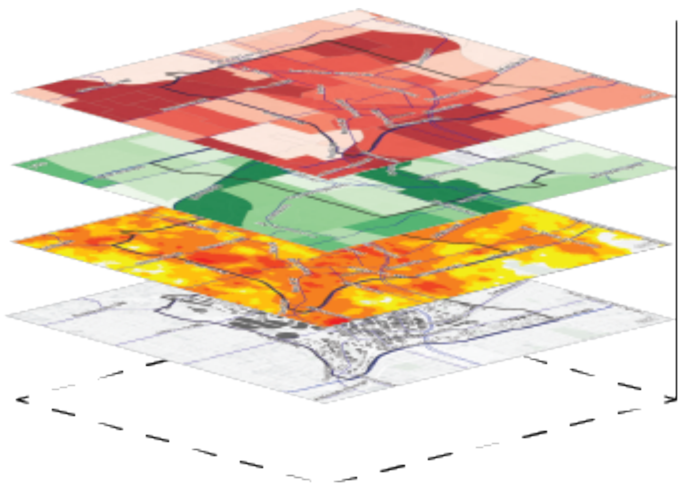
Spatial Analysis of Sustainability and Climate Vulnerability in Downtown Atlanta

Sustainable Cities Studio 2019

Study Prepared for Central Atlanta Progress (CAP)



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1. Introduction

This technical report outlines the background, research methods, and proposed solutions from a vulnerability assessment performed on Downtown Atlanta. This assessment was the Capstone Project for the Fall 2019 Sustainable Cities Studio at Georgia Tech. An accompanying website designed for public outreach can be found at: https://cpcapstone2019.wixsite.com/mysite

1.1. Central Atlanta Progress

Central Atlanta Progress (CAP) is the Community Improvement District for Downtown Atlanta. CAP works with neighborhoods, government, and business interests to plan for the future of the Downtown core and the surrounding areas, with a specific focus on the region bounded by North Avenue to the north, Boulevard to the east, I-20 to the south, and Northside Drive to the west.

A Community Improvement District (CID) is a unit of government with power to provide governmental services and facilities such as waste collection and security among others. To finance such facilities or services, CIDs can assess fees, taxes, and assessments on commercial or industrial real property within the district. CIDs also receive grants and matching funds from state and federal agencies (Council of Quality Growth, 2019).

In 2017 Atlanta's city council approved CAP's new Downtown Master Plan, a comprehensive document that focuses on six major strategies to improve the area. These strategies are Quality of Life, Heritage, Neighborhoods, Economic Development, the Urban Forest, and Transportation.

1.2. Sustainability

The United Nations defines Sustainable Development (a.k.a, Sustainability) as a "type of development that meets the needs of the present without compromising the needs of future generations" (Brundtland, 1987).

Presently, CAP is focusing on developing a sustainability plan for the district. Sustainability is composed of three pillars: the environment, the economy, and equity. Sustainability is best thought of as a stool with three legs and although the environment is most closely associated with sustainability, the stool cannot stand without all three legs (Furman, n.d.). Our Sustainability and Climate Vulnerability Assessment incorporates the three pillars of sustainability to support CAP's sustainability initiative.

1.3. Climate Change Vulnerability

Climate change vulnerability is defined by the IPCC as "a core concept that describes the degree to which a natural or social system is susceptible to, and unable to cope with, adverse effects of climate change" (IPCC, 2007) and it is typically measured through a blend of Sensitivity, Exposure, and Adaptive Capacity.

In 2015, a climate change vulnerability assessment of all of Georgia was performed by Binita KC and J. Marshall Shepherd of the University of Georgia's Geography Department in conjunction with Cassandra Johnson Gaither of the United States Department of Agriculture (USDA) Forest Service. This study offered a detailed assessment of the entire state of Georgia, incorporating both environmental and social vulnerability. This study, however, operated at a county level, which is far too large of a scale to apply within our relatively tiny area of interest. We also found a very detailed Climate Vulnerability Analysis performed on the city of Minneapolis by Laurelyn Sandkamp, Karina Martin, and Cameran J. Bailey of the Humphrey School of Public Affairs at the University of Minnesota (2015). This study also looked at both environmental and social factors impacting vulnerability by place, with data scales ranging from census tracts to 1-kilometer grids.

We found the City of Minneapolis Climate Vulnerability Analysis (2015) to be a good starting point for the analysis we wanted to perform, as it was much closer to the scale we needed for a Downtown Atlanta-specific analysis. One marked improvement we wanted to make on both of these studies was the incorporation of economic factors in addition to equity and environmental measures. In doing so, we could properly address all three pillars of sustainability and give CAP the best guidance possible to assist them in creating their Sustainability Plan and future climate adaptation plan. We also used the most high resolution data possible for each metric, ranging from parcel level to zip code and census tract level.

1.4. Spatial Analysis

Our analysis was based on the Geographic Information System (GIS) technology ArcGIS. GIS is a subset of spatial analysis that allows numerical information about places to be displayed interactively on an electronic map. Spatial analysis was first used in England in 1854 when a physician named John Snow mapped cholera cases to find their source: a previously unsuspected water pump centrally located to the outbreak (GIS Geography, 2019). In the last 165 years, this technology has become widely adopted for software like Google Maps and Uber, but has even more powerful applications when it comes to urban and regional planning.

In its application to a vulnerability analysis, spatial analysis provides an analytical and visual understanding of the relationship between geographic location and vulnerability influencing factors (Esri Press Team, 2018). Because transportation, healthcare, education, and even temperature can vary wildly from neighborhood to neighborhood, it is important to look at risk factors affecting Downtown not just in aggregate, but in the context of specific location. By layering different maps, areas of concentrated vulnerability can be identified, showing CAP exactly which neighborhoods face the greatest threat and what type of responses might help to mitigate that risk.

Atlanta is known as a food destination in the Southeast and is one of the major factors for Atlanta's pull in tourism. However, due to the effects of climate change on agriculture in Georgia and elsewhere, food prices are expected to increase (Georgia Organics, 2019). This may make it increasingly pricier to eat out or buy groceries. Top soil in Atlanta was found to be hotter and drier, hindering certain crops growth in recent years. This could be contributed to climate change along with other factors (Georgia Organics, 2019).

1.5. Studio Structure

Completing one deliverable amongst a class of 10 required us to divide into smaller teams with specific focus areas. At the start of the semester, we defined the objectives of our teams and split ourselves up based on personal interests, skills, and majors. The Social/Policy, Economic, and Science & Technology teams each studied one of the three pillars of sustainability, while the Engineering and Design team coordinated everyone's work and built deliverables such as a class website and presentation posters.

1.5.1. The Social/Policy Team

The social team focused on vulnerabilities specifically tied to social equity. Team members Emily Anderson (Public Policy), Richard Leo Ludwig (Public Policy), and Lisa Harris Pattillo (Masters- Real Estate Development), leveraged resources like SimplyAnalytics and the American Community Survey to map healthcare and poverty in Downtown Atlanta. Leo also took the lead on managing our unified ArcGIS website, translating layers for all the maps into this system.

1.5.2. The Economics Team

Gemma Park and Eliaz Bourez (both Economics and International Affairs) analyzed the interaction between climate change and variables like commercial energy usage or small business vulnerability.

1.5.3. The Science & Technology Team

Almi Mansaray (Environmental Engineering) and Kathrine Udell (Earth and Atmospheric Sciences) were tasked with precisely measuring the environmental realities of Atlanta's Downtown. Creating this analysis at a scale that was small enough to be meaningful for analysis required in-depth research and innovative approaches to measurement. The majority of their effort was spent on quantifying the impacts of localized warming through the urban heat island effect as well as flood risk.

1.5.4. The Engineering & Design Team

Kat Drummons (Industrial Design), Bryce Huber (Civil Engineering), Kateryna Polyakova (Civil Engineering), and Max Rafferty (Industrial Engineering) functioned as a catch-all team for the rest of this vulnerability analysis. Kat's design skills were incredibly helpful in building our website and designing presentations. Meanwhile Kate, Max, and Bryce did much of the background organizational work including managing files, writing website and report content, and comparing CAP's Downtown Master Plan to the challenges we predict Downtown Atlanta will face due to climate change.

2. Methods

2.1. Framework

Several vulnerability frameworks with an emphasis on policy responses to climate change have emerged from the literature (Kelly & Adger, 2000). Vulnerability frameworks are also classified as biophysical or social. Biophysical vulnerabilities are related to the impact from natural hazards (Brooks, 2003), while social vulnerabilities are viewed as the societal response to such impacts (Emrich & Cutter, 2011).

Social vulnerability can also be classified between "start-point vulnerabilities" and "end-point vulnerabilities." The "end-point vulnerabilities" approach measures the impact of climate change on a social system (Füssel, 2005), while the "start-point vulnerability" approach takes into consideration a pre-existing state generated by socio-economic conditions that determines the ability of a society to respond to a climate change impact (KC, Shepherd & Johnson, 2015).

Generally, studies indicate that poverty is the main driving factor of social vulnerability; however, the interaction among social, economic, and environmental factors (i.e. the three pillars of sustainability) may provide a better framework of the conditions in which climate vulnerability is taking place. As such, this study takes into consideration these three pillars for the climate vulnerability analysis of Downtown Atlanta as it was performed by the City of Minneapolis (2015).

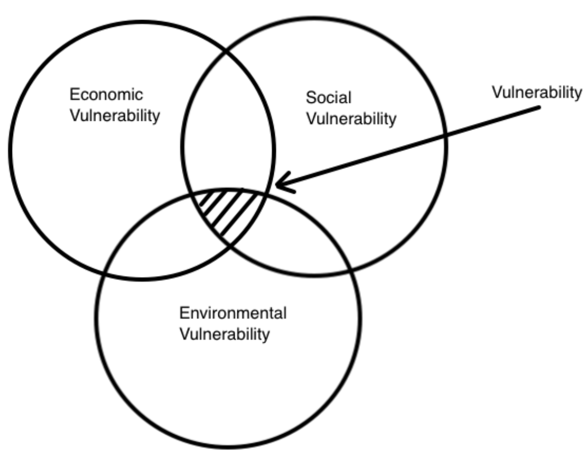

Figure 2.1. Intersection between social, economic, and environmental vulnerabilities

2.2. Data Collection: Maps

Our team collected data from existing GIS maps and also created new maps that reflected the variables used in the study. Maps were divided into general maps, for general purposes; economic maps (ECO); social maps (SOC), and environmental maps (ENV).

2.2.1. General Maps

General maps are maps used as a baseline for analysis. These maps include general topics such as boundaries, political divisions, roads, and buildings.

2.2.1.1. CAP Downtown Boundary

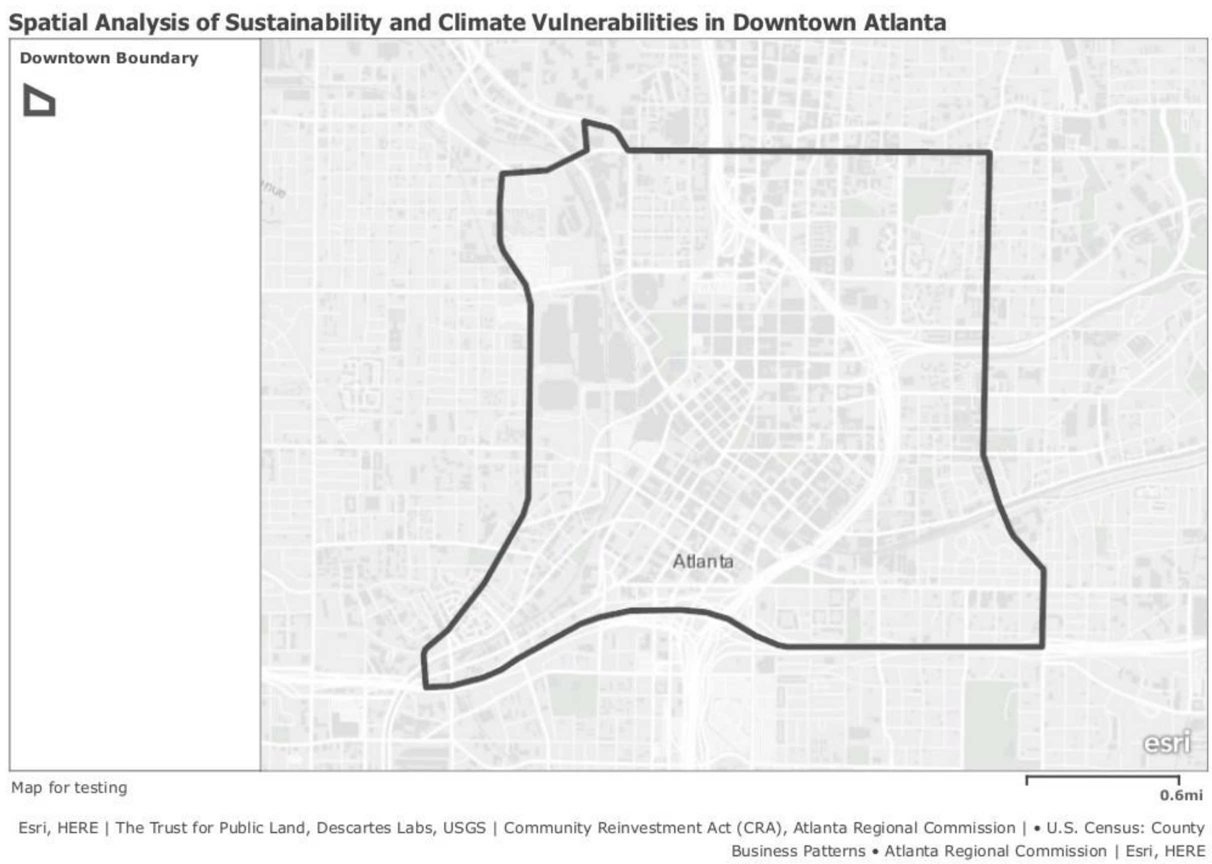

Figure 2.2. The Downtown area boundary, as defined by CAP, is shown in the black outline

For any spatial analysis to be meaningful the space of interest must be defined. Central Atlanta Progress (CAP) defines Downtown as outlined above: bounded by North Avenue to the north, I-20 to the south, Boulevard to the east, and Northside to the west. As many of our map layers pull from census tracts or zip codes that are only partially within Downtown, this overlay is on by default to contextualize our measurements.

