homes.

Energy use rates vary more by climate region than by metropolitan area. Regardless of unit mix or housing stock age, energy use for heating and air conditioning is higher in northern metropolitan areas (e.g., Boston, Chicago, Cleveland, and Philadelphia) and lower in the drier areas of the southwest (e.g., Phoenix and Los Angeles).6 Energy use for lighting and appliances is generally lower in sunnier locations (Phoenix, Los Angeles, Miami, and Denver) and higher in cloudier and more northern metros such as Cleveland and Chicago. Based on data reported in the 2009 RECS, Atlanta’s lighting and appliance energy use is greater than might be otherwise expected, while Boston’s is lower.

Housing turnover rates7 also vary by metropolitan area, although not as widely as housing characteristics and forecast population growth. With 9 percent (on average) of its population changing house every year, Phoenix residents are far more mobile than Clevelanders, only 5 percent of whom move annually. To the degree that existing housing energy retrofit policies might be keyed to when a unit turns over, small yearly differences in moving activity become very large cumulative differences.

Carbon intensity, the weight (in kilograms) of the carbon dioxide produced when generating a million BTUs of heating or cooling (or the equivalent amount of electricity) also varies locally, primarily because of interstate and interregional differences in the use of fossil fuels versus renewables.8 At 34.3 and 32.7 kilograms of CO₂ produced per million BTU, Cleveland and Denver, both of which rely on coal-burning plants for their electricity, have the highest carbon intensities; while Los Angeles, which makes greater use of nuclear, wind, and hydro power, has the lowest at 10.7 kg/million BTU.

Simulation Results

Figure 1 uses a series of waterfall-style charts to summarize the projected 2030 CO₂ emissions levels for each scenario and metro area. The initial bar in each metro area chart indicates the projected 2030 emissions increase over 2010 levels for the baseline scenario. Subsequent bars indicate the cumulative reduction in CO₂ emissions associated with each successive scenario. The final bar indicates the level of emissions reductions compared to the original goals of the Obama Administration’s Clean Power Plan.9 Table 2 summarizes the scenario results across all eleven case study metros, reporting the average emissions reduction (or increase) associated with each scenario as compared to 2010 and the 2030 Baseline scenario. The results in the gray-shaded rows of Table 2 assume that Clean Power Plan continues; the results in the unshaded rows assume that it is not. A full set of simulation results are included as Appendix B, which may be downloaded as an Excel file from the publishers’ website.

Rather than summarize the numerical results of each metro area/scenario combination shown in Figure 1, we consider the range of likely CO₂ emissions reductions (as compared to 2010 levels) associated with each scenario, and the factors that contribute to that range:

1. Absent any residential energy conservation mandates (2030 Baseline), residential energy consumption and CO₂ emissions levels will rise in parallel with metropolitan population growth. Emissions growth rates will lead population growth rates in older metros like Boston, Chicago, and Philadelphia, where new homes are generally bigger and use more total energy than older homes.

2. Compared to doing nothing (2030 Baseline), the effect of imposing new home energy conservation requirements (scenario R1) would be to reduce residential CO₂ emissions by an average of 6 percent. The CO₂ emissions reductions attributable to new home conservation mandates would be larger (i.e., in the range of 10–13 percent) in fast-growing metros with high year-round cooling loads such as Houston and Phoenix, and smaller (e.g., 3–5 percent) in slower-growing metros such as Boston, Chicago, Cleveland, and Philadelphia.

3. Much has been made of the superior energy performance of attached homes over detached ones, so we might expect that encouraging homebuyers to forego a new single-family detached home in favor of a condominium or townhouse would result in substantial energy savings and CO₂ reductions. This is not in fact the case. Compared to a future in which all new homes are required to meet stringent energy conservation standards (scenario R1), reducing the number of new detached single-family homes by 25 percent (and increasing the number of new attached units by...
a corresponding amount, as in scenario R2) would have virtually no incremental benefit in terms of reduced residential energy use and CO₂ emissions. Of the eleven metros considered in this analysis, the only one in which a shift from single-family to attached housing would produce any noticeable energy conservation benefits is fast-growing Phoenix. As new homes of all types become more energy efficient, the energy-use differential between larger and smaller homes will grow smaller, reducing the energy and emissions benefits of any substituting attached homes for detached ones.

4. Requiring existing homes to also meet energy conservation standards (scenario R3) would reduce average residential CO₂ emissions by another 19 percent over and above the reductions achieved by new construction mandates alone (scenario R1). Compared to the 2030 status quo (baseline), adding existing home conservation mandates would reduce residential CO₂ emissions by between 22 percent (Atlanta and Houston) and 27 percent (Los Angeles, Miami, and Philadelphia). Compared to 2010 emissions levels, the effects of imposing energy conservation mandates on both new and existing homes would be to reduce CO₂ emissions by an average of 6 percent, with slower-growing Boston and temperate Los Angeles performing the best of the eleven metros. Conservation mandates can only go so far, especially in the face of rapid population growth: even with new and existing energy conservation mandates in place, CO₂ emissions levels in hypergrowth Phoenix would still increase 40 percent over 2010 levels.

5. Residential retrofit requirements keyed to occupancy changes (scenario R4) are likely to be even more effective at reducing energy consumption in metropolitan areas where people move more frequently than average. In fast-growing Phoenix for example, where, according to the 2010 Decennial Census, single-family homes turn over at a rate of about 10 percent per year (twice the national rate), imposing turnover-based energy conservation retrofit standards (scenario R4) would reduce residential CO₂ emissions by 41 percent compared to the 2030 status quo (Baseline), by an additional 28 percent compared to

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**Figure 1.** Sequential comparison of 2030 residential energy conservation scenario results for the Atlanta, Boston, Chicago, Cleveland, Denver, Houston, Los Angeles, Miami, Philadelphia, Phoenix, and Seattle metropolitan areas.
new construction standards alone (scenario R1), and by an additional 18 percent compared to retrofit standards keyed to the national average turnover rate of 5 percent (scenario R3). Even in slow-growth Cleveland, where single-family turnover rates are just slightly above the national average, the cumulative effects of imposing turnover-based energy conservation mandates would be to further reduce residential CO₂ emissions by 18 percent as compared to retrofit standards keyed to the national turnover rate.

With housing accounting for roughly 20 percent of US CO₂ emissions (US Energy Information Administration), implementing the full suite of residential energy conservation programs included in scenario 4, and coupling them with a successful Clean Power Program, has the potential to reduce total US CO₂ emissions by an average of nearly 10 percent over 2010 levels, and by nearly 12 percent over projected 2030 levels. Even in the absence of Clean Power, residential energy conservation mandates have the potential to reduce national CO₂ emission by an average of 6 percent over 2010 levels, and by 9 percent compared to projected 2030 emissions.

### Modeling VMT and CO₂ Emissions Reductions Resulting from Increased Infill Development

We turn next to the potential for increased infill development (i.e., compact growth) to reduce automobile-based CO₂ emissions. The relationship between higher-density infill development and reduced automobile use has always had something of a “chicken and egg” quality to it. On the infill or “egg” side of the relationship, increasing residential densities is usually seen as a necessary precondition to achieving the ridership growth required to support additional rail and bus service. On the “chicken” side of the relationship, successfully shepherd- ing a high-density infill development project through a contentious local approvals process may require the reassuring presence of high-quality transit service.

