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# Impacts of compact growth and electric vehicles on future air quality and urban exposures may be mixed

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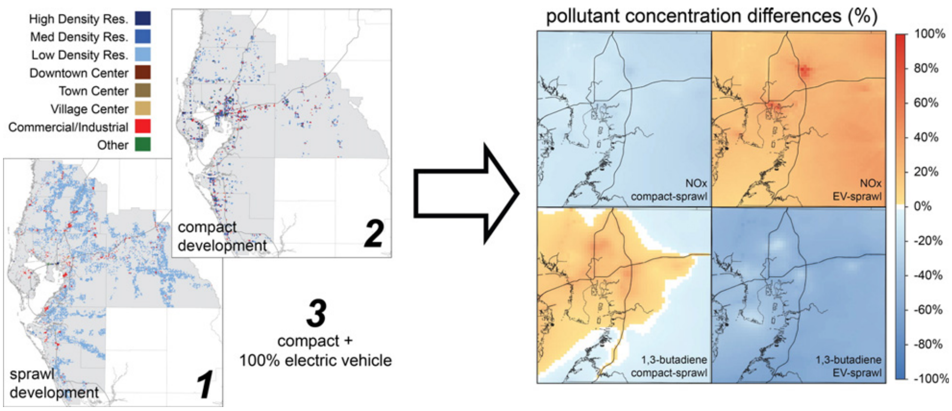
## HIGHLIGHTS

- Impacts of urban design on future air quality and exposure were investigated.
- Compact urban form was predicted to have lower area-wide emissions than sprawl.
- Compact form lowered $NO_x$ exposure but increased exposure to butadiene and benzene.
- Electric vehicles increased $NO_x$ exposure, but lowered exposure to the other pollutants.
- Multiple pollutants and source types need to be considered during urban design.

## GRAPHICAL ABSTRACT



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## ABSTRACT

'Smart' growth and electric vehicles are potential solutions to the negative impacts of worldwide urbanization on air pollution and health. However, the effects of planning strategies on distinct types of pollutants, and on human exposures, remain understudied. The goal of this work was to investigate the potential impacts of alternative urban designs for the area around Tampa, Florida USA, on emissions, ambient concentrations, and exposures to oxides of nitrogen ($NO_x$), 1,3-butadiene, and benzene. We studied three potential future scenarios: sprawling growth, compact growth, and 100% vehicle fleet electrification with compact growth. We projected emissions in the seven-county region to 2050 based on One Bay regional visioning plan data. We estimated pollutant concentrations in the county that contains Tampa using the CALPUFF dispersion model. We applied residential population projections to forecast acute (highest hour) and chronic (annual average) exposure. The compact scenario was projected to result in lower regional emissions of all pollutants than sprawl, with differences of −18%, −3%, and −14% for $NO_x$, butadiene, and benzene, respectively. Within Hillsborough County, the compact form also had lower emissions, concentrations, and exposures than sprawl for $NO_x$ (−16%/−5% for acute/chronic exposures, respectively), but higher exposures for butadiene (+41%/+30%) and benzene (+21%/+9%). The addition of complete vehicle fleet electrification to the compact scenario mitigated these in-county increases for the latter pollutants, lowering predicted exposures to butadiene (−25%/−39%) and benzene

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(−5%/−19%), but also resulted in higher exposures to $NO_x$ (+81%/+30%) due to increased demand on power plants. These results suggest that compact forms may have mixed impacts on exposures and health. 'Smart' urban designs should consider multiple pollutants and the diverse mix of pollutant sources. Cleaner power generation will also likely be needed to support aggressive adoption of electric vehicles.

## 1. Introduction

Exposures to ambient air pollution is associated with a wide range of adverse health effects ranging from minor respiratory tract irritation to increased mortality (Brunekreef and Holgate, 2002; Kampa and Castanas, 2008). Recent estimates suggest that ambient air pollution exposure is a leading environmental health risk factor, and contributes to over three million premature deaths per year worldwide (Forouzanfar et al., 2015). Rapid growth of urban areas around the world (Cohen, 2004) has contributed to these impacts. After 2020, population growth is predicted to occur almost exclusively in urban areas (United Nations, 2015). The United States is no exception to this global phenomenon. From 1980 to 2010, the US urban population increased by 49% and the area of urbanized land increased by 108%. From 2000–2010, 98% of US population growth occurred in urban areas (U.S. Census Bureau, 1983, 2013).