2.2.1.2. Neighborhood Planning Units (NPUs)

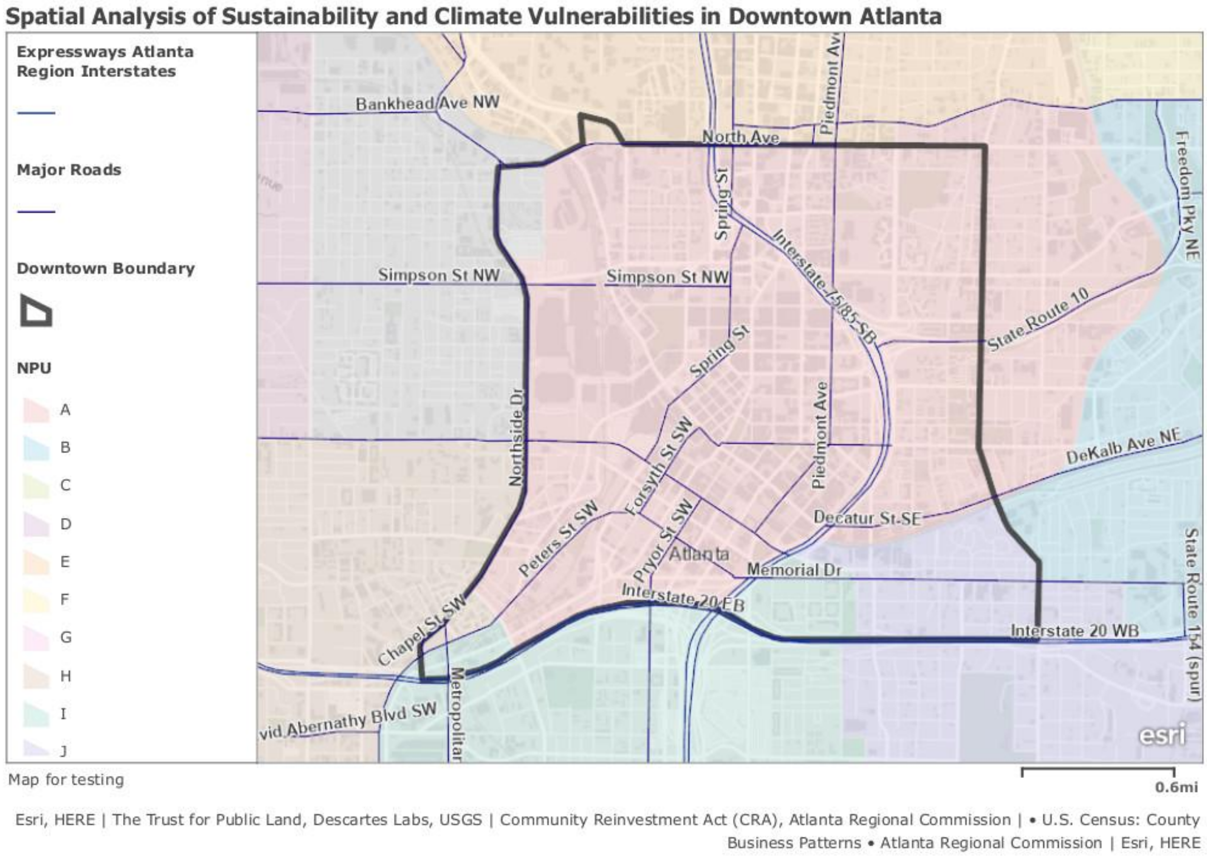

Figure 2.3. Neighborhood Planning Units map

Atlanta uses zones called Neighborhood Planning Units (NPUs) to give citizens a more direct channel to critique zoning and future land use decisions. The system, established by Mayor Maynard Jackson at the start of his term in 1974, consists of 25 NPUs throughout the city. The majority of Downtown Atlanta falls within NPU M and small, peripheral parts of Downtown fall within NPUs E, L, T, V, and W. NPU M's chairperson is Rebecca Rice, the planner is Matt Adams, and the interim assistant director is Leah LaRue (City of Atlanta, 2019). CAP works with all relevant NPUs to continue improvement in Downtown.

NPUs meet monthly and are run under their own bylaws without compensation or city funding. Meetings focus on topics that concern the neighborhood, such as new businesses and changes to existing businesses. The meetings are also a way for city organizations to update members of the NPUs. Updates include information on arrests and safety, transportation improvements, and initiatives. The size and influence of an NPU is limited to its geographical bounds; therefore, NPUs are very good at solving issues in their neighborhoods but they have difficulty influencing Atlanta as a whole.

2.2.1.3. Roads and Interstates

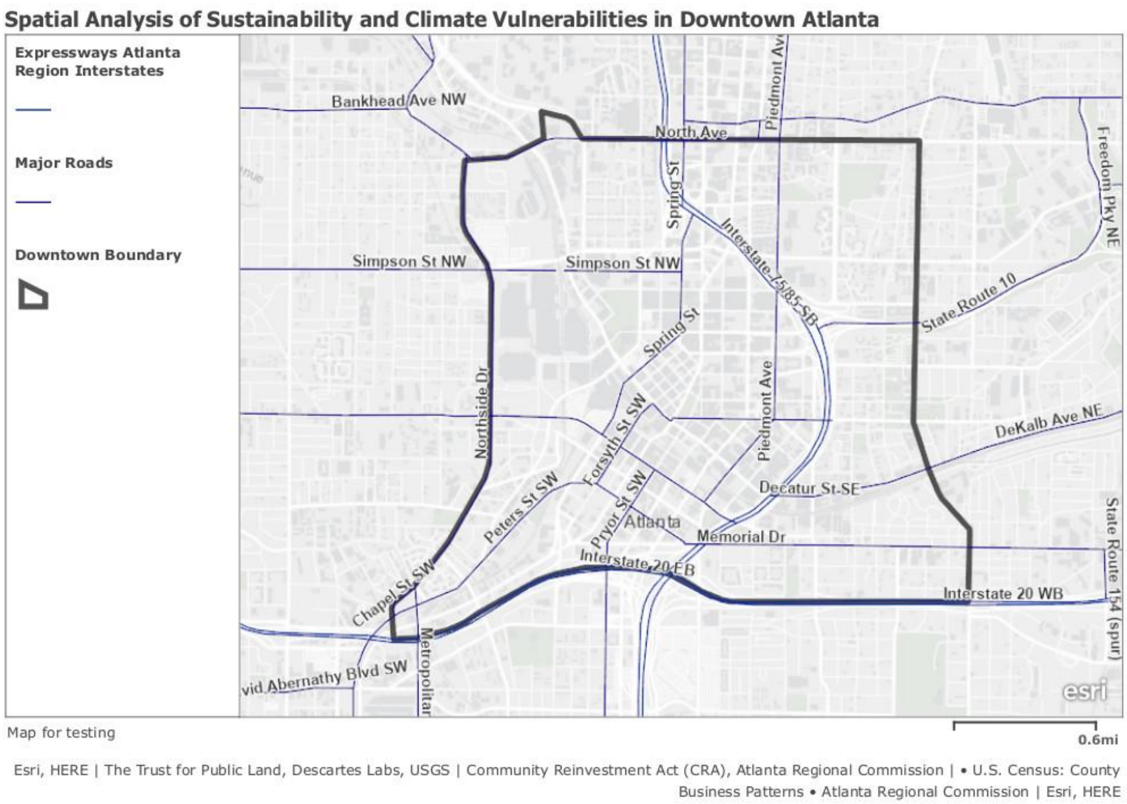

Figure 2.4. Roads and interstates map which shows major roads in purple and interstates in navy blue

The American interstate system experienced rapid expansion after the passage of the Federal-Aid Highway Act. Under this act, local governments had tremendous say in where to place interstate highways while the federal government paid for 90% of the cost. In the context of the 1950s, local governments in Atlanta and many other American cities bulldozed some “blighted” neighborhoods (those made up mainly of people of color) and built in their place extra-wide highways that served not just to move cars, but to form a physical barrier between white and black neighborhoods.

2.2.1.4. Downtown Building Footprints

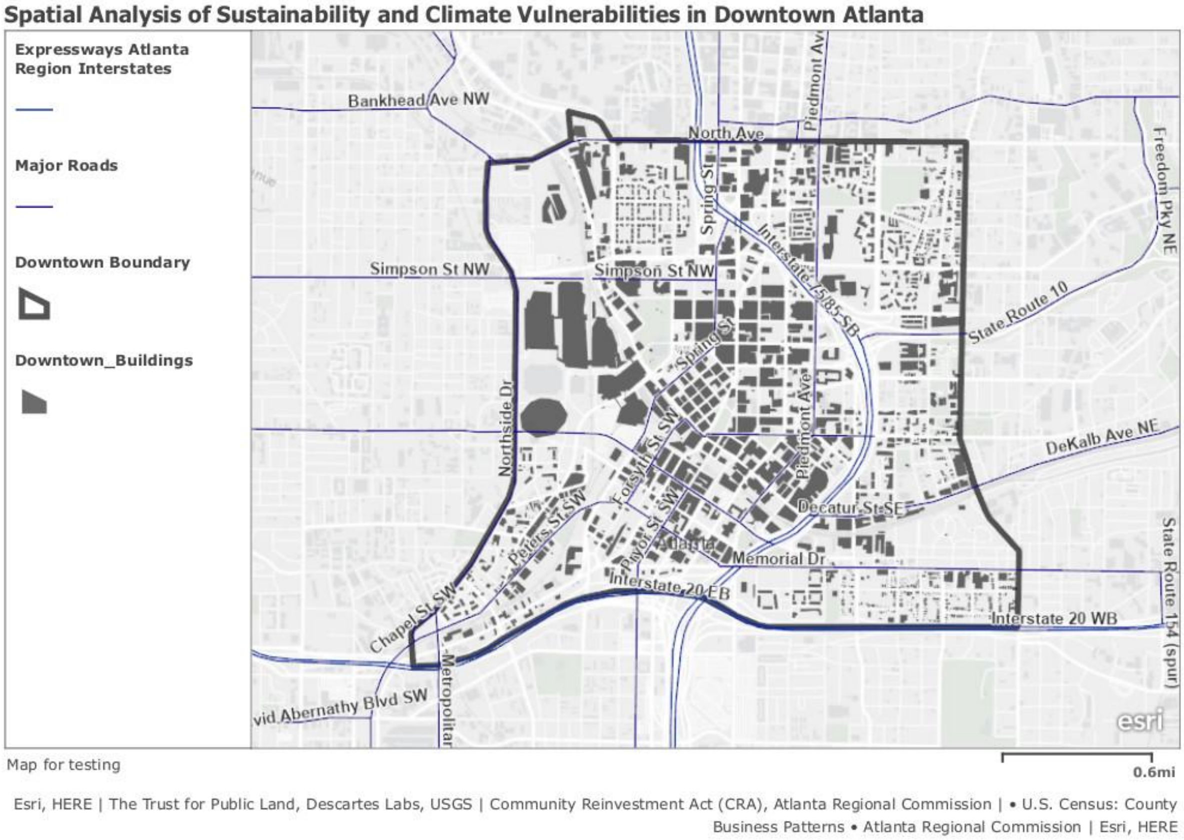

Figure 2.5. Downtown building footprints map

This layer depicts the footprints of all the buildings within the Downtown area. Data was provided by the Atlanta Department of City Planning GIS Office (DCP GIS 2018).

2.2.2. Economic Maps

Economic maps are maps related to economic entities in the Downtown area that have the potential of being vulnerable to the impacts of climate change. The economic entities identified are small businesses and restaurants. Visits to restaurants can be used as a proxy of economic activities in the area. These maps focus on economic vulnerability factors pertaining to the Downtown Atlanta area, more specifically, disposable income, small business loans, the number of small businesses, unemployment, and energy consumption both commercially and residentially. These factors can be used to gather an idea about the economic health of different portions of downtown as well as which areas are the most economically vulnerable to climate change impacts.

2.2.2.1. Small Business by Zip Code Map

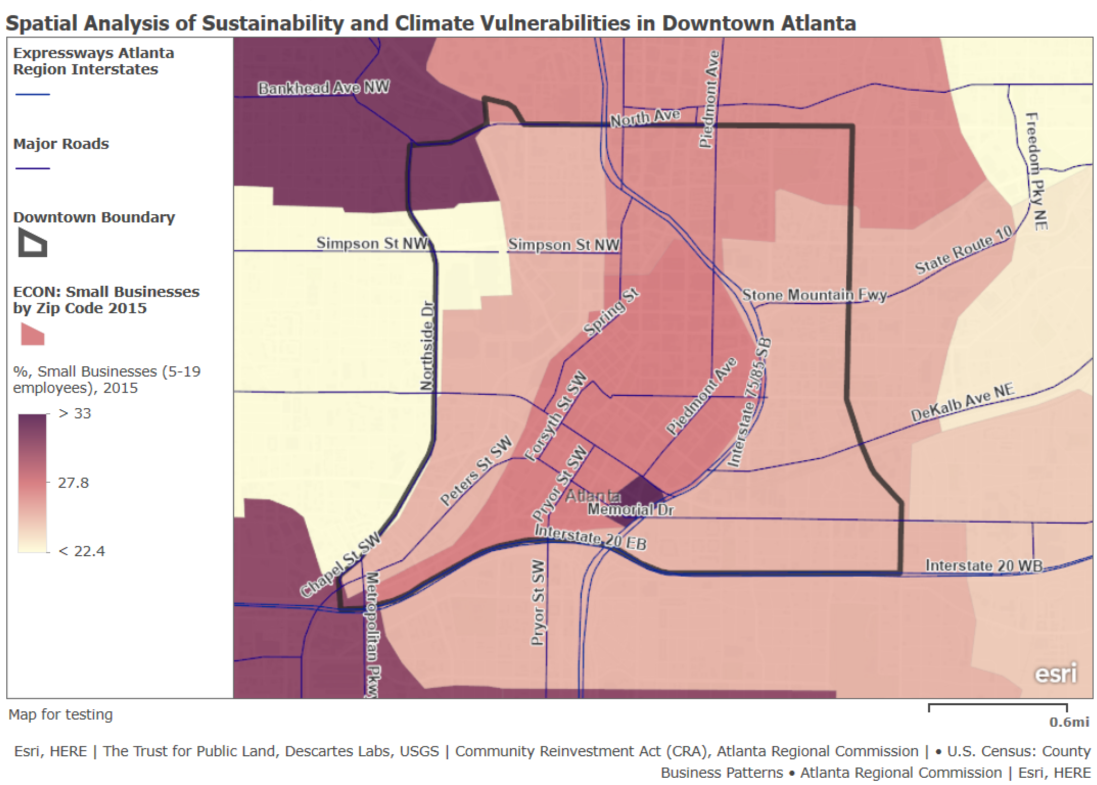

Figure 2.6. Percent small business by zip code map

There are many key benefits to small business investment, one of those being the fact that areas with small businesses have a stronger community identity which is one of the key factors listed in CAP's Downtown Master Plan as something the citizens of Atlanta truly value (Central Atlanta Progress, 2019, p. 150-152). There are also environmental benefits associated with small business investment. Small businesses help facilitate walkability downtown, therefore decreasing CO_2 emissions from driving and traffic congestion. Lastly they also increase market competition as well as employment, which plays a major role in bettering Downtown Atlanta's equity factor.