This section builds on this two-way relationship to explore the potential of infill promotion policies coupled with programs designed to increase travel by foot, bicycle, or public transit to significantly reduce vehicle-based CO₂ emissions. It does so by developing and evaluating five 2030 transportation scenarios using the same eleven case study metros discussed in Part III. These scenarios are distinguished by four differences. The first is the amount of current and future automobile travel per person, expressed in terms of per capita vehicle miles of travel, or VMT. The second is the share of future population growth directed to infill sites in each metro’s designated core area. The third is the additional increment of population density resulting from increased infill development. And the fourth is the observed and projected relationship between population density and per capita VMT. This last relationship is expressed as an elasticity, in which a percentage increase in population density is associated with a percentage decrease (or increase) in per capita VMT. Each of these factors is discussed in greater detail below.

The five scenarios are as follows:

- In the **2030 Baseline Scenario**, per capita VMT is assumed to remain at current (2014) levels through

| 2030 Residential Energy Use Scenario | Percentage CO₂ Emissions Difference from 2010 | Percentage CO₂ Emissions Difference from 2030 Baseline (No Clean Power Plan) |
|--------------------------------------|---------------------------------------------|---------------------------------------------------------|
|                                      | Average (%) | High Performer (%) | Low Performer (%) | Average (%) | High Performer (%) | Low Performer (%) |
| Baseline 2030 without Clean Power    | 26          | Los Angeles (+7)   | Phoenix (+87)    | na          | na                | na               |
| Baseline 2030 with Clean Power       | −1          | Chicago (−10)      | Phoenix (+29)    | −21         | Denver (−33)      | Boston (−7)      |
| R1: Tougher New Construction Standards | 19          | Los Angeles (+5)   | Phoenix (+63)    | −6          | Phoenix (−13)     | Los Angeles (−2) |
| R2: New Construction and Multifamily Shift | 18          | Los Angeles (+5)   | Phoenix (+60)    | −6          | Phoenix (−15)     | Los Angeles (−2) |
| R3: New Construction and Retrofit Standards | −6          | Los Angeles (−22)  | Phoenix (+40)    | −25         | Los Angeles, Miami, Philadelphia (−27) | Atlanta and Houston (−22) |
| R4: Retrofit with Local Residential Turnover Rates | −31         | Los Angeles (−46)  | Phoenix (+11)    | −45         | Los Angeles (−50) | Phoenix (−41)    |
| R4 with Clean Power                  | −46         | Miami and Denver (−52) | Phoenix (−24)    | −57         | Denver (−66)      | Boston (−49)     |
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2030. Infill development activity (measured as the share of metropolitan population growth likely to occur in core neighborhoods) is also assumed to remain at contemporary (1990–2010) levels. The elasticity of (per capita) VMT with respect to population density is assumed to be .10, meaning that a 10 percent increase in population density would be accompanied by just a 1 percent decrease in per capita VMT.

- The T1, Trending VMT Scenario, differs from the 2030 Baseline scenario in terms of per capita VMT but not with respect to infill activity or the elasticity of VMT versus density. Specifically, per capita VMT is assumed not to remain at 2014 levels, but to instead follow the observed 2000–2014 trend line. In the cases of Atlanta, Denver, Houston, Los Angeles, and Seattle, this trend is downward, toward lower per capita VMT levels. In the cases of Boston, Cleveland, Miami, Philadelphia, and Phoenix, the trend goes in the other direction, toward higher per capita VMT.

- The T2, Compact Growth Scenario, differs from the 2030 Baseline scenario in terms of per capita VMT and from the T1, Trending VMT, scenario in terms of infill activity. In scenario T2 (as in scenario T1), per capita VMT is projected to continue following its 2000–2014 trend line. In terms of infill, scenario T2 projects that future infill activity will occur at 150 percent of its historical rate. In the cases of Boston and Los Angeles, this latter assumption has the effect of raising future infill shares into the range of 20 percent or more. In the other case study metros, this increase in infill activity is more modest, putting future infill shares in the range of 5–15 percent.11

- The T3, Compact Growth and Modal Diversion Scenario, is similar to scenario T2 (above) in terms of following 2000–2014 per capita VMT trends, and in assuming future infill activity occurs at 150 percent of prior rates, but differs in its use of a more favorable per capita VMT density elasticity of −.25. This assumes that increases in population density are coupled with improved accessibility, urban design, and land use diversification. In short, more growth occurs in the more central and urban parts of the metropolis. This change has the effect of coupling higher infill activity levels and residential densities to lower levels of (per capita) auto travel in both core and noncore areas.

- The T4, Compact Growth and Super Modal Diversion, scenario is similar to the T2 and T3 scenarios (above) in terms of following 2000–2014 per capita VMT trends, and in assuming future infill activity occurs at 150 percent of prior rates, but differs in its use of an even more elastic per capita VMT-to-density-and-urban-form elasticity. Instead of this elasticity being set at −.10 (scenario T2) or −.25 (scenario T3), it is reset to an even more elastic value of −.50. This latter value is analogous to reducing the amount of automobile travel by 50 percent for every 100 percent increase in residential density. As with scenario T3, higher housing densities alone will not encourage most people to walk or take public transit in place of driving. Getting enough people to cut their driving distances in half—which is what increasing the VMT elasticity from −0.1 to −0.5 actually means—would require actively retrofitting most existing residential neighborhoods with a diverse mix of commercial and retail land uses. It would also require curtailing the supply of free on-street parking and reducing required parking ratios for all new development. Most importantly, it would require substantial improvements in regional accessibility to jobs throughout the metropolis.

A Closer Look at VMT Trends, Infill Levels, and VMT–Density Elasticities

A key component of any metropolitan-scale transportation congestion or pollution scenario is VMT, or vehicle miles of travel. VMT measures the total mileage of private vehicles per day or per year.12 All else being equal, higher VMT levels are associated with more congestion and additional pollution, including CO2 emissions. VMT estimates are typically reported on a per-household or per-person basis from data collected as part of a national or metropolitan-level travel behavior survey. Total VMT is then estimated by multiplying per capita VMT by population.

Aggregate VMT levels are the product of many factors, including the locations and spatial distributions of trip origins and destinations, the availability and cost of alternative travel modes, household sizes and income levels, congestion levels, as well as broader societal and demographic preferences. Per capita VMT in the United States was on a steady upward trajectory until 2004, but then, for reasons transportation planners are still struggling to understand, started to level off, and then decline.13,14 According to the US Department of Transportation’s Bureau of Transportation Statistics (BTS), between 2004 and 2014, per capita VMT for the country declined by 7 percent, though it has since started to increase again.15

These national trends are not necessarily mirrored at the local level. Among the eleven metro areas included in this paper, per capita VMT in 2014 varied from a low of 5,390 per year in Philadelphia, where both population densities and public transit coverage are fairly high, to a high of 7,868 in Atlanta, where densities are much lower and regional transit coverage is more selective.16 VMT trends also vary widely by metro area. In Denver, for example, per capita VMT declined by 16.5 percent between 2000 and 2014. In Chicago, by contrast, per capita VMT rose by 32.8 percent over the same period. From 2000 to 2014 per capita VMT fell in four of the ten case study metros (Atlanta, Denver, Houston, and Los Angeles) but rose in six (Boston, Chicago, Cleveland, Miami, Philadelphia, and Phoenix)
A second key component of each scenario concerns the rate of infill housing construction. The term “infill” refers to new residential construction in core neighborhoods commonly regarded as “built-out.” From 1940 until 1990, the vast majority of new housing construction in the United States occurred as suburban development far from existing downtowns. This began changing in the mid-1990s as many suburban communities began running out of easily accessible development sites, and as rising traffic congestion and community pressures for “smarter growth” made new suburban subdivisions less attractive. It accelerated further in the new millennium as aging Baby Boomers and younger households—the so-called Millennial generation born after 1980—began returning to urban neighborhoods en masse (Myers 2016). According to building permit counts collected by the EPA, in 209 of the country’s largest metropolitan areas, infill development accounted for one-fifth of new housing construction (Ramsey 2012).