To better control urban air pollution and reduce adverse health effects of pollution exposure, many mitigation strategies have been proposed, among them is improved urban planning. The question of which urban form is most sustainable, i.e. which best accommodates the rapid expansion of cities while maintaining and improving socioeconomic services, and reducing negative environmental consequences such as urban air pollution, has been extensively discussed in the field of urban planning. Within about the last two decades researchers have also started to seriously investigate the impacts of urban form on air quality (Breheny, 1996). Characterization of urban form involves the consideration of many factors related to the types and spatial configuration of residences, destinations, transportation infrastructure, and other land uses (Newman and Kenworthy, 1999). Although indices quantifying sprawl have been developed (Ewing et al., 2002), due to the complexity involved, studies of comparative impacts on air quality (Borrego et al., 2006; Clark et al., 2011; De Ridder et al., 2008; Frank et al., 2000; Kahyaoğlu-Koračin et al., 2009; Liu, 2003; McDonald-Buller et al., 2010; Niemeier et al., 2011; Song et al., 2008; Stone et al., 2007, 2009) often simplify combinations of characteristics into categories representing two more abstract constructs: sprawl and compact urban form.

The sprawl form can be characterized by low-density single-use development, scattered and segregated destinations, lack of central activity centers, and sparse travel networks. Sprawl has been found to encourage the use of private motor-vehicles, while discouraging public transit and active travel (Ewing, 1997; Ewing and Cervero, 2010). Specifically, increased vehicle miles travelled and resultant mobile source emissions are usually associated with sprawl forms (Song et al., 2008). Conversely, compact urban form can be characterized by high density mixed-use developments in or near activity centers, and high accessibility to multi-modal travel networks (Ewing et al., 2002). Compact forms have gained popularity among urban planners as they have been shown to decrease impacts on agricultural lands and wetlands, conserve green spaces, and reduce energy and water use (Chang et al., 2010; Ewing and Rong, 2008; Westerink et al., 2012). Previous researchers have also suggested that compact form could potentially improve air quality and decrease pollution exposure by decreasing motor-vehicle use (through changes in travel mode choices toward public transit, walking and biking) and by decreasing travel distances (through changes in residential location choices) (Boarnet and Crane, 2001). Indeed, several studies of impacts on air quality have found that compact forms may decrease emissions and concentrations of some pollutants regionally (Borrego et al., 2006; De Ridder et al., 2008; Stone, 2008; Stone et al., 2007, 2009; Kahyaoğlu-Koračin et al., 2009; Bechle et al., 2011). However, other studies also predict that higher density urban forms could result in higher population-weighted residential exposures than sprawling forms, particularly for primary particulate components, due to the co-location of population and emissions (Schweitzer and Zhou, 2010; Hixson et al., 2010, 2012; McDonald-Buller et al., 2010; Clark et al., 2011; Martins, 2012). This is consistent with findings that proximity to traffic and active travel are associated with increased human exposure to some pollutants (Kaur et al., 2007). However, urban residents are simultaneously exposed to a variety of air pollutants, and impacts on exposure can differ between pollutants because spatial and temporal patterns of emissions and concentrations differ (e.g. Yu and Stuart, 2016). Studies on the impacts of urban form on multi-pollutant exposure remain limited and mechanisms are still too uncertain to adequately inform policy and planning choices.

One of the transportation choices that has been suggested as a potential remedy for near-road exposures is use of electric vehicles (EV). Due to their zero tailpipe emissions, EVs are generally considered to be a clean alternative to conventional vehicles. Previous studies suggest that wide adoption of EVs, i.e., fleet electrification, could decrease concentrations and exposures to a few important urban pollutants (Electric Power Research Institute, 2007b; Li et al., 2016; Tobollik et al., 2016), particularly in congested inner-cities (Jochem et al., 2016), and could decrease overall emissions of greenhouse gases (Electric Power Research Institute, 2007a; Stephan and Sullivan, 2008; Becker et al., 2009). However, fleet electrification increases electricity demand from power plants, and hence can increase emission from power plants (Electric Power Research Institute, 2007b; Alhajeri et al., 2011; Li et al., 2016). In a study of fine particulate pollution in several Chinese cities, Ji et al. (2015) found that this effect could lead to higher exposures for socio-economically disadvantaged populations living near coal-fired power plants. A few studies suggest that the balance of costs and benefits of fleet electrification likely depends of the power plant fuel mix, EV charging profiles, and urban geography (Funk and Rabl, 1999; Hawkins et al., 2012; Li et al., 2016; Tessum et al., 2014; Ji et al., 2015; Jochem et al., 2016). Overall, further studies are needed to better understand these interactions and their impacts on air quality and environmental health, particularly considering multiple types of pollutants.

The objective of this study was to inform understanding of impacts of urban growth form and fleet electrification on urban air quality and population exposures. To do this, we predicted impacts of three potential future urban development scenarios for the area surrounding Tampa, Florida in 2050 on three important urban pollutants ($NO_x$, benzene and 1,3-butadiene). We considered a sprawl scenario, a compact scenario, and the compact scenario with complete vehicle fleet electrification. We hypothesized that the compact scenario would result in increased exposures for urban residents, but that fleet electrification would effectively mitigate those exposures. For each scenario, we projected emissions using local visioning data, determined spatial concentration distributions using dispersion modeling, and estimated population-weighted human exposure to each pollutant. Results were compared across pollutants and scenarios to inform knowledge on both the effects of urban and transportation design choices on air pollution exposure, and the mechanisms of these effects.