This map was developed by the Research & Analytics Group of the Atlanta Regional Commission, using data from U.S. Census: County Business Patterns to show number and density of business establishments and payroll data, for 2005-2015, by zip code in the Atlanta region. This map gathers data on several types of businesses but we choose to observe only the proportion of small businesses in the area. By focusing on small businesses we stay coherent with the previous work that has been done and with expectations from CAP.

2.2.2.2. Small Business Loans Map

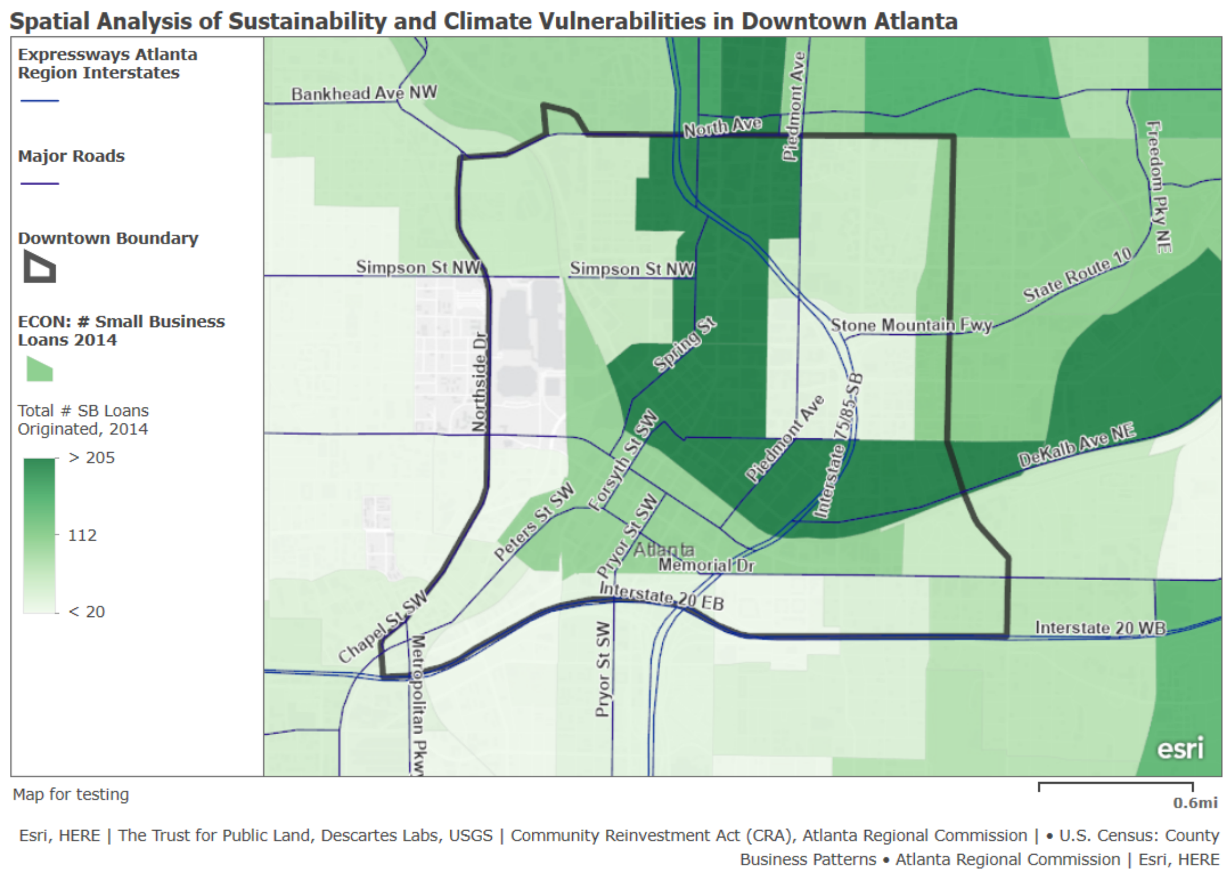

Figure 2.7. Small business loans map which shows the number of small business loans originated from each zip code

This small business loans map looks at areas that have the largest small business investment. We are interested in determining whether this map correlates with where small businesses are actually located.

Considering how the existence of small businesses in an area affect the different sustainability factors in our report, it seemed coherent to emphasize their actual proportion among all businesses. Our report will be used by a certain audience who might be sensitive to the small business evolution in Downtown. Therefore, we want our report to directly speak to the people who are affected by our results as well as those who benefit from it. Thus, this could be used by Downtown customers, business owners, and inhabitants.

This map was built by the by the Research & Analytics Group of the Atlanta Regional Commission. To develop the map this team was using data from Community Reinvestment Act (CRA). It can show total amount and number of small business loans, by loan size, for 2014, by census tract in the Atlanta region. The fact that this map is divided by census tract help us to have a precise overview of the economic small business development in Downtown.

2.2.2.3. Restaurant Visits in the Downtown Area Map

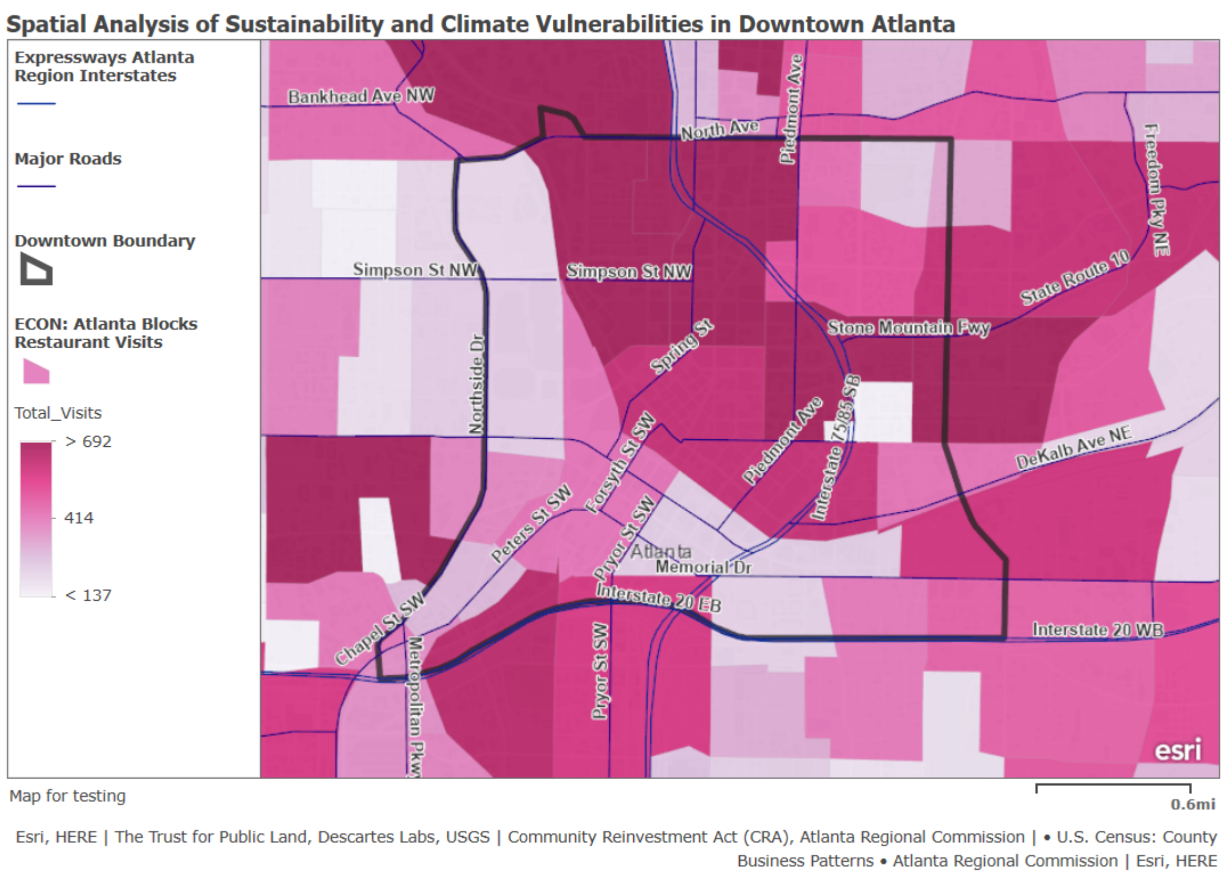

Figure 2.8. Map of total restaurant visits in the Downtown area with dark pink being most visited and white being least visited

This map represents the restaurant visits in the Downtown area, which allows us to figure out which parts of Atlanta people are spending their time as well as their money in. Areas not highlighted in this map may indicate areas that are in greater need of economic development investment. They may not be receiving the customer base necessary to operate successful businesses. It may also indicate a distinct lack of businesses overall, which means that the area is still in need of subsides and or investment to increase quality of life in that area.

This data came from helen_biz using feature services of publicly sourced data from ArcGIS Online. The map is representative of survey data taken from multiple restaurants in the Downtown area in 2017.

2.2.2.4. Commercial Electricity Consumption

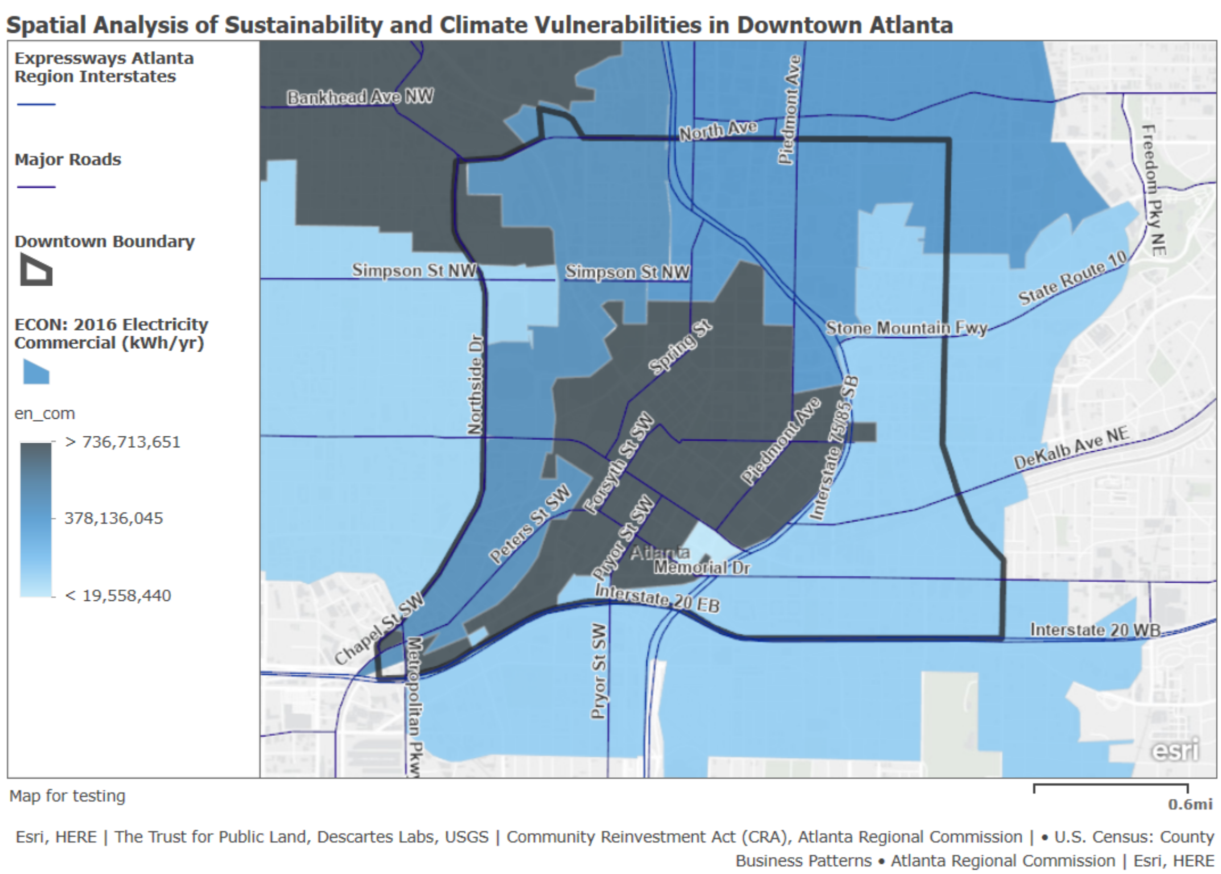

Figure 2.9. Commercial electricity consumption map

This map of commercial electricity consumption allows us to determine which Atlanta businesses are spending a large proportion of their income on electricity. High consumption areas may be more vulnerable to rising electricity costs, depending on whether those businesses have the financial capital to absorb energy expenditure increases or not. This would be a step toward calculating the energy burden of businesses in Downtown Atlanta.