New homes constructed in built-out prewar neighborhoods clearly qualify as infill housing, but what of new homes constructed in postwar suburbs, on dead shopping center sites, or on sites previously passed over for development? Should they also be considered infill? To sidestep the problem of having to come up with an all-purposes-all-places definition of infill, we will regard infill as any new housing built in a metropolitan area’s “core neighborhoods.” For the purposes of ensuring consistency across the eleven case study metros, we identify core neighborhoods as those census tracts located less than half the distance between a metro area’s CBD and the average CBD–census tract distance for all of its census tracts (US Census Bureau 2016b).¹⁷

To help make this core neighborhood concept clearer, consider the following comparisons between the Atlanta and Philadelphia metropolitan areas. In Atlanta, the average distance between the CBD and the region’s 946 census tracts is 30.2 km. Dividing this distance in half and using the result to identify Atlanta’s core neighborhoods yields a core area of 221 census tracts, 286 square miles, and 603,000 residents as of 2010. Atlanta’s core area accounted for just 11.6 percent of the region’s population in 2010, and just 1.8 percent of its population growth between 1990 and 2010. Philadelphia’s core area, identified using the same method, included 26 percent of the region’s population in 2010.

The various population growth, density, infill share, per capita VMT, and VMT–density elasticity scenario inputs are listed by metropolitan area in Table 3. Tract-level population counts and residential density estimates were obtained from the 1990 and 2010 Decennial Censuses; metropolitan-level VMT and per capita VMT estimates were obtained from the results of the Texas Transportation Institute’s 2014 and 2015 Urban Mobility Survey. In terms of projected population growth, we used the same MPO-sourced estimates as in Part II.¹⁸

Simulation Results

Figure 2 uses a second series of waterfall charts to summarize the projected 2030 CO₂ emissions levels associated with each infill scenario. The initial bar in each metro area chart indicates the projected increase in CO₂ emission by 2030 (compared to 2010) assuming no change in infill development policy. Subsequent bars indicate the incremental reduction in CO₂ emissions associated with each successive infill and travel behavior scenario. The final bar indicates the additional emissions reductions achievable assuming that the Trump Administration does not relax or renegotiate the Obama Administration’s agreement to raise vehicle fuel economy standards to 54.5 miles per gallon (mpg) by 2027.

Table 4 summarizes the infill and transportation scenario results across all eleven case study metros, reporting the average emissions reduction (or increase) associated with each scenario as compared to 2014 and the 2030 Baseline scenario. The results in the gray-shaded rows of Table 4 assume that President Obama’s 2011 agreement with US automobile manufacturers to raise their vehicles’ average fuel economy to 54.5 mpg by 2025 remains in place; the results in the unshaded rows assume that the Trump Administration cancels that agreement. A fuller set of simulation results are included as Appendix C, which may be downloaded as an Excel file from the publishers’ website.

Rather than summarize the numerical results of each metro area/scenario combination, we touch on five sets of takeaway observations that cross multiple scenarios and metros:

1. Absent concurrent efforts to expand public transit service or to direct infill development into particular transit corridors, the potential for infill-oriented compact growth programs to significantly reduce automobile-based CO₂ emissions is extremely limited. Even in growing metro areas such as Los Angeles or Denver that have room to accommodate increased infill development and are inclined to steer development accordingly, the resulting increase in average densities will be too small to encourage enough drivers to abandon their cars in favor of walking, biking, or using public transit. Increasing infill activity by 50 percent over current levels (as proposed in scenario T2) would at most be associated with an 8 percent reduction in regional 2030 VMT and CO₂ emissions levels as compared to not promoting expanded infill activity (Baseline). In some metros—the aforementioned Los Angeles, for example, this is because the baseline level of infill activity is already relatively high. In other metros, notably Atlanta, Miami, and Phoenix, it is because core area densities are so low that the increase in residential density (and associated trip-making) resulting from increased infill activity is
Table 3. Metro Area Inputs into the Infill Development and VMT Model.

| Model Inputs                                      | Source                        | Atlanta | Boston | Chicago | Cleveland | Denver | Houston | LA and Orange Counties | Greater Miami | Philadelphia | Phoenix | Seattle |
|---------------------------------------------------|-------------------------------|---------|--------|---------|-----------|--------|---------|------------------------|---------------|--------------|----------|---------|
| **Baseline information**                          |                               |         |        |         |           |        |         |                        |               |              |          |         |
| Metro area population, 2010                        | Census Bureau                 | 5,226,888 | 4,476,644 | 9,455,664 | 1,992,798 | 5,927,036 | 12,789,034 | 5,276,004 | 5,894,521 | 4,117,935 | 3,439,809 |
| Core area population, 2010                         | Calculated from tract data    | 603,815 | 1,264,382 | 2,102,972 | 309,595 | 373,754 | 976,317 | 2,798,766 | 1,720,666 | 1,546,658 | 545,171 | 948,713 |
| Core area share of metro population, 2010          | Calculated from tract data    | 11.6%   | 28.2%  | 22.2%  | 15.5%  | 14.7%  | 16.3%  | 21.9%  | 32.6%  | 26.2%  | 13.2%  | 24.7%  |
| Core area share of metro population growth, 1990–2010 | Calculated from tract data    | 1.8%   | 14.3%  | 8.7%  | 506.1%  | 11.4%  | 3.6%  | 13.7%  | 4.1%  | -12.4%  | 5.8%  | 19.2%  |
| Metro area (sq. miles), 2010                       | Calculated from tract data    | 7,604.80 | 3,982.40 | 8,451.20 | 3,512.00 | 7,420.00 | 9,218.00 | 5,103.00 | 5,773.00 | 4,298.00 | 13,117.00 | 13,117.00 |
| Metro population density (persons/sq. mile), 2010  | Calculated from tract data    | 687     | 1,125  | 1,119  | 567    | 342    | 643    | 2,506   | 1,371   | 314    | 262    |
| Core area (sq. miles), 2010                        | Calculated from tract data    | 286.4   | 164    | 162    | 71     | 89     | 239    | 207    | 663    | 178    | 182    |
| Core area population density (persons/sq. mile), 2010 | Calculated from tract data    | 2,108   | 7,691  | 12,981 | 4,360  | 4,199  | 4,047  | 13,521  | 2,595  | 2,995  | 4,663  |
| Noncore area population density, 2010              | Calculated from tract data    | 632     | 842    | 887    | 489    | 295    | 552    | 2,040   | 696    | 1,055  | 276    | 200    |
| Estimated annual VMT (millions), 2014              | Texas Transportation Institute | 35,407  | 28,187 | 49,845 | 11,556  | 5,103.00 | 5,773.00 | 4,298.00 | 13,117.00 | 13,117.00 |
| Estimated daily VMT (millions), 2014               | Texas Transportation Institute | 97.01   | 77.22  | 133.88 | 31.66  | 90.88  | 240.65 | 90.44  | 82.11  | 69.23  | 55.72  |
| Annual per capita VMT, 2000                        | Texas Transportation Institute | 8,272  | 6,186  | 5,518  | 5,741  | 7,088  | 7,884  | 7,487  | 5,687  | 4,993  | 6,270  | 7,180  |
| Annual per capita VMT, 2014                        | Texas Transportation Institute | 7,868  | 6,348  | 5,617  | 5,968  | 6,655  | 6,952  | 5,633  | 5,390  | 6,438  | 6,116  |
| Percentage change in per capita VMT, 2000–2014     | Calculated                     | -4.9%  | 2.6%  | 1.8%  | 14.0%  | -15.8% | -15.9% | -7.2%  | -0.9%  | 8.0%  | 2.7%  | -14.8% |
| Annualized percent change in per capita VMT, 2000–2014 | Calculated                     | -0.5%  | 0.3%  | 0.2%  | 1.3%  | -1.7%  | -1.7%  | -0.7%  | -0.1%  | 0.8%  | 0.3%  | -1.6%  |
| Estimated auto-based CO2 emissions (metric tons), 2014 | Calculated from TTI data       | 13     | 10    | 18    | 4     | 6     | 12    | 31    | 11    | 9     | 7     |