This data is from Georgia Power's data collection gathered in 2016. It looks specifically at energy consumption from businesses and it is not publicly sourced data. It is separated by zip codes within the downtown area. The numbers are based on kilowatt hours per year of energy consumption.

2.2.2.5. Residential Electricity Consumption

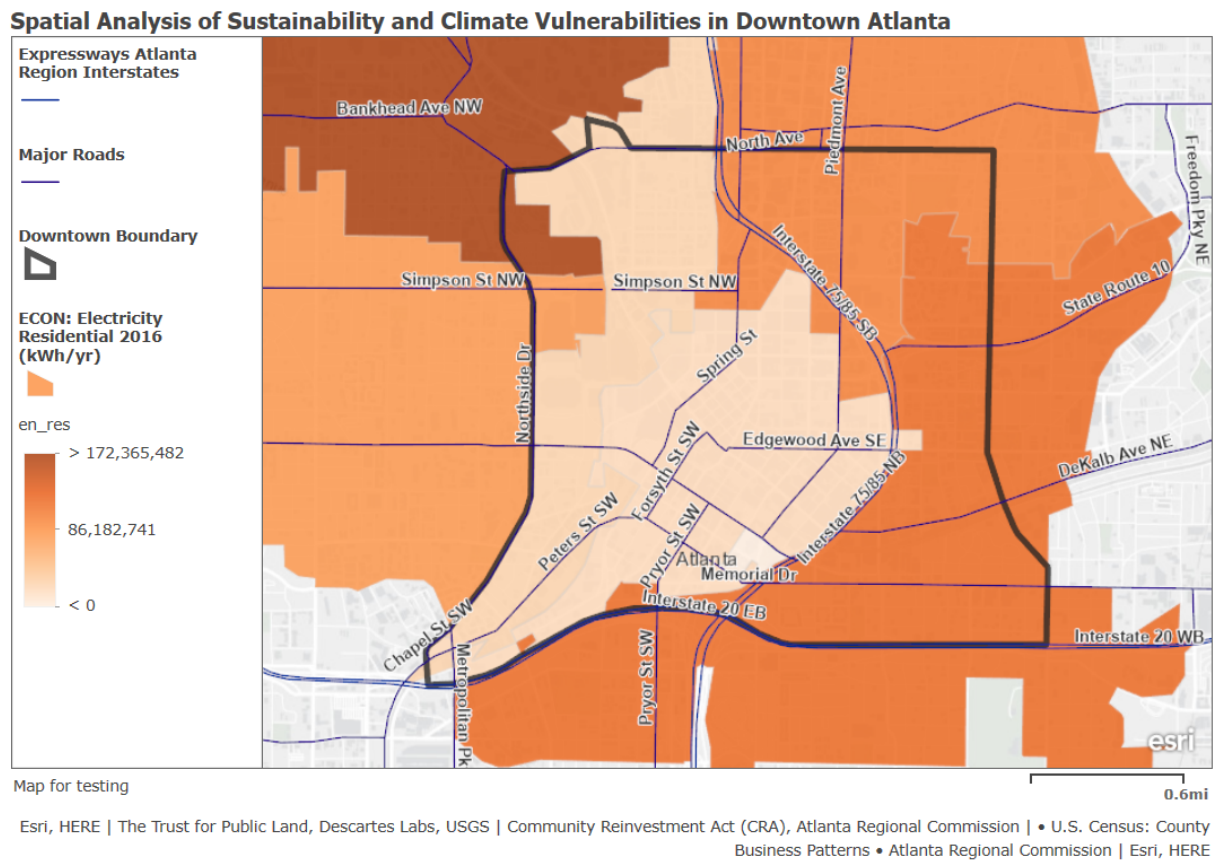

Figure 2.10. Residential electricity consumption map

The residential electricity consumption map provides an overview of areas of vulnerability where people are spending a larger part of their income on electricity consumption. It could directly affect the revenue of small businesses nearby because people may spend less of their money at those establishments, instead saving it for electricity costs.

This map was developed with data found from Georgia Power's data collection gathered in 2016. It looks specifically at energy consumption from businesses and it is not publicly sourced data. It is separated by zip codes within the downtown area. The numbers are based on kilowatt hours per year of energy consumption.

2.2.2.6. Percentage Unemployed Map

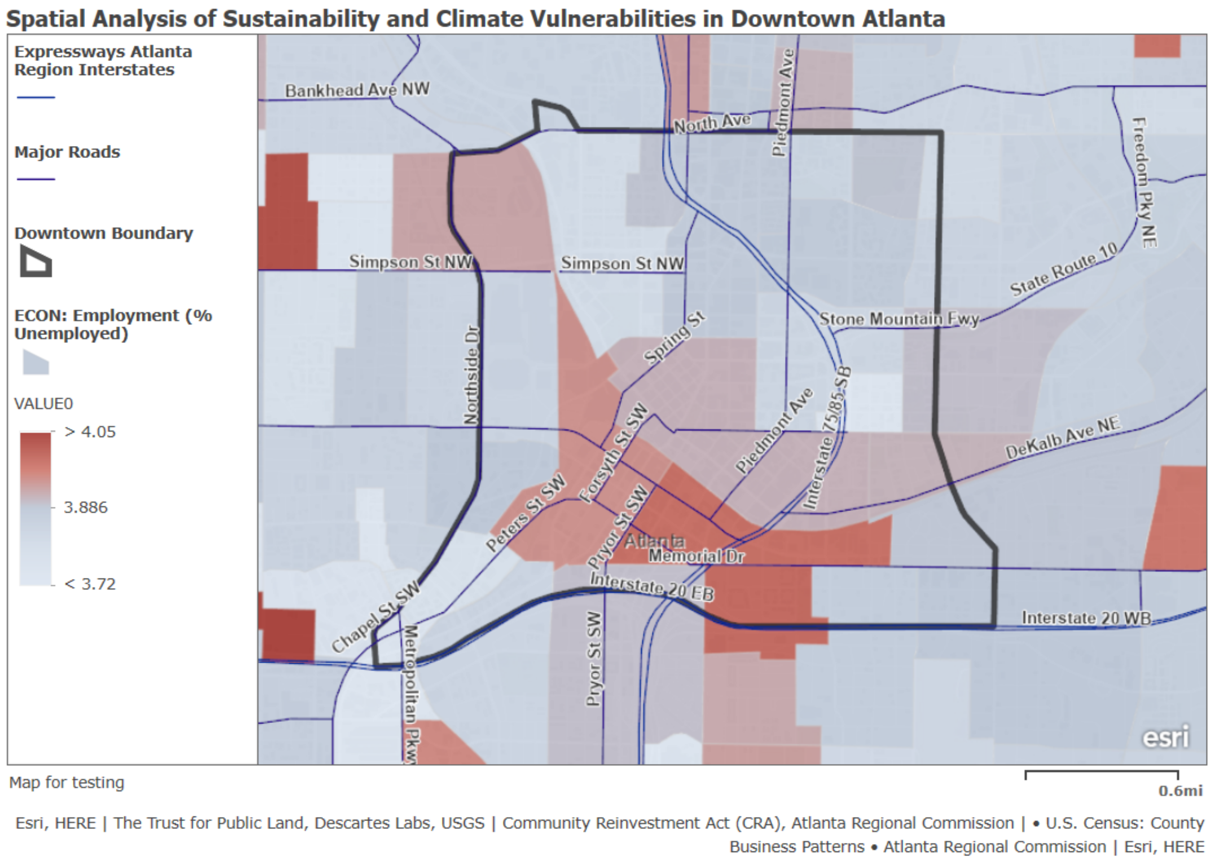

Figure 2.11. Percentage unemployed map

The percentage unemployed map can be used to decipher where vulnerable populations, such as those that are homelessness, disabled, and in-between jobs, are located. Areas in possible need of government intervention to access and implement equity measures within the Downtown area may also be identified through this map. Identifying such populations and areas is significant as those without jobs are more vulnerable to the negative effects of climate change such as poor air quality, urban heat island effect, and flooding.

This data is sourced from SimplyAnalytics, whose parent company Easy Analytic Software, Inc. (EASI) compiles data from the most recent US Census, American

Community Survey, and ACS Public Use Microdata Sample to create year-by-year estimates.
The data set is based on the 2019 Census, therefore is data is up to date and provides us with an as accurate as possible representation of the current downtown Atlanta population. The data points are spatially based on census tract.

2.2.3. Equity Maps

Social maps were selected by the Social/Policy Team to represent the most pressing equity issues in Downtown Atlanta related to access to resources and public health. These maps include poverty, energy burden, uninsurance, access to transportation, and asthma.

2.2.3.1. Energy Burden Map.

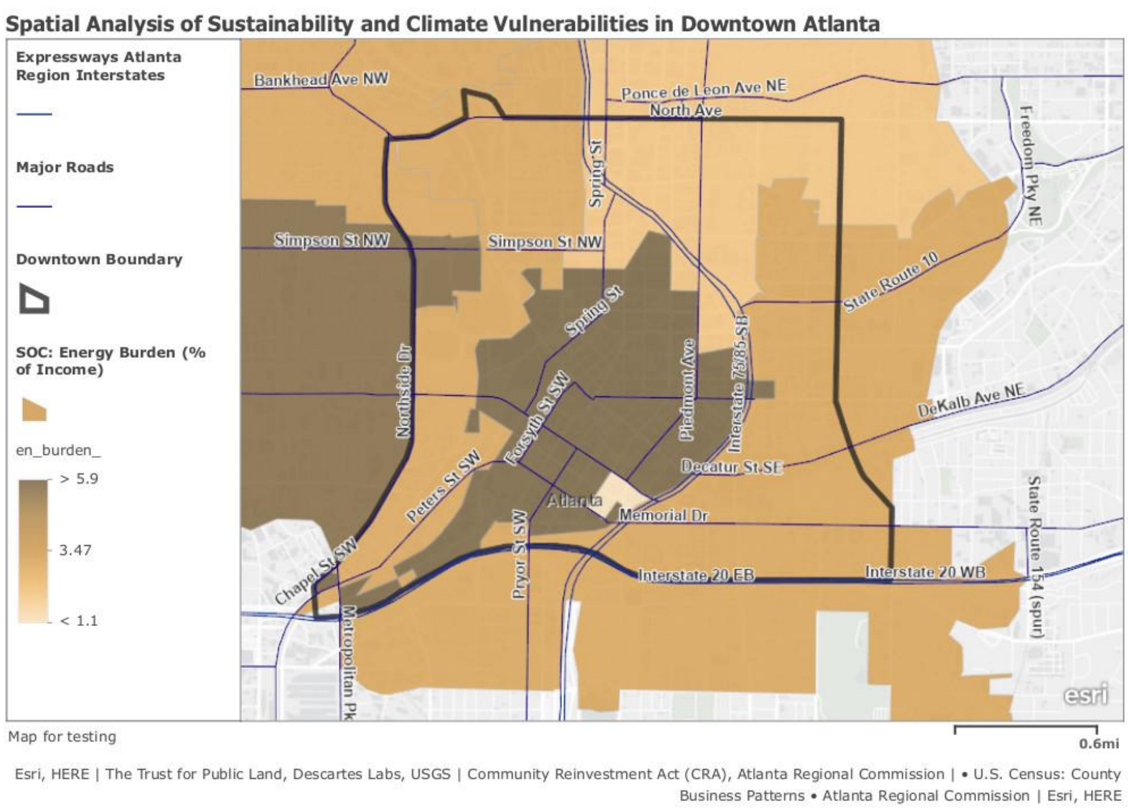

Figure 2.12. Energy burden map

Energy burden is an important variable to consider when measuring vulnerability because of the potential to show unequal effects of climate change. A high energy burden reduces the ability of low-income residents to mitigate the effects of climate change. As average temperatures rise, some residents are unable to keep up with growing expenditures on household energy. This exacerbates the negative health effects that result from increased heat exposure. Nationally, Atlanta ranks 3rd highest in low-income energy burden levels (Brown, Oxman & Toktay, 2018).

This layer shows the median portion of household income spent on energy costs, by zip code. The national average household energy burden is 3.5% (ACEEE, 2017). The U.S. Department of Health and Human Services classifies an energy burden of above 6% as "unaffordable" (Colton, What is the Home Affordability Gap, 2017). A significant portion of the Downtown area has a measured energy burden of 7.5%, shown in brown in this layer.

Data is from: Brown, M., Oxman, M., Toktay, B., Ahmadi, M., Ahmad, N., Shadi, Y.M., Ahmed, S.B., Froyd, E. (2018). The Low-Income Energy Burden of Atlanta Households. Georgia Institute of Technology, Atlanta.

2.2.3.2. Percentage of Uninsured Map

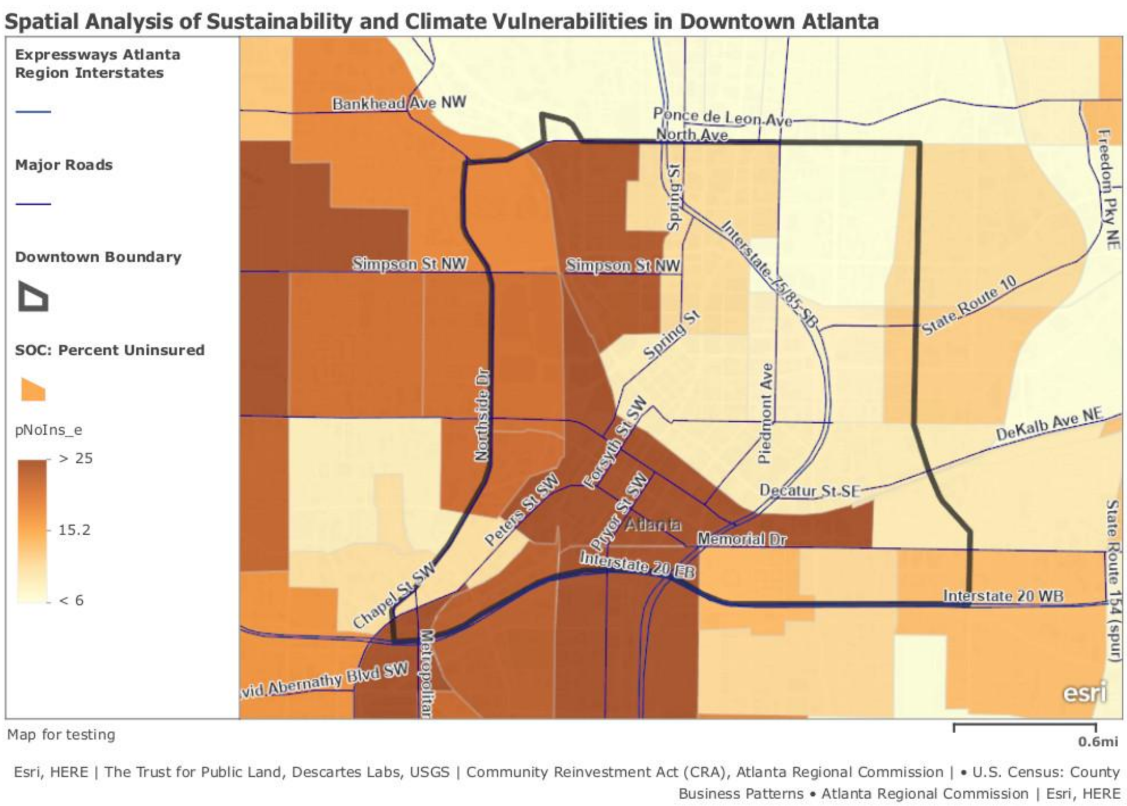

Figure 2.13. Percentage of uninsured map

We chose to analyze this data in relation to our vulnerability assessment because of the implications a high proportion of uninsured people have on a region. Georgia's health care system is not meeting the needs of its diverse and growing population. Roughly 1.3 million Georgians are uninsured and many more are at risk of losing coverage (U.S. Census Bureau, 2018). The burden of a large, persistent group of uninsured Georgians is widespread. Those without health insurance experience financial vulnerability associated with high medical bills and delays in primary and preventive care, resulting in worse health outcomes. Those with health insurance experience higher costs because of uncompensated care provided to the uninsured. The public pays for uncompensated care through taxes and higher premiums.

This layer was created by the Research & Analytics Group of the Atlanta Regional Commission, using data from the U.S. Census Bureau's American Community Survey 5-year estimates for 2012-2016.

2.2.3.3. Percentage in Poverty Map.

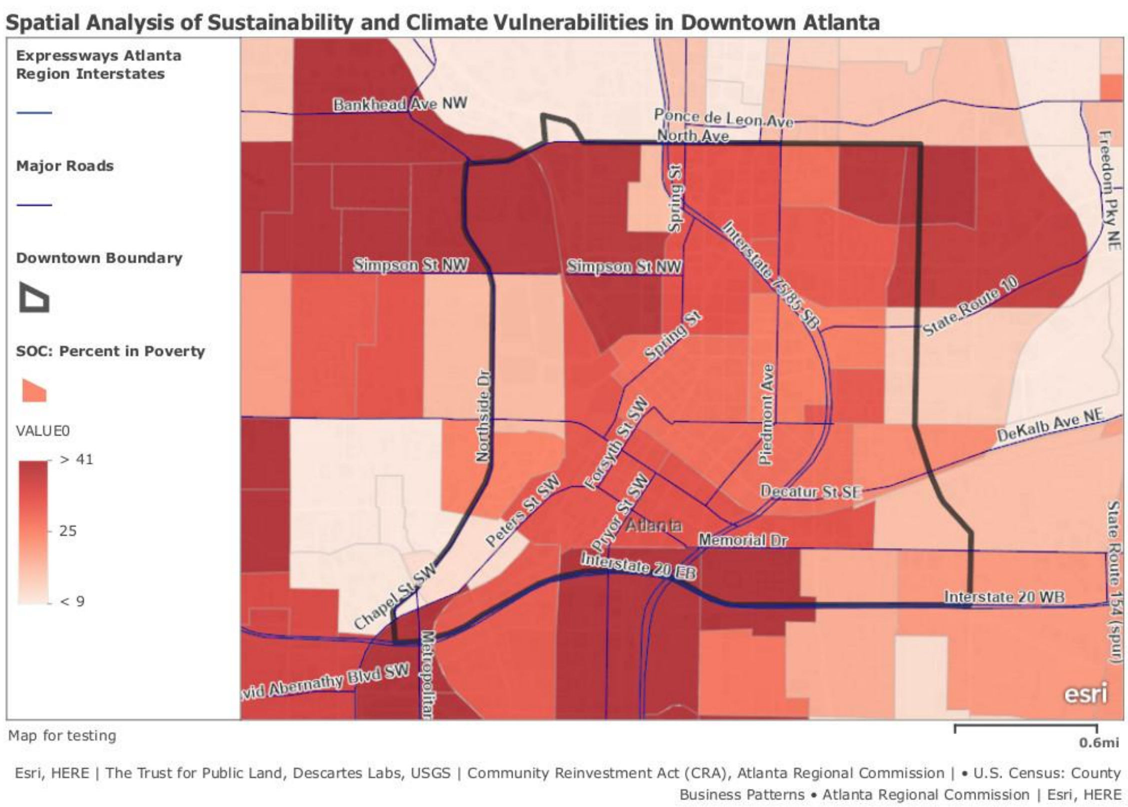

Figure 2.14. Percentage of people in poverty map

Poverty, defined as the inability to meet basic needs of shelter, food, proper sanitation, education, and healthcare, is a variable we have chosen in measuring vulnerability because of the broad implications of cost on a person or community's ability to adapt to climate change. This is a problem in Atlanta as the city was ranked worst in income inequality in the U.S. (Foster & Lu, 2018). The wealthiest 5% (those earning $240,000+) of Atlanta households and those in the bottom 20% (earning less than $14,850 or less) is significantly higher than in any other American city (Foster & Lu, 2018). While wealthy Atlantans are able to use their air conditioning units more or insulate their homes as heat waves intensify, those living in poverty will not have those options to avoid the health effects of higher temperatures.

The data used to create this layers is sourced from SimplyAnalytics, whose parent company Easy Analytic Software, Inc. (EASI) compiles data from the most recent US Census, American Community Survey, and ACS Public Use Microdata Sample to create year-by-year estimates (SimplyAnalytics 2019).

2.2.3.4. Transit Frequency Map

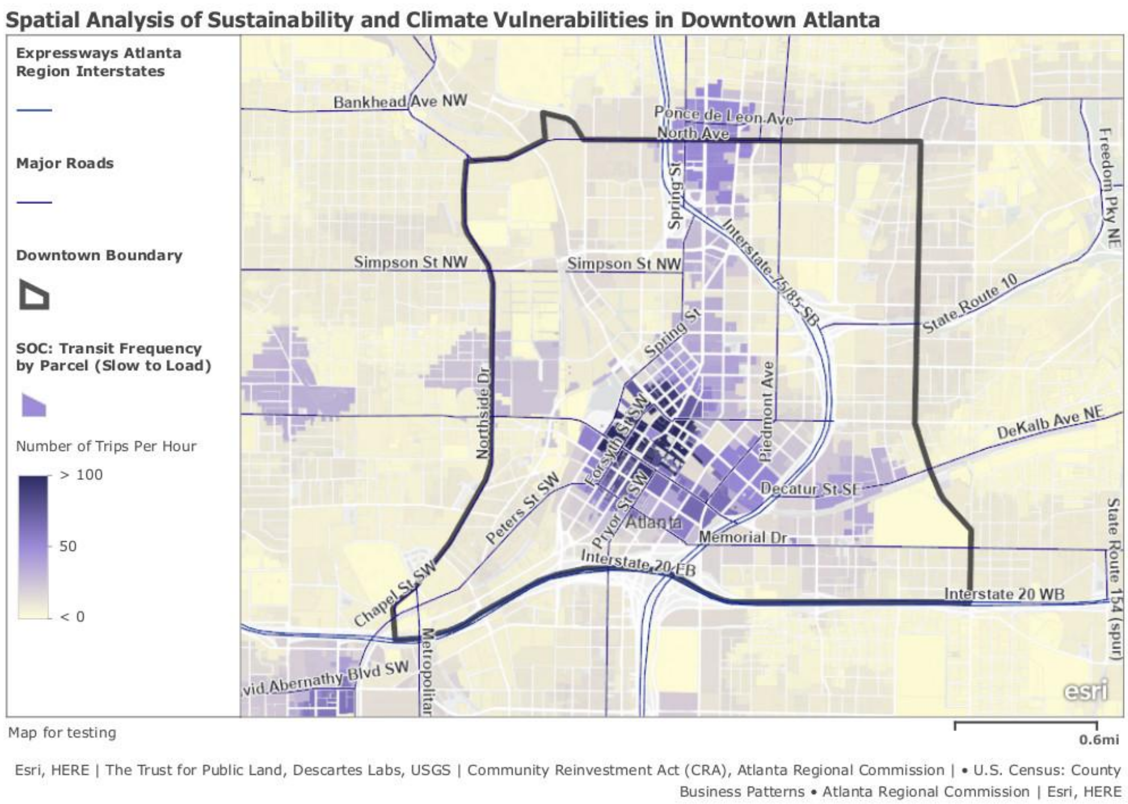

Figure 2.15. Transit frequency by parcel map

Transit frequency is an important indicator for each of the three priorities of sustainability planning. It provides access to jobs and economic activity, reduces the number of vehicles on the road, and cuts carbon emissions. In terms of the social aspects of sustainability, we focus on the accessibility of transit to disabled and low income individuals, relatively high connectivity of Downtown Atlanta compared to surrounding areas, and the public health impacts of increasing transit utilization.

This data comes from 2018 GTFS (General Transit Feed Specification) data published by MARTA and compiled by the Atlanta Regional Commission.

2.2.3.5. Asthma Count Map

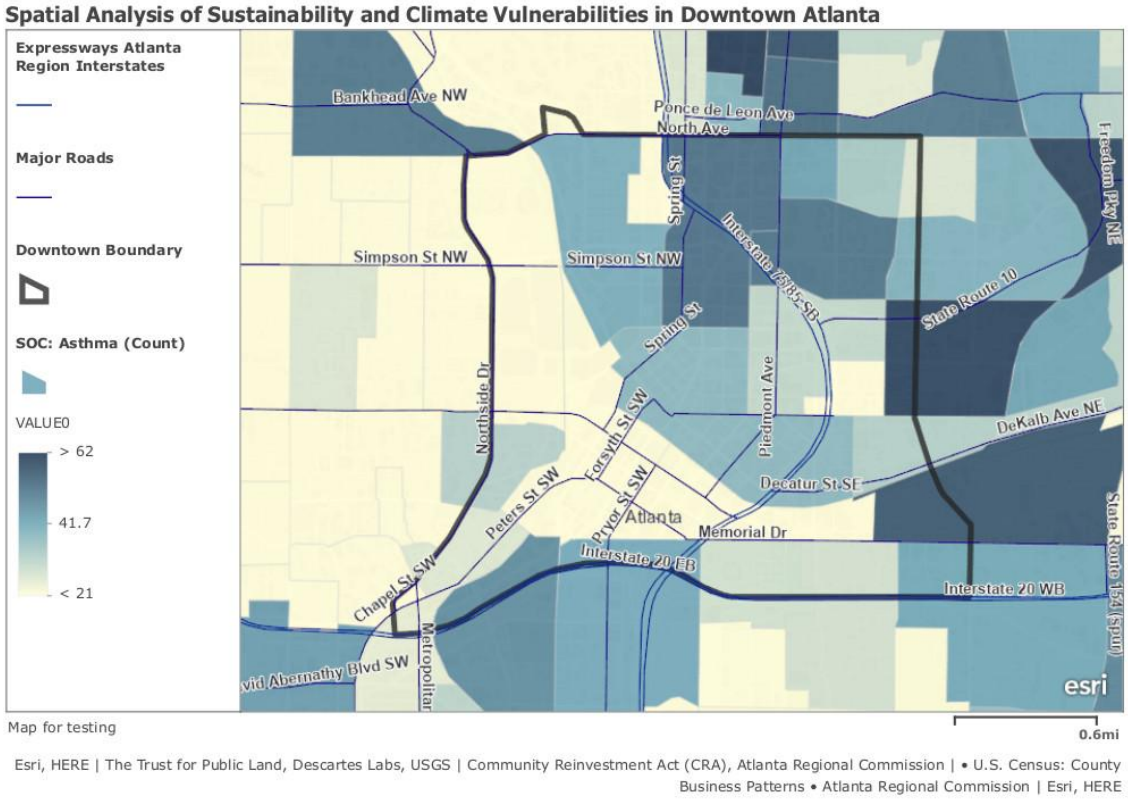

Figure 2.16. Asthma count map

The asthma count for Downtown is an important indicator of air quality exposure. Health and environmental factors are often related, as "researchers have found an association between increased hospital admissions for asthma and particulate matter, an outdoor air pollutant" (Asthma and Allergy Foundation of America, 2019). In 2017, there were 663,053 adults in Georgia with asthma, and 108 of these cases resulted in death (Asthma and Allergy Foundation of America, 2019).

The data are from national and state surveillance systems administered by the Center for Disease Control and Prevention, available at CDC.gov. According to the Asthma and Allergy Foundation of America, ten people die every day from asthma. Most of these deaths are preventable with proper management, access to adequate medical care, housing improvements and better air quality. Yet, asthma still remains one of the most prevalent chronic diseases in our nation. It is also one of the most costly diseases – with an estimated annual cost to society of $82 billion (Asthma and Allergy Foundation of America, 2019).

2.2.4. Science & Technology Maps

The Science & Technology team selected maps specifically related to climate change such as CO_2 emissions, floods, and heat. Floods are heat are the most prominent climate change impacts in the Downtown area.