| Calculated or projected inputs                     |                              |         |        |         |           |        |         |                        |               |              |          |         |
| Projected metro area population, 2030F             | MPO                           | 6,780,000 | 4,780,000 | 10,800,000 | 2,326,000 | 3,420,100 | 8,676,100 | 13,707,000 | 6,387,400 | 6,240,000 | 7,387,700 | 4,513,589 |
| Per capita VMT, 2030F                              | Current (2014) levels         | 7,868   | 6,348  | 5,617  | 6,547   | 5,968   | 6,655   | 6,952   | 5,633   | 5,390   | 6,438   | 6,116   |
| Continuation of 2000–2014 trend*                   | 7,431   | 6,539  | 5,732  | 7,047   | 5,468   | 6,135   | 6,452   | 5,572   | 5,883   | 6,637   | 4,732   |
| Core area share of metro population growth, 2010–2030F | Current share (2000–2010)     | 1.8%    | 14.3%  | 8.7%  | 15.5%  | 11.4%  | 3.6%  | 13.7%  | 4.1%  | -12.4%  | 5.8%  | 19.2%  |
| Assuming 50% increase over 1990–2010 growth share | 11.6%  | 21.5%  | 13.1%  | 15.5%  | 17.1%  | 5.3%  | 20.6%  | 6.1%  | 26.2%  | 8.7%  | 28.8%  |
| VMT–density “elasticity”                          | Baseline and T1 and T2 scenarios | -0.10  | -0.10  | -0.10  | -0.10  | -0.10  | -0.10  | -0.10  | -0.10  | -0.10  | -0.10  | -0.10  |
| T3 scenario                                        | -0.25  | -0.25  | -0.25  | -0.25  | -0.25  | -0.25  | -0.25  | -0.25  | -0.25  | -0.25  | -0.25  |
| T4 scenario                                        | -0.50  | -0.50  | -0.50  | -0.50  | -0.50  | -0.50  | -0.50  | -0.50  | -0.50  | -0.50  | -0.50  |

a. Trend-line extensions were limited to 500 VMT per capita over/under the 2014 level.
not likely to promote additional pedestrian activity, or make expanded transit service any more economical. Lastly, in markets like Boston, Chicago, Cleveland, Denver, Houston, Los Angeles, Miami, Philadelphia, Phoenix, and Seattle metropolitan areas, core area densities and transit use are already high by national standards, low rates of metropolitan population growth will mean there are fewer new residents to allocate to core and noncore areas. Averaged across all eleven case study metros, the effects of increasing core-area infill activity by 50 percent would be to reduce 2030 CO₂ emissions levels by just 2 percent.

2. In most urban areas, having regular access to a car is so essential to the needs of everyday life that most travelers cannot or will not stop driving entirely, even...
allowing for the expanded modal options afforded by increased residential densities. As a result, even if local governments were to be successful in systematically promoting higher-density development forms, at −0.1, average VMT–density elasticity is simply too small to trigger a wholesale shift away from private car use to other modes. To the extent that this elasticity might be made even more elastic, either by making core areas more walkable, improving the quality of regional transit service, or increasing land use mixes, there might be additional and significant reductions in regional VMT and thus CO₂ emissions. In fast-growing and car-dependent Houston for example, a change in the VMT–density elasticity from −0.1 to −0.25 coupled with an increase in core area densities (scenario T3) would be associated with a 14 percent reduction in 2030 VMT and CO₂ emission levels as compared to the 2030 baseline. The situations in Atlanta, Denver, and Phoenix are similar to those in Houston. In Phoenix, the combination of a 50 percent increase in infill activity and a −0.1 to −0.25 change in the VMT–density elasticity would be associated with a 10 percent reduction in 2030 VMT and CO₂ emissions as compared to 2030 baseline levels. In fast-growing places like Atlanta, Denver, Houston, Miami, and Phoenix, the key question regional land use and transportation planners should be asking themselves is what specific and coordinated combinations of increased infill development and improved transit service and walkability might lead the largest number of future residents to move the aggregate VMT–density elasticity in a more favorable direction.

3. Transformative improvements in public transit service quality and neighborhood walkability would have their greatest potential effect on reducing VMT and CO₂ emissions in growing metropolitan areas like Atlanta, Denver, Houston, and Phoenix. In Houston, for example, moving from scenario T3 to T4 and doubling the VMT–density elasticity from −0.25 to −0.50—the type of change associated with massive improvements in regional transit service and urban and suburban walkability—coupled with substantial increases in infill activity would result in a near doubling of achievable emissions reductions (from 14 to 26 percent) as compared to the 2030 Baseline scenario.

4. Although per capita VMT may be decreasing nationally, it appears to be on the upswing in some metropolitan areas. Among the eleven case study metro areas, per capita VMT increased between 2000 and 2014 by 2.7 percent in Phoenix, by 2.6 percent in Boston, by 8 percent in Philadelphia, and by a whopping 14 percent in Cleveland. These increases are the result of several factors, including recovery from the Great Recession, shifting patterns of job growth, stable and now lower gas prices, and a lack of adequate transit service or capacity to accommodate population growth. While these adverse VMT trends may slow or ultimately reverse themselves, regional transportation and air quality planners should not assume such favorable shifts will occur.

When all is said and done, the potential for increased residential densities to reduce regional CO₂ emissions is dwarfed by potential improvements in vehicle fuel economy. Compared to the “best case” 26 percent emissions reduction associated with higher residential densities and increased public transit use (e.g., scenario T4 in Houston), increasing average vehicle fuel economy from the present level of 25 to 40 mpg would double VMT and emissions reductions. In Houston, this would result in a 53 percent VMT and emissions reduction when compared to the 2030 baseline. Averaged over all eleven case study metros, the effects of increasing vehicle fuel economy would be to reduce auto-based CO₂ emissions by 38 percent in the absence of any compact growth and modal diversion policies, and by 46 percent in their presence. Improving average fuel economy is doubly necessary to offset the large population increases anticipated for most western and southern metropolitan areas, and to counteract shifts in driving activity in older cities like Boston, Chicago, Cleveland, and Philadelphia, where, contrary to national trends, per capita VMT seems to be on the upswing.

Although electric and autonomous vehicles are unlikely to have enough market penetration to affect our results by 2030, these technologies merit additional mention. Because of their much lower carbon intensity, electric vehicles, particularly if powered by renewable energy, could substantially reduce the amount of emissions per VMT. This would dramatically reduce emissions, but also the benefits of reducing VMT-based emissions through land use planning. Autonomous vehicles have the potential to reduce or increase VMT substantially depending on how consumers respond. On the one hand, the technology may lead to substantially more driving, not just by extending automobility to the old, young, and physically disabled but also by increasing the amount that current drivers drive. On the other hand, improvement to public transportation and lower parking needs might increase the desirability of car-free urban lifestyles and allow for substantially more infill housing and mixed-use developments.