2.2.4.1. CO_2 Emissions from Electricity Map

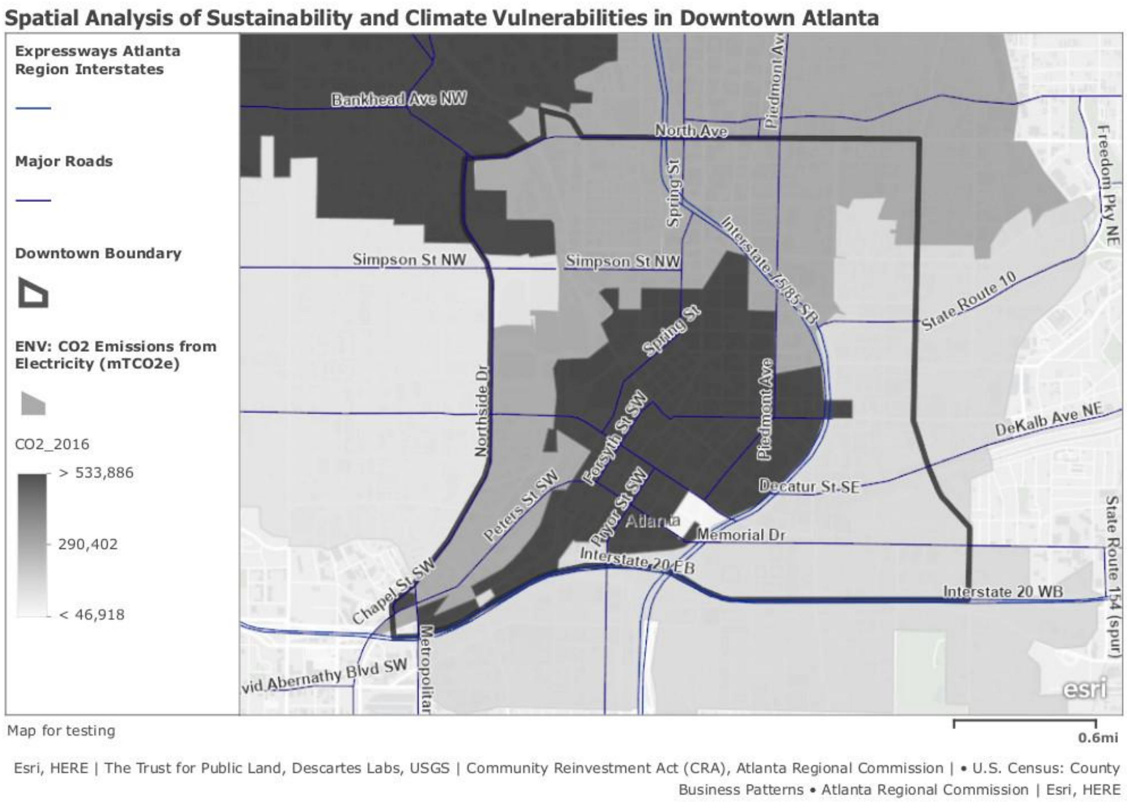

Figure 2.17. CO_2 emissions from electricity map

This map shows the amount of carbon emissions produced by electricity in the Downtown area represented in metric-tons of CO_2 equivalent. The data was extracted from the City of Atlanta GHG Emissions inventory of 2016 (Garcia, 2017). The emissions correspond to Scope 2, which means that the emissions are being produced at the source of electricity, which is out of the boundaries of Downtown. However, this map can serve as an indicator of the areas in Downtown where carbon (i.e., pollution) is generated and it can be compared with other socio-economic factors.

2.2.4.2. Downtown Flood Map

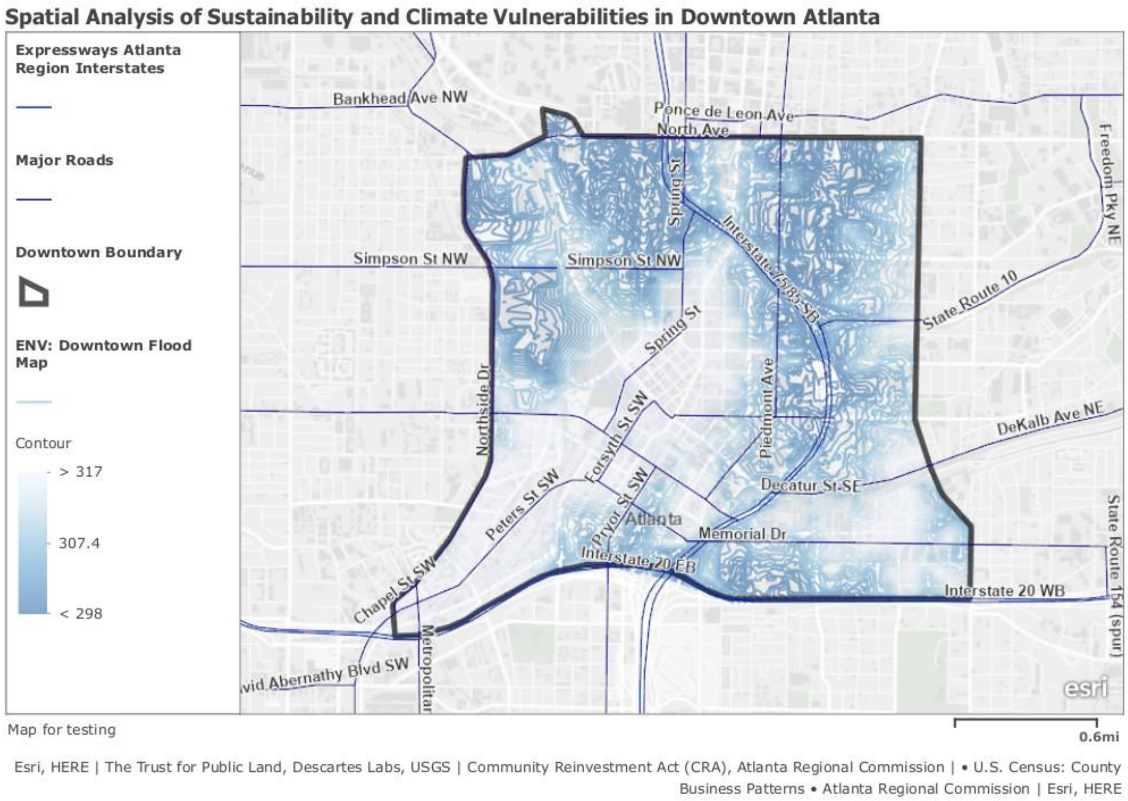

Figure 2.18. Flood map for Downtown Atlanta

On this map, darker blue areas indicate more water accumulation from precipitation during times of flooding. This map was created using a DEM (digital elevation model) of Downtown Atlanta with a resolution of 1/9 arc-seconds per pixel (approximately 3m/pixel at this latitude) from USGS. The DEM was produced in 2011. It is from a larger program called USGS 3D Elevation Program (3DEP). The DEM looks at the bare ground topography so does not include buildings in the analysis, only "what's on the ground" (such as roads).

We recreated the CAP Downtown Master Plan map because we received an image of the map that was already created and wanted to be able to utilize it on GIS. Now we can overlay this map onto our other maps to detect vulnerable areas since the "Parcel" flooding map will mostly be helpful to inform businesses where on their property they need to focus their efforts and this map will show where the Downtown area as a whole needs to focus their efforts.

2.2.4.3. Parcel Flood Map

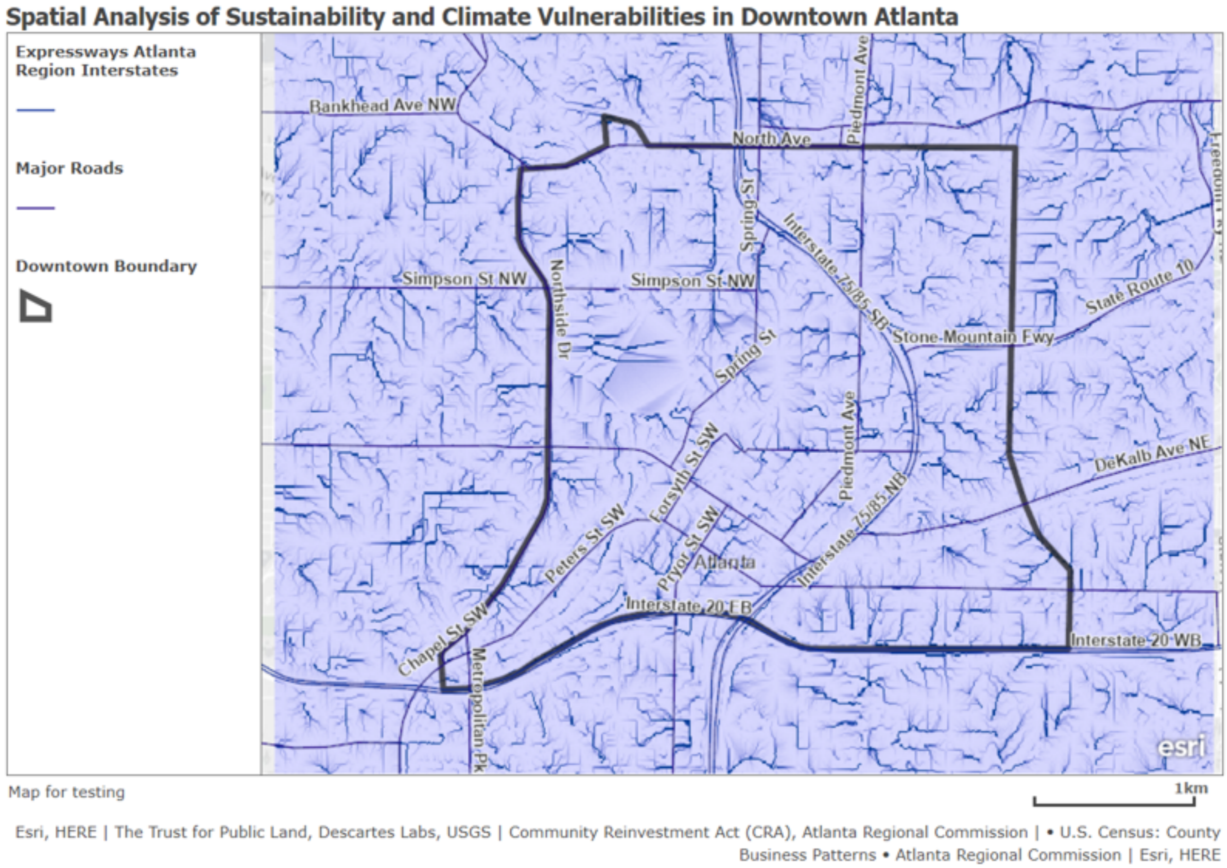

Figure 2.19. Downtown Atlanta parcel flood map

On this map, darker blue areas indicate more water accumulation from precipitation. This map was created using a DEM (digital elevation model) of Downtown Atlanta with a resolution of 1/9 arc-seconds per pixel (approximately 3m/pixel at this latitude) from USGS. The DEM was produced in 2011. It is from a larger program called USGS 3D Elevation Program (3DEP). The DEM looks at the bare ground topography so does not include buildings in the analysis, only “what’s on the ground” (such as roads).

The DEM was input into ArcMap where a built in tool in the Hydrology Toolbox (flow direction) was used to calculate which direction water would flow on a pixel by pixel basis (3x3m square of space in Downtown). Once the flow direction was calculated, another tool called flow accumulation was used to produce the final product. The flow accumulation tool calculates the number of pixels which “flow” into a given pixel. So the darkest parts of the lines indicate pixels in which a large number of surrounding pixels flow into. These are local “flood” points because they ignore the large scale trend of the topography of the region and look at the very local scale. Basically, it is saying if a drop of water fell onto a certain piece of land, it would first flow downhill to the "local" low point (at this scale the local flood areas are on the scale of tens of meters) so this map can be used to determine the "flood zone" on an individual parcel which can be used to determine drain placement or green infrastructure needs rather than for the whole of the CAP focus area (which the flood map previously created by CAP has achieved). This map will tell an observer which areas of the street or properties will accumulate water initially during a rain event. The previously created map will inform the city of at-risk areas for severe flooding where a large amount of water is accumulated at a regional (where the region in this case is the CAP defined area) scale.

The darker areas of the map are indicating the lowest areas of ground in the Downtown area. This showcases the initial areas where water pools during precipitation events. This map indicates which individuals areas are affected by rain and flooding events first and the most. Buildings that fall on dark blue areas are more affected by rain events because even in non flood events water pools in these areas making them more susceptible to damage during heavy precipitation events comparative to others in the area. These low points in the ground are scattered all over the Downtown area. Many of these low zones fall over places where small business and residential buildings are present. These places may be more vulnerable to flooding events since they are at a higher risk of not recovering from other natural disaster events that induce flooding. This map slightly differs from the map located in the master plan which indicates any ground under 950 elevation as low points and indicates where water flows overall on a larger scale throughout the Downtown area during a flooding event.

The significance of this map is that it shows the local low points in the Downtown area. This is helpful since traditional flood maps usually show a flooding plain where everything will be affected in major flooding events. This map allows us to see which areas are affected by less major events since water accumulates and travels through these areas. This will allow more targeted flood planning.

2.2.4.4. Normalized Difference Vegetation Index (NDVI) Heat Map

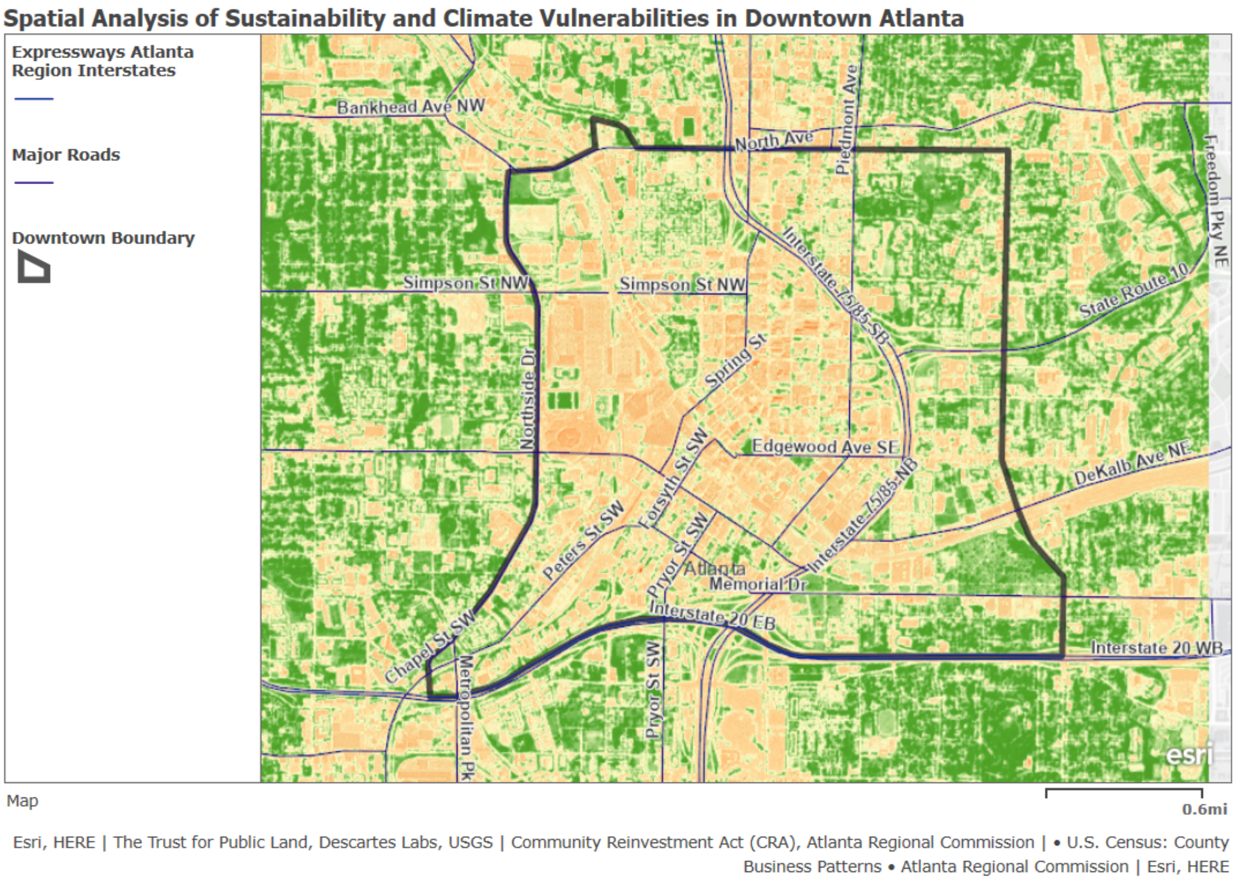

Figure 2.20. Normalized Difference Vegetation Index (NDVI) heat map

This map is an NDVI map for Downtown Atlanta. Areas in green indicate well-vegetated areas, and areas in red indicate poorly vegetated areas. This is used as a proxy for the urban heat island effect, where poorly vegetated areas are more vulnerable to heat and represent areas of man-made development. This map was created using imagery downloaded from Planet, a company which owns their own array of satellites called the PlanetScope Dove Constellation. This imagery is at 3 meters per pixel resolution, allowing for a highly detailed examination of the Downtown area. We selected the source image specifically because it was taken during the hottest week during September, which could be used as a proxy for how the weather in Downtown Atlanta may be in the future due to climate change. Using this four-band satellite image, we processed the red and near infrared bands in ArcMap to obtain NDVI, which is what is displayed here.

The heat island map shows greenery in the area as a proxy for urban heat island effect. Areas lacking green cover correspond with the most elevated heat levels due to the urban environment. The hotter parts of the area correspond to major buildings such as the stadium, large attractions like the Football Hall of Fame, and other large corporate buildings. This indicates that heat island effect is correlated with the man-made environment. Many buildings in the area that were not developed with green infrastructure exacerbate heat problems Downtown.

This map allows the viewer to see where greenspace is within the city. By doing so it reveals the hottest areas of the city and also where plant life is lacking. Shareholders viewing this map can see exactly where in the city they can have an impact by adding more greenery. In the map you can also see the effectiveness of green roofs compared to typical roofs by looking at locations such as the Clough Undergraduate Commons at Georgia Tech.

2.2.4.5. Urban Heat Island Map

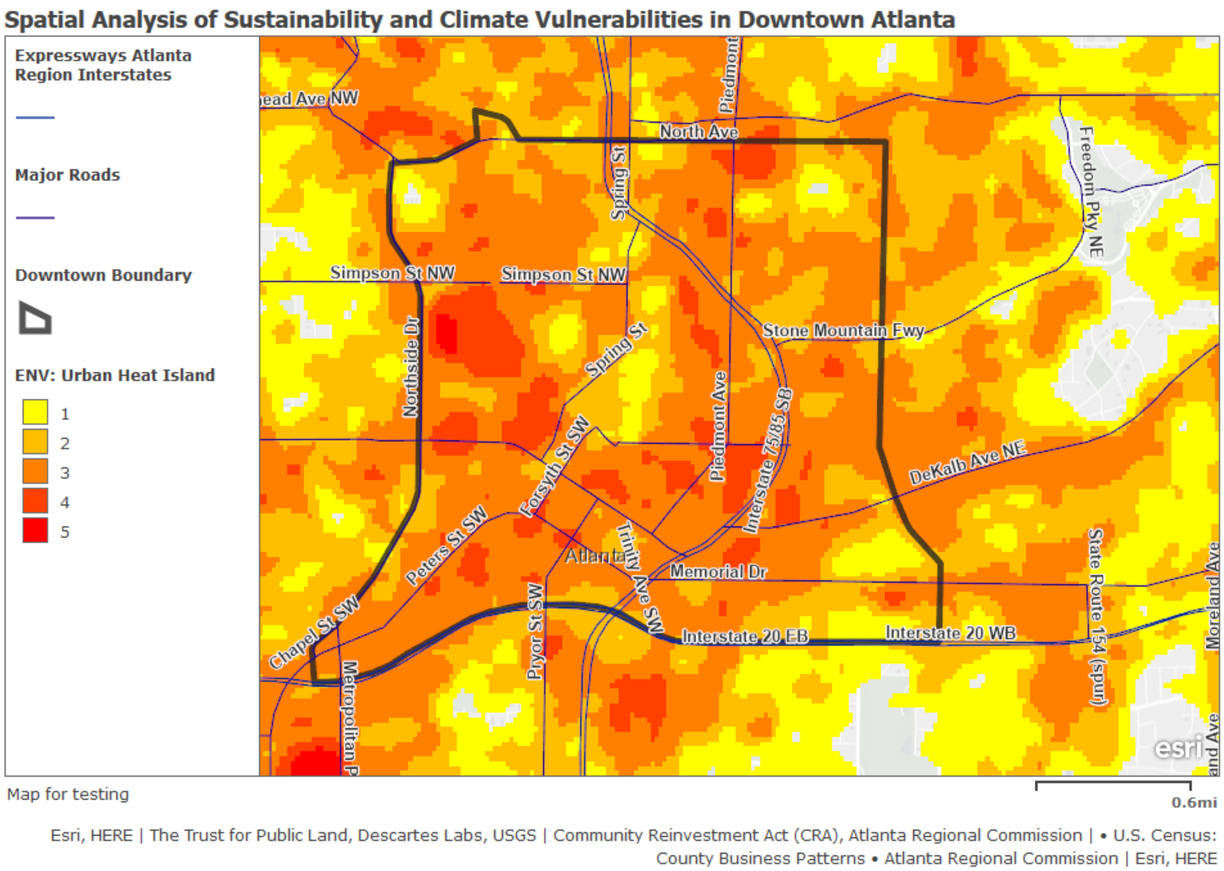

Figure 2.21. Urban heat island map

This heat island map was created using imagery from Landsat 8, which is at 30 meters per pixel resolution. It shows the difference in land surface temperature in different parts of the Downtown Atlanta area. The darkest shades shows the accumulation of the most heat. The hotter parts of the area correspond to major buildings and large attractions in the area, such as the Mercedes-Benz Stadium, World Congress Center, and CNN Center. This indicates that heat island effect is correlated massive development and large tracts of paved land. The many buildings in the area not developed with green infrastructure exacerbate the heat Downtown. This map only looks at relative temperatures to the average of the city, it does not indicate actual temperatures. Severity is measured on a scale of 1 to 5, with 1 being a relatively mild heat area (slightly above the mean for the city), and 5 being a severe heat area (significantly above the mean for the city). It is important to note that most of the Downtown area is at least slightly above the mean for the city.

3. Analysis & Discussion

Each team researched and selected one map in their respective group that represented more vulnerability to climate change and overlapped this map with maps from the two other teams in order to determine how this vulnerability can be affected by other pillars of sustainability. The results of these analyses are shown in this chapter.

3.1. Social Team Analysis

The asthma map shows the number of cases of asthma in each census tract, as reported by the MRI Consumer Survey. The unemployment map shows the share of the adult population who is unemployed in each census tract. In this data, unemployment is defined as the population who is available and willing to work but not currently working. The Urban Heat Island (UHI) effect map shows areas within the Downtown boundary that show temperature increase due to the UHI effect.

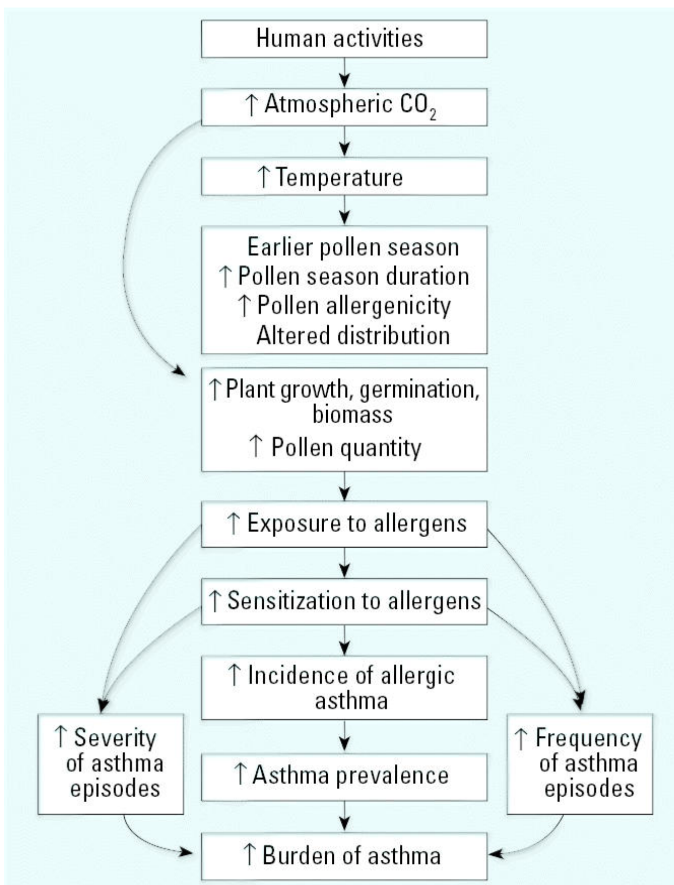

Figure 3.1. The relationship between climate change and the rise in asthma prevalence and severity (Beggs, 2005)

Asthma is a condition largely affected by climate conditions, as airborne allergens are generally produced at a higher rate in warmer conditions (Beggs, 2010). An increase in atmospheric CO_2 affects the prevalence and severity of asthma, as CO_2 stimulates plant growth (Sherry et al., 2007). Figure 3.1 shows the interaction between increasing CO_2 levels and the increasing global burden of asthma. Droughts and windy conditions transport pollen and spores across the region, exacerbating symptoms (Beggs, 2005). This increase in pollen leads to more frequent ambulance calls and hospital visits related to symptoms of asthma (Heguy et al., 2008; Breton et al., 2006).

Climate change indirectly causes increases in smog and allergens like pollen and fungi through temperature increases. As well as CO_2 concentrations, the UHI effect is an additional source of temperature increase in urban areas (Bartholy, 2018). The UHI effect has been found to heighten respiratory illness, and in one study was found to increase respiratory related hospital admissions (Lai & Cheng, 2010).

The maps we have compiled of asthma counts, the urban heat island effect, and unemployment reveal relationships between these factors in the Downtown Atlanta area. When comparing the census tracts with high asthma counts of over 40 to the areas with pronounced UHI effect, there is a clear correlation. Areas with high asthma counts within the Downtown area are present at locations with a measured UHI effect that creates an above average ambient temperature. According to the Bureau of Labor Statistics, the average unemployment rate for the Metropolitan Atlanta area was 3.8% in February of 2019, when the data used in our unemployment map was collected (Bureau of Labor Statistics, 2019).

Asthma and risk of unemployment have been found to be slightly positively correlated, but a direct relationship cannot be determined because of the many factors that impact both unemployment rates and severity of asthma symptoms (Taponen et al., 2017). While it is difficult to find a correlation between asthma and unemployment within the boundaries of the Downtown area, increased severity and number of cases of asthma in adults has clear economic effects on productivity. The 2017 study by Taponen et al. indicates that “some adults with asthma cope well in working life while others face problems” such as illness-related absences or unemployment. The main factor that divides asthmatic workers from those who are unemployed is the nature of their work. The same study found that in non-manual workers, asthma was less frequently a problem that caused absences or unemployment (Taponen et al., 2017).

3.2. Economic Team Analysis

To further analyze these maps, we decided to derive a hypothesis based on spatial analysis used to make environmental, economic, and social maps. We decided to overlay the urban heat island map, the energy burden and the restaurant visits map in order to test our theory that the heat island effect increases residential energy burden and in turn decreases the amount of disposable income available in the Downtown Atlanta area.