**Climate Plans as Confirmatory Evidence?**

How are we to evaluate the reliability and usefulness of these simulation results? Or, to put it in terms familiar to modelers and policy analysts, how are we to validate them? Broadly speaking, there are two approaches to validating simulation
model results. The first is to look to confirmatory results from comparable studies conducted in comparable circumstances (or which analyze similar alternatives or scenarios), but which make use of complementary methodologies. A second approach involves using the same data, but with a differently structured model.19

Following the logic of the first approach, we reviewed the current crop of climate action plans and related documents produced in each of the eleven case study metro areas looking for programs or strategies that connect residential energy conservation standards and increased infill development to reduced greenhouse gas emissions (Appendix A identifies each climate action plan by name and website address). The results of this review are summarized in Table 5. While most of the case study metropolitan areas recognize that these connections exist and are important, except for Los Angeles, none has yet connected specific residential conservation mandates or infill development/modal diversion programs to particular levels of CO2 reduction. Instead, most bundle these types of programs under a broader heading of strategies intended to help meet overall emissions reduction goals or target.

When it comes to considering mandatory residential energy conservation standards, most of the case study metropolitan areas acknowledge the likely efficacy of such programs, articulate the need to collect better data, and indicate that they may be considered in the future. What they do not do is include them on their list of action items. Nor do they connect particular mandates to particular emissions reductions. Atlanta, for example, talks about the need to improve enforcement of current residential energy conservation standards and to work with state and local utilities, but does not connect such actions to particular CO2 emissions reductions. Boston, Cleveland, Houston, Los Angeles, and Philadelphia are similarly vague. Denver and Seattle are only slightly more proactive. Denver’s CAP was last updated in 2015 and promises to implement a next generation of energy conservation mandates sometime in the future, linking such mandates to a 4 percent potential reduction in CO2 emissions. Seattle, which last updated its CAP in 2013, commits to requiring energy audits for large residential buildings (but does not say how it will use the results of those audits) and establishing an energy rating system for use by buyers and sellers of single-family homes. Chicago, with the oldest CAP in the group, remains the most ambitious, at least on paper. Chicago’s CAP, produced in 2008, states that all of the new homes built in the city between 2008 and 2020 (projected to number 65,000) would have to meet LEED energy standards, and that it would undertake a city-funded program to retrofit 400,000 existing homes by 2020. The combination of these two initiatives was projected to reduce the Chicago’s CO2 emissions by 4.5 percent by 2020 as compared to 2005 levels.

Building on the analytical capacity of their MPOs, most of the case study metros do a better job linking prospective investments in transit service (backed by supportive land use changes) to likely reductions in CO2 emissions. Atlanta lists a suite of land use policy shifts and transportation investments designed to reduce CO2 emissions by 20 percent by 2020 as compared to 2009. Boston’s Greenovate Plan, produced in 2014, promises that the city’s public transit and pedestrian investment programs will yield a 5.5 percent reduction in emissions by 2020 (compared to 2005 levels). Slow-growing Chicago and Cleveland are more circumspect in their ambitions, suggesting that their efforts to better connect land use and transportation will yield emissions reductions on the order of 1 to 3.5 percent. Faster-growing Denver and Los Angeles see gradual densification and planned expansions in transit service as the key to offsetting increases in emissions due to prospective population growth. Looking to 2050, the Delaware Valley Regional Planning Commission, the MPO for the Philadelphia region, projects that the combination of a more urban-centered form of regional development coupled with investments in public transit could account for an 80 percent reduction in mobile-source emissions. Seattle is the most ambitious of all. Its planners promise to put in place policies directing 45 percent of its future population growth and 85 percent of its future job growth into existing urban centers, resulting in an 80 percent reduction in vehicle-based CO2 emissions by 2030 (as compared to 2008). In contrast to the ambitions and specificity of Philadelphia and Seattle, Miami and Phoenix acknowledge the connections between land use, transit service, and CO2 emissions, but do not commit to particular emissions reduction targets.

One other set of studies deserve mention in this regard. Under the terms of SB 375, MPOs in California are required to develop Sustainable Communities Strategies (SCSs) indicating the specific steps their constituent communities will take to reduce vehicle-based greenhouse gas emissions. As a condition of receiving state transportation funding, these SCS plans must be certified by the California Air Resources Board (CARB). According to the SCS documentation submitted by the state’s major MPOs to the CARB (and later, after some methodological and political wrangling, certified by them), the results of pursuing a combination of pro-infill and pro-density regulatory incentives, coordinated rail and bus investments, and reduced parking requirements would result in total greenhouse gas emissions reductions ranging from 5 percent (in the San Joaquin Valley) to 8 percent (in Southern California) by 2020 (as compared to 2005), and 10 to 16 percent by 2035.21

Implementation Issues

We have until now finessed the most difficult question of all: whether planners possess the necessary implementation tools required to achieve meaningful CO2 reductions at the local level? This is actually three questions. The first is whether such tools exist and are legally authorized. The second is whether such tools are effective. And the third is whether they are likely to garner the political backing required to support their use.
| Sponsoring Entity and Plan Document | Initiative Area: Compact Growth and Modal Diversion | Initiative Area: New and Existing Residential Building Energy Conservation |
|-----------------------------------|--------------------------------------------------|------------------------------------------------------------------|
| City of Atlanta: Climate Action Plan Update (2015) and Connect Atlanta Transportation Action Plan (2008) | Proposals: Increase the number of residents with a 10-minute walk to transit from 70,000 to 500,000; build 900 miles of new sidewalks and reduce the average block size in future development areas by 25% to encourage additional walking; focus new residential development with a 20-minute commute of Downtown, Midtown and Buckhead employment centers | Proposals: Work with the state and local utilities to expand the availability of residential energy conservation tax credits and retrofit subsidies; improve enforcement of new home energy conservation standards |
| City of Boston: Greenovate Boston: 2014 Climate Action Plan Update | Priorities: Expand public transportation coverage and service; expand biking and walking facilities | Priorities: Explore the role of energy-use intensity standards for new buildings, and work with the state (Massachusetts) to explore the potential for retrofit standards |
| City of Chicago (with Center for Neighborhood Technologies): Chicago Climate Action Plan, 2008 | Priorities: Mix land uses and promote compact development to double pedestrian and bicycle trips (to 1 million per day), and increase transit ridership by 30% by 2020 | Strategies: Require all new residential homes (65%) to be built to LEED or equivalent standards by 2020; retrofit 47% of existing residential building stock (400k units) by 2020, with 30% reduction in energy use/retrofitted unit |
| City of Cleveland: Cleveland Climate Action Plan (2013) | Priorities: Increase Cleveland’s population density from 4,800 to 6,000 people per square mile by 2030, making it possible to reduce single-occupancy vehicle mode share from 69% (in 2010) to 55% by 2030 | Priorities: Establish and support residential retrofit programs; develop and implement additional energy conservation requirements for new homes |
| Denver (City and County): Climate Action Plan 2015 | Priorities: Promote transit-oriented development (TOD), car-sharing, and other region-scale multimodal transportation service options. Support regional compact growth plan (Denver Blueprint) | Strategies: Implement energy-efficient building strategies across all building types, including Beyond (next generation) building codes; vague promises to improve energy efficiency of existing homes |
| Houston | No reports, documents, or plans are available | Projected reduction of 431,500 (MMT) of CO₂ by 2020 (3.4% of 2010 emissions) |
| City of Los Angeles and Southern California Association of Governments (SCAG) | SCAG 2016 Regional Transportation Plan/Sustainable Communities Strategy: Direct new population growth into transit and multimodal corridors; promote transit-oriented development; expand regional transit services. | Projected reduction of 96,300 (MMT) of CO₂ by 2030 (1% of 2010 citywide CO₂ emissions) |
| Miami-Dade 2010 Greenprint Plan and 2014 Progress Report | Strategies: Promote corridor-based land use and transportation planning; and transmit-oriented development (TOD)to increase transit ridership and pedestrian activity | Projected reduction of 100,000 or more MMT of CO₂ by 2020 (1% of 2005 Denver CO₂ emissions) |
| City of Philadelphia and Delaware Valley Regional Planning Commission (DVRPC) | DVRPC: Connections 2040. Goals: Promote a hierarchical system of center-based urban development that supports a more modally balanced transportation system to contribute to an 80% reduction in mobile-source emissions by 2050 | Strategies: Implement energy-efficient building strategies across all building types, including Beyond (next generation) building codes; vague promises to improve energy efficiency of existing homes |
| City of Phoenix and Maricopa Association of Governments (MAG) | The Maricopa Association of Governments (MAG) 2015 Regional Transportation Plan (RTP), adopted in 2014, does not explicitly address reducing transportation-based greenhouse gas emissions | City of Los Angeles Sustainability Plan (PLAAN), 2014. Strategies: Adopt procedures to track building energy use to prepare for the adoption of more ambitious new building energy standards |
| City of Seattle: Climate Action Plan (2013) | Develop programs to ensure that at least 45% of Seattle's future population growth and 85% of its future job growth occur in existing urban centers and villages while expanding supporting transit services and pedestrian facilities | Philadelphia Mayor's Office of Sustainability/Drexel University: Deep Carbon Emissions Reduction Report (2015). Goal: Achieve energy-based emissions reductions of 73% (gas) and 27% (electricity) by 2050 based on current (2013) residential CO₂ emissions of 3.7 MMT |
Turning first to the question of whether sufficient implementation tools exist, the broad answer is yes, although the legal availability of particular techniques varies by type and geography. When trying to reduce residential energy consumption, municipalities can use their ample regulatory powers to embed energy conservation requirements in local building and occupancy codes. They can give tax abatements to the owners of properties that use less energy; or tax credits and rebates to property owners who install energy-conserving features. They can make investments in community-level renewable energy facilities, or in projects like district heating, which take advantage of economies of scale.

In terms of redirecting new development to infill locations, municipalities can use regulatory tools like zoning to redirect development from fringe to infill locations, or to reward developers who build residential and mixed-use projects at higher densities. As in Maryland, states can provide supplemental funding to localities who actively pursue smart growth projects. Or, they can make place-specific investments in facilities such as schools, parks, and retail districts to attract new residents to central locations.

Turning to the issue of modal diversion, municipalities can use their regulatory powers to limit rather than expand the supply of parking, and to ensure that developers of new projects provide walking and biking facilities. In terms of pricing, municipalities can selectively subsidize transit use and/or use parking fees and other charges to make driving more expensive. Because travelers choose their modes principally on the basis of convenience and service quality rather than cost, municipalities can invest in projects, facilities, and technologies that make walking, biking, and transit use easier, more convenient, and more reliable.

Table 6 presents a noncomprehensive list of available residential energy conservation, infill development, and modal diversion programs organized by type, that is, whether the program is regulatory, relies on pricing or subsidies, or is project-based. Each program is rated on four effectiveness criteria: goal-effectiveness, cost-effectiveness, scale-effectiveness, and pushback probability. Goal-effectiveness refers to the ability of a program to achieve its intended goal because it employs an appropriate technology and/or is supported by robust institutions. A program may be said to be cost-effective if the costs of achieving its purposes are reasonable relative to the alternatives. Programs that are scale-effective are those that can be scaled upward from the level of an individual project or neighborhood to the community or regional level. Pushback potential refers to the likelihood that those who are not advantaged by a program, or who are actually disadvantaged, will successfully organize to prevent its implementation.22

One type of effectiveness does not automatically imply others. A particular program may be goal-effective but at such a high cost as to be cost-ineffective. Alternately, a program may be goal- and cost-effective at the level of an individual project or case, but not at the larger community or regional level.

To better understand these distinctions, consider the case of residential energy conservation codes. As applied to new homes, such codes are likely to be goal-effective, cost-effective, and scale-effective: they can be widely applied, their costs are reasonable (in comparison to the cost of building construction), and they can be made to work at the community as well as individual building level. Retrofit codes, on the other hand, can be designed to be goal-effective (i.e., to reduce energy consumption in existing homes), but depending on how they are imposed on existing property owners, may not be cost-effective or scale-effective. Moreover, to the degree that their costs fall on property owners who do not quickly realize their benefits, retrofit programs will have a high pushback potential.

Finally, it is important to acknowledge that this analysis does not consider benefits that do not directly relate to CO₂ emissions. For example, higher infill development and lower VMT rates are likely to lead to lower overall fiscal expenditures, lower fatality rates, lower local pollution, and reduced land consumption. The purpose of this analysis is not to evaluate the overall costs and benefits of any program, but to focus narrowly on their relationship to climate change.

Most of the regulatory and pricing-based residential energy conservation programs score fairly well. As a group, they exhibit moderate or high goal-effectiveness, moderate-to-high cost-effectiveness, and low or moderate pushback potential. In terms of scale-effectiveness, the regulatory programs generally outperform the pricing and subsidy programs. (We included state carbon taxes and cap and trade programs because several states have versions of them in place, although their effectiveness remains to be determined.) Depending on how they are targeted and the level of energy conservation required, residential retrofit programs are likely to be somewhat less effective than new construction code programs.

The set of compact growth and infill promotion programs are a more diverse lot. For financial as well as historical reasons, most efforts to refocus population growth from suburban to core areas have been regulatory rather than monetary in nature.23 Over the course of the last ninety years, local land use regulations have proven to be broadly effective at limiting development densities and land uses, but they have proven to be far less effective at redirecting growth from outlying locations back into urban cores. This has been true even in places such as Portland where they have been adopted regionally. And because they deal expressly with private property rights, the imposition of new land use regulations almost always generates legal challenges to their use.

Rather than rely on regulation alone to promote infill development, several states and regions have subsidized it. The most notable of these is Maryland, which, through its Priority Funding Areas Program, has directed millions of dollars of grant and loan funds to public and private projects located in designated urban cores and which further the state’s smart growth policy goals.24 In a similar vein, the San Francisco Bay Area’s Metropolitan Transportation
| Approach                                    | Program Type                  | Program                                                                 | Goal-Effectiveness | Cost-Effectiveness | Scale-Effectiveness | Pushback Potential |
|---------------------------------------------|-------------------------------|-------------------------------------------------------------------------|--------------------|--------------------|--------------------|--------------------|
| Residential energy conservation standards   | Regulatory programs           | New construction building codes                                         | High               | High               | High               | Low                |
| Pricing and subsidy programs                |                               | Existing building retrofit and occupancy codes                          | Moderate           | Moderate           | Moderate           | Moderate           |
|                                             |                               | Electricity and natural gas block pricing and conservation discounts     | Moderate           | High               | Low                | Moderate           |
| Investment programs and projects            | Regulatory Programs           | Property tax abatements for property owners who install energy-conserving features | High               | Moderate           | High               | Low                |
|                                             |                               | State tax credits/utility-provided incentives for approved end-use generation facilities | High               | Moderate           | Moderate           | Low                |
|                                             |                               | State and local carbon taxes or “cap-and-trade” programs               | Unknown            | High               | Unknown            | High               |
|                                             |                               | Retrofit grants to low-income households                                 | Low                | High               | Low                | Low                |
|                                             |                               | State and local investments in renewable energy and community-wide facilities |                    |                    |                    | Will depend on the particular project |
| Compact growth (infill and urban containment) programs | Regulatory Programs           | Suburb-to-core growth redirection: Urban growth boundaries and greenbelts | Low                | Unknown            | Must be implemented regionally | High               |
|                                             |                               | Suburb-to-core growth redirection programs: Transfer of development rights (TDR) | Unknown            | Unknown            | Must be implemented regionally | Unknown            |
|                                             |                               | Suburb-to-core growth redirection programs: Limits on suburban annexation | Low                | High               | Must be implemented regionally | High               |
|                                             | Pricing and subsidy programs  | Core area upzoning                                                       | Moderate           | High               | Low                | High               |
|                                             |                               | Expedited development permitting in core areas                          | Low                | High               | Low                | Moderate           |
|                                             |                               | Residential density bonuses in core areas                               | High               | High               | Moderate           | Moderate           |
|                                             |                               | Government subsidies and enhanced financing for privately developed compact growth/infill projects | High               | Moderate           | Moderate           | Low                |
|                                             |                               | State grants to communities meeting compact growth goals                | High               | Moderate           | Low                | Low                |
|                                             |                               | Differential impact fees and adequate public facilities requirements    | Low                | High               | Must be implemented regionally | Low                |
|                                             |                               | Property and other tax breaks for eligible compact growth projects       | Unknown            | Unknown            | Must be implemented regionally | Low                |
| Investment Programs and Projects            | Expanded funding for core area public facilities (schools, parks, public realm improvements) | Will depend on the particular project and community                       |                    |                    |                    |                    |
| Increased modal diversion                   | Regulatory programs           | Reduced parking requirements in core areas                              | Moderate           | High               | High               | Low                |
|                                             |                               | Licensing of private shared-ride services                               | High               | High               | High               | Moderate           |
|                                             |                               | Mandate pedestrian-friendly urban design features                      | Low                | High               | High               | Low                |
|                                             | Pricing and subsidy programs  | Core area congestion charges                                             | Moderate           | High               | High               | High               |
|                                             |                               | Higher long-term parking rates in core locations                        | Moderate           | High               | High               | Moderate           |
|                                             |                               | Steep fare discounts for regular transit use                            | High               | Moderate           | High               | Low                |
|                                             |                               | VMT-based auto registration fees                                        | Low                | High               | Must be implemented regionally | High               |
| Investment programs and projects            | Public transport investments that expand geographical coverage           | High                       | Low                | High               | Low                |                    |
|                                             | Public transport investments that enhance service quality, frequency, and speed | High                       | Moderate           | High               | Low                |                    |
|                                             | Public transport investments that enhance service convenience             | High                       | Low                | High               | Low                |                    |
|                                             | Investments in bike- and pedestrian facilities, connectivity, and convenience | High                       | Moderate           | High               | Low                |                    |
Commission administered, until recently, a Transportation for Livable Communities program, which directed funds to civic and private projects designed to promote walking, biking, and transit use. Metro, the regional government for Portland, Oregon, operates a similar program. Each of these programs have been worthwhile in that they have funded worthwhile projects that might not have otherwise gone forward, but there is no evidence that they have yet generated systematically higher residential densities, or systematically reduced auto-dependency. By the criteria listed in Table 6, these types of programs are mostly goal-effective and cost-effective, but not scale-effective—at least not yet.

Taken as a group, the various modal diversion programs listed in the bottom third of Table 6 are reasonably goal-effective and, when implemented on a corridor or regional level, also likely to be cost-effective and scale-effective. So why have they not been more broadly implemented? One answer is that the subsidy and investment programs that are likely to be the most effective are also the ones that are the costliest. Another is that federal funding for local transportation projects has mostly been directed toward projects that reduce regional automobile congestion rather than expand mobility. Until recently, many transit investment programs were oversold, triggering a backlash when they did not live up to expectations. Instead of focusing on improving the connection between land use and transportation at the level of the individual traveler, the principal rationale behind many transit investment projects is to extend service to previously underserved areas. To the degree that future efforts to connect compact growth programs with transportation investment or pricing programs focus on enhancing traveler mobility rather than just broadening accessibility, they offer the potential to achieve meaningful reductions in CO₂ emissions.

**Summary Reflections**

When we submitted the first draft of this article in June 2016, we, like many others, assumed that “President Hilary Clinton” would leave in place the Obama Administration’s Clean Power Plan and much higher corporate average fuel economy (CAFE) standards. The intent of our initial draft was therefore to investigate the degree to which local residential energy conservation mandates and compact growth programs might complement these two national level initiatives. Seen in this now quaint context, our findings are simple and straightforward: Averaged across the eleven case study metros, implementing energy conservation mandates on new and existing homes would reduce CO₂ emissions in 2030 by an average of 30 percent over and above the reductions achievable under the Clean Power Plan alone (Reduction rates vary from a low of 14 percent in Phoenix to a high of 44 percent in the Los Angeles region). In terms of implementation, residential conservation standards were found to be goal-effective, cost-effective, scale-effective, and in the case of new construction standards, reasonably resistant to local political pushback.

Local compact growth programs do not perform as well. If accompanied by aggressive efforts to get drivers out of their cars and onto public transit and their feet, and depending on the city, infill and compact growth programs could reduce auto-based 2030 CO₂ emissions by as much as 25 percent over and above any emissions reductions attributable to higher fuel economy standards. Unaccompanied by aggressive modal diversion programs, the stand-alone potential for local infill and compact growth programs to reduce auto-based CO₂ emissions falls into a more modest range of 0 to 7 percent. Based on past performance, local compact growth programs are also likely to have problems in terms of their goal- and scale-efficiency, and their potential to incur political pushback.

With Clean Power and the higher CAFE standards now both at risk, the nature of our inquiry has changed. Instead of viewing local energy conservation mandates and compact growth policies as complements to national climate change efforts, we must now view them as substitutes. In this new context, fully implementing new and existing residential energy conservation mandates in the absence of the Clean Power Plan would result in 2010-to-2030 emissions changes ranging from -39 percent in Boston to +11 percent in Phoenix. Likewise, implementing aggressive infill development and modal diversion strategies in the absence of increased vehicle fuel economy standards would result in auto-related CO₂ emissions falling by 4 percent in Miami by 2030 (as compared to 2014), but increasing by 22 percent in Houston and 30 percent in Cleveland. In the presence of higher fuel economy standards, compact growth programs are mostly of marginal importance. In their absence, promoting infill and development and compact growth becomes much more important. If indeed the Trump Administration steps completely away from its responsibilities to reduce CO₂ emissions, thereby requiring interested state and local governments to take on a bigger role, those same government entities will have to get a lot better at using their regulatory, pricing, and investment powers to reduce auto-dependency and residential energy use.

Beyond issues of policy, this manuscript demonstrates the enduring usefulness of simple but not simplistic models for evaluating the potential impacts of large-scale built environment policy changes; and the importance of considering how such impacts are likely to vary by metropolitan area. Finally, and not unimportantly, it illustrates the value of treating the built environment as a single system in which interventions in housing, land use, and transportation can be seen as complementary and reinforcing. To the degree that local planners can help lead the fight against climate change, it will be because of their ability to integrate policy and programmatic interventions across functional planning areas.
Appendix A

Climate Action Plans and Related Documents Reviewed

- **Atlanta**: Atlanta Regional Commission, “Understanding the Regulatory Environment of Climate Change and the Impact of Community Design on Greenhouse Gas Emissions” (2014), http://www.atlantaregional.com/environment/air/climate-change.

- **Boston**: Office of Mayor Martin Walsh, “Greenovate Boston: 2014 Climate Action Plan Update 2014,” https://www.cityofboston.gov/eoe/pdfs/Greenovate%20Boston%202014%20CAP%20Update_Full.pdf

- **Cleveland**: Sustainable Cleveland 2019, “Cleveland Climate Action Plan: Building Thriving and Healthy Neighborhoods,” 2013, http://www.sustainablecleveland.org/climate_action.

- **Chicago**: Chicago Metropolitan Agency for Planning (CMAP), “Climate Adaptation Guidebook for Municipalities in the Chicago Region,” June 2013, http://www.cmap.illinois.gov/documents/10180/14136/FY13-0119%20Climate%20Adaptation%20Toolkit.pdf/ff5e3867-8278-4867-841a-9090847a; ICF International, “Chicago 2010 Regional Greenhouse Gas Emissions Inventory” (2012), https://www.cityofchicago.org/content/.../Chicago_2010_Regional_GHG_Inventory.pdf; Chicago Mayor’s Office, “Chicago 2020 Proposed Mitigation and Implementation Strategies” (2012), http://climatechicago.fieldmuseum.org/sites/default/files/CCAP_5_SUMMARIES_English.pdf

- **Denver**: City and County of Denver, “Climatext Action Plan 2015 (2015),” https://www.denvergov.org/.../Climate/CAP%20-%20FINAL%20WEB.

- **Los Angeles**: Southern California Association of Governments, “2016-2040 Final RTP and Sustainable Communities Strategy” (2016), http://scagttpscs.net/Pages/FINAL2016RTPSCS.aspx

- **Philadelphia**: Office of Mayor Michael Nutter, “Greenworks Philadelphia (2009),” https://beta.phila.gov/media/20160419140515/2009-greenworks-vision.pdf; “2015 Greenworks Progress Report (2015),” https://beta.phila.gov/media/20160419140539/2015-greenworks-progress-report.pdf; “Growing Stronger—Toward a Climate-Ready Philadelphia (2015),” https://beta.phila.gov/media/20160504162056/Growing-Stronger-Toward-a-Climate-Ready-Philadelphia.pdf

- **Phoenix**: City of Phoenix/ICLEI, “Climate Action Plan for Government Operations” (October 2009), https://www.phoenix.gov/oepsite/Documents/d_026991.pdf; Maricopa Association of Governments, “2035 Regional Transportation Plan (January 2014),” https://www.azmag.gov/Documents/RTP_2013-08-28_Draft-2035-Regional-Transportation-Plan-(RTP).pdf; “ASU Global Institute of Sustainability, 2012 Greenhouse Gas Emissions Reduction Report (December 2013),” https://www.phoenix.gov/Documents/106458.pdf

- **Seattle**: Seattle Office of Sustainability and Environment, “Seattle Climate Action Plan (June 2013),” http://www.seattle.gov/Documents/Departments/OSE/2013_CAP_20130612.pdf; “Seattle Climate Action Plan Implementation Strategy (June 2013),” http://www.seattle.gov/Documents/Departments/OSE/FinalCAPImplementationStrategy.pdf

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Notes

1. These included (1) The Clean Power Plan, originally scheduled to take effect in 2016, and which would have imposed state-based greenhouse gas reduction mandates on power plants, and (2) a doubling of vehicle fuel economy standards from their 2011 level of 27.5 miles per gallon, to 54.5 miles per gallon by 2025. These two initiatives were to serve as the basis of the United States’ commitment under the 2015 Paris Climate Agreement to reduce US carbon dioxide (CO2) emissions by 32 percent by 2030 (compared to 2005 levels).

2. In March 2017, President Trump directed Scott Pruitt, the Director of the US Environmental Protection Agency to cancel the Clean Power Plan. On June 1, 2017, he announced his intention to withdraw the United States from the Paris Climate Agreement. At the time of this writing (July 2017), he is said to be considering rolling-back automobile and light truck fuel economy standards to much lower levels.

3. At –.09, the elasticity estimate for land use mix is only slightly higher. Higher residential densities do result in a bit more walking and a bit more transit use (with consensus elasticity estimates of .07 for both). Of the various built environment variables that affect travel behavior, the ones that matter most are distance-based: people who live near stores walk to them more (e = .25), people who live or work close to a transit station use transit more (e = .29), and people who live near a CBD drive less (e = -.22).

4. When making housing unit projections for 2030, we started with the population projections published by each Metropolitan Planning Organization (MPO). We divided these population projections by the average household size in 2010 to yield 2030 household and housing unit forecasts, and distributed them to the different structure types (e.g., one-family detached, one-family attached, two- to four-unit structures, five-plus-unit
The calculations used to generate a scenario result are as follows: (1) MPO-based 2030 population projections are used to calculate a projected 2010–2030 population increment for each metropolitan area; (2) the projected 2010–2030 population increment is divided into core area and noncore area components based on each metro’s historical core area population growth share, or on the parameters of a particular scenario; (3) the resulting core and noncore population growth increments are added to their respective 2010 population counts to yield separate core and noncore area 2030 population projections; (4) the two 2030 (core and noncore) population projections are divided by the amount of core and noncore land area in 2010 to yield projected core and noncore population densities; (5) the two (core and noncore) density projections are multiplied by scenario-specific estimates of the VMT–density elasticity to yield core and noncore 2030 per capita VMT projections; (6) the two 2030 per capita VMT projections are multiplied by their respective 2030 population projections to yield core and noncore 2030 VMT projections; and (7) the core and noncore 2030 VMT projections are combined into a single 2030 VMT projection, which is multiplied by one of two CO2 emissions factors. The first CO2 emissions factor assumes a 2030 fleetwide fuel efficiency level of 25 miles per gallon. This is the average real-world fuel economy level of new cars sold in 2015. The second emissions factor assumes a 2030 fleetwide fuel efficiency level of 40 miles per gallon. This is less than the 2025 fuel economy standards promulgated by the EPA in 2012, but more in line with expected real-world performance given the rate at which older and less fuel-efficient cars are likely to be replaced.

A third approach, commonly used for validating statistical and machine learning–based models goes under the term cross-validation. The original data set is randomly divided in half, with the first half then used to build or calibrate the model, and the second half used to confirm the calibration results.

Most climate action plans undertaken to date have been undertaken by single municipalities and not by larger planning units such as counties or MPOs. Thus, they mostly consider actions to be undertaken by single municipalities rather than programs that might be coordinated at the metropolitan scale. The unspoken assumption behind this approach seems to be that if the most populous city in a metropolitan area undertakes particular energy conservation or emissions reduction programs, then their smaller neighbors will follow suit. Even when potential programs are considered at a metropolitan scale (usually by the MPO), as in the Philadelphia case, great care is taken to emphasize the voluntary rather than coercive nature of their implementation. The big exception to this “go-it-alone” approach is in California, where each of the state’s MPOs must, under the provisions of AB 32 and SB 375, consider infill development incentives and coordinated funding for alternative modes at a metropolitan level.

These reductions are summarized on the CARB website at https://www.arb.ca.gov/cc/sb375/sb375.htm.

The idea of pushback potential draws on the observations of political scientist James Q. Wilson (Wilson 1984) regarding the difficulties of implementing regulatory programs. Most regulations, Wilson noted, tend to generate small benefits for many while incurring high costs for a few. Even though such programs might pass a cost–benefit test, they create a strong incentive for those few who bear the costs to out-organize and out-politic the many program beneficiaries.

The legitimacy of zoning and other regulations as appropriate uses of local government’s police power was established by the Supreme Court in Euclid v Ambler (1927).
24. Details of Maryland’s PFA program can be found at http://www.mdp.state.md.us/ourproducts/pfamap.shtml.

25. Even if the Trump Administration succeeds in killing the Clean Power Plan, most energy policy analysts expect the trend toward the increased use of renewables and natural gas to continue, resulting in CO₂ emissions levels that are broadly comparable to those that would have been achieved under Clean Power.

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