We assume that the residential budget is limited and can be affected by external factors. We choose the energy burden maps to localise the different residential area where the energy consumption constitutes a large part of the disposable income. We assume that in the areas vulnerable to increasing temperatures residents will have to increase energy consumption in order to fight the heat. This can be characterized by an increased usage of ACs or electronic cooling fans. Based on this assumption that people consume more energy in "hotter" areas, we can suppose that residents will be more vulnerable in the areas with higher temperatures as they will experience a higher energy burden as a percent of their income. Consequently, people in the Downtown area would also tend to have less disposable income for other economic activities due to the extra money spent on energy in their homes. In the article *'I don't want to die': As the country bakes, studies show poor city neighborhoods are often much hotter than wealthy ones,* Mccoy (2018) stated that those in low socioeconomic status areas tend to bear the brunt of the increasing temperature, further worsening their situation.

With the inclusion of the third map on restaurant visits, we are able to look at the areas where restaurants are being visited by residents the most and then use this as a proxy for disposable income and economic activity. This combination of all three spatial analysis maps assess the loss of income from residents due to climate change vulnerabilities while also looking at the economic activity impact in Downtown Atlanta. Considering that people are spending more money on energy consumption, their disposable income will also diminish and, with that, their ability to spend money eating out will decrease as well. This relationship between disposable income and food expenditures is depicted in Morrison (2019) article *USDA ERS - Food Prices and Spending*, shown in Fig XYZ. If our hypothesis is true, we should see a correlation, when overlapping these maps, between a strong heat island effect, a heavy energy burden, and a low level of restaurant visits in a certain area. This area affected by all three factors will show us the parts of Downtown Atlanta that are the most economically vulnerable to climate change.

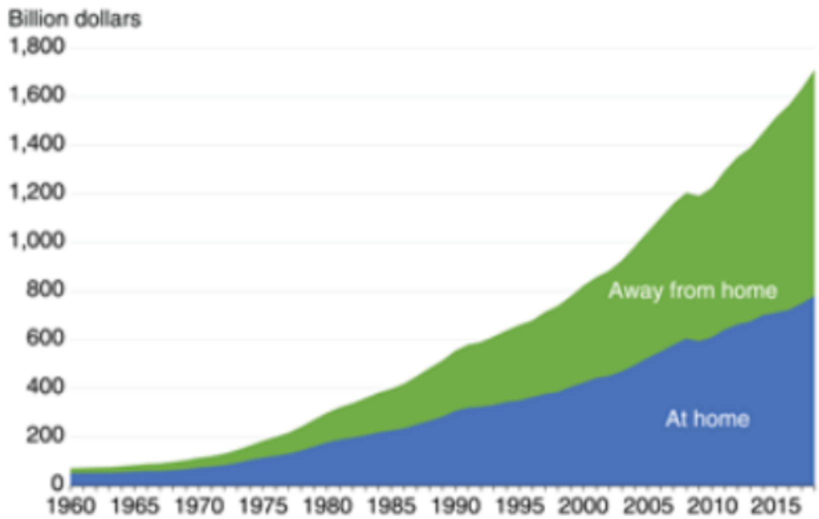

Figure 3.2. US. food-away-from-home spending continued to outpace food-at-home spending in 2018. In 2018, food spending by U.S. consumers, business, and government entities totalled $1.71 trillion. Food away-from-home accounted for 54.4 percent of total food expenditures, up from 50.1 percent in 2009. Morrison, R. (2019). USDA ERS - Food Prices and Spending. [online]Ers.usda.gov. Available at: https://www.ers.usda.gov/data-products/ag-and-food-statistics-charting-the-essentials/food-prices-and-spending/?topicId=14885 [Accessed 20 Nov. 2019].

Figure 3.3. Food spending and share of disposable income spent on food across U.S. households, 2018. As their incomes rise, households spend more money on food but it

represents a smaller overall budget share. In 2018, households in the lowest income quintile spend an average of $4,109 on food, representing 35.1 percent of income, while households in the highest income quintile spend an average of $13,348 on food, representing 8.2 percent of income. Morrison, R. (2019). USDA ERS - Food Prices and Spending. [online] Ers.usda.gov. Available at: https://www.ers.usda.gov/data-products/ag-and-food-statistics-charting-the-essentials/food-prices-and-spending/?topicId=14885 [Accessed 20 Nov. 2019].

3.3. Science Team Analysis

3.3.1. Lack of Insurance and Floods

As experienced in 2017 with Hurricane Harvey, most homes are not covered for flood insurance and many small businesses have little to no flood insurance. This ultimately means that the majority of those affected by severe flooding events are confronted with large bills they will need to pay for out of pocket.

The Downtown flood map shows that there are flooding points scattered throughout the area. Many of theses low points are predominantly in areas of the city where there are higher rates of uninsured residents. Even for residents who have homeowner insurance, flood insurance is typically not part of their coverage. For an individual to get flood insurance, they typically need to get it through the National Flood Insurance Program or NFIP. Only those in the most vulnerable flooding zones are required to buy flood insurance, so many people go without it if they are not required to purchase it. Many claim that the insurance is inequitable because the premium is unaffordable and would be even more so without government subsidizing.

"Hunter of the CFA said that homeowners without flood insurance can possibly apply for federal disaster relief benefits, but those come in the form of low interest loans, a burden for those already struggling with too much debt." - The Associated Press, 2017

"Cities are more likely to be affected by flash floods due to the predominant impermeable surfaces, such as asphalt, and the lack of natural drainage systems." - Yates Insurance, 2017

"Homeowners with water damage can get paid through their homeowners insurance but only if wind blows out a window or sends a roof aloft first, allowing the water in. If the water rushes through the floorboard or walls, you're not covered." - USA Today, 2017

"Property insurance typically doesn't cover flooding, and flood insurance remains by and large a federal government program run by the Federal Emergency Management Agency, or FEMA." - Insurance Journal, 2018

"Nearly 100% of commercial policyholders with business incomes of less than US$ 250,000 had no flood coverage at all." - Munich RE Survey, 2018

"Hurricane Harvey in 2017. With four days of rainfall, the tropical cyclone inflicted US$125 billion in damages to the Houston metropolitan area(6) The most troubling fact was that about 70% of the damages were uninsured(7), leaving many businesses without any recovery funding." - NOAA and Insurance Business Mag statistics in a report by Munich RE, 2018

In 2009, Atlanta experienced a large unexpected flood, the impacts of which are shown in Figure 3.4 below. Atlanta can expect to experience more extreme weather events with the progression of climate change, so even though the city is landlocked it will still need to address flood concerns.

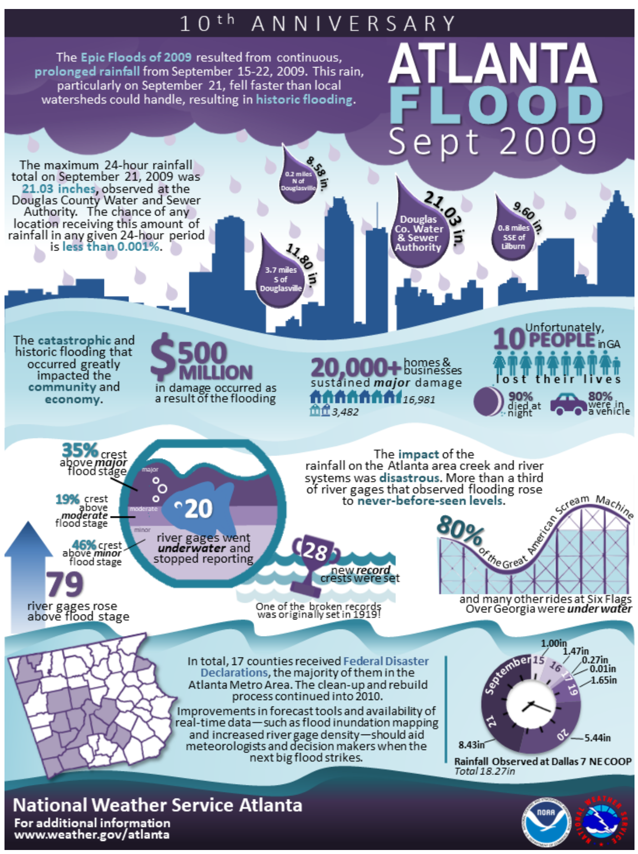

Figure 3.4. Flood impacts on the city of Atlanta. 17 counties received Federal Disaster Declarations, most of them in the Downtown Atlanta Metro Area. Retrieved from https://www.weather.gov/ffc/atlanta_floods_anniv

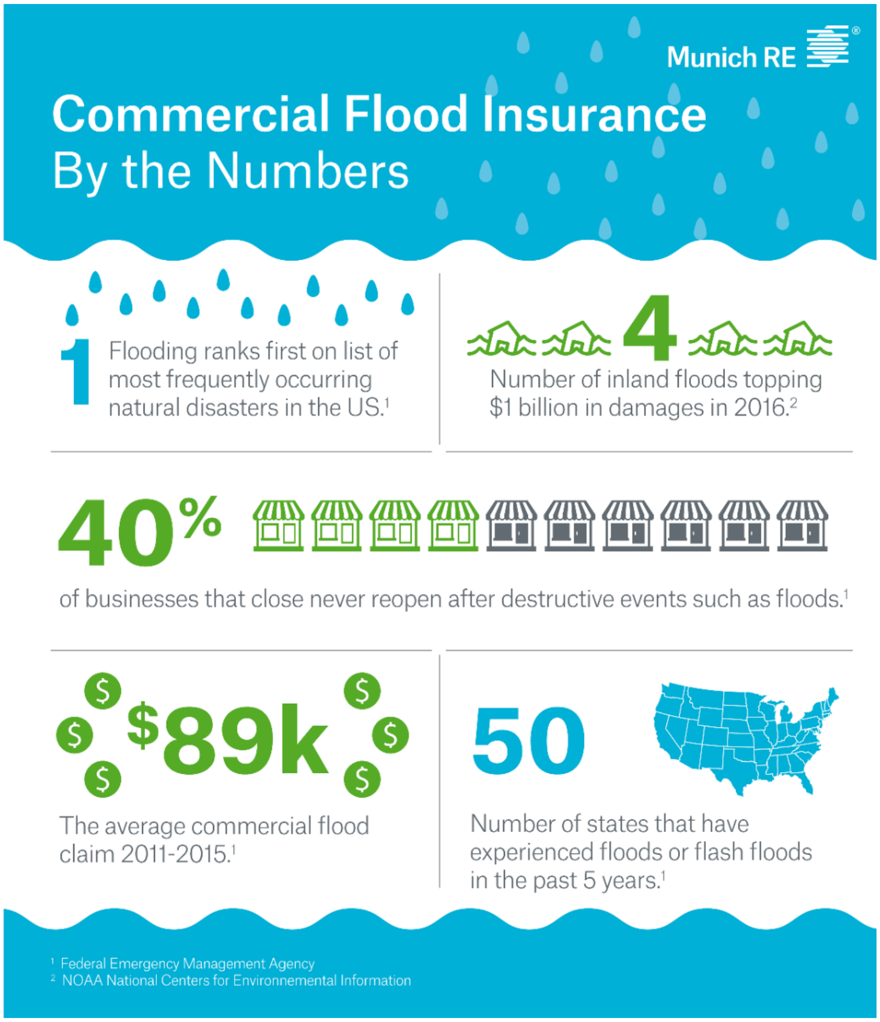

Figure 3.5. Floods in the commercial sector. Retrieved from https://www.munichre.com/topics-online/en/climate-change-and-natural-disasters/natural-disasters/floods/flood-usa-lack-of-flood-insurance.html

3.3.2. Overlapping of Small Business Loans Map and Flood Maps

When overlapped, the area with the highest rate of small business loans (our proxy for small business density) falls within both the least likely to flood and most likely to flood zones. Those businesses located near the interstate are most at risk of flooding. By utilizing our parcel level flood map, we can show where these at-risk individuals need to focus their efforts within their own property to reduce the effects of flooding through design and engineering solutions.

3.3.3. Overlapping of the Uninsured Individuals Map with Flooding Maps

The water accumulation map of Downtown Atlanta shows that there are acute flooding points scattered throughout the observed area. Many of theses low points are predominant in areas of the city where there are higher rates of uninsured residents. Uninsured residents are more likely to come from low-income families, part time and contingent labor workers, wage-earners in smaller-sized firms, lower-waged firms, non-unionized firms, and lack a high school education. These demographics are historically more likely to be minority and marginalized groups. Not only this but these groups are more likely to have lower familial wealth and savings (Institute of Medicine, 2001). This makes recovery from disaster events, such as floods, far more devastating.

In addition, the Downtown core is generally a high-elevation spot in the Atlanta region, and water flows out of this area into the surrounding areas. One of those areas is mostly residential and uninsured. If the Downtown area takes efforts to redirect and store flood water, it may be able to reduce the burden placed on these individuals downhill from the area. In that regard, the physical pollution and litter from Downtown can be expected to flow away from Downtown into the surrounding areas which puts a higher responsibility on Downtown because what is done there most affects those around it.

4. Proposed Solutions

4.1. Social Team

Currently the network of air quality monitors in Georgia is not dense enough to draw conclusions on the impact of air quality on specific communities. There are around 35 air monitoring sites in operation in 30 counties across the state that are used to monitor Georgia's compliance with the National Ambient Air Quality Standards (Ambient Air Monitoring Program, n.d.).

Air quality can change within different communities in a city as large as Atlanta, and thus expose some populations to significantly different levels of pollutants than others (Apte, 2017). In California, a state policy was put in place which mandates community-level air monitoring. Los Angeles has partnered with air monitoring equipment manufacturer Aeroqual to create lower cost monitors in order to achieve this community-based air monitoring network (Williams, 2018). There are further innovation efforts in this field that will likely lead to the development of a relatively inexpensive air monitoring sensor.

Community level air monitoring in Atlanta would allow for prevention of asthma-related absences from work due to hospitalization or asthma attacks. Manual workers with asthma are particularly vulnerable to poor air quality days. Community level sensors can be used to alert vulnerable populations of specific areas within the city to avoid due to poor air quality, which can be used by firms to more efficiently choose work sites in order to avoid negative health impacts on vulnerable outdoor workers.

4.2. Economic Team

In Atlanta, the energy that powers our lights, heat our homes, and fuels our transportation comes almost exclusively from fossil fuels such as coal, oil, and natural gas. When we use less energy, we burn less fossil fuels, leading to lower emissions of carbon dioxide which is a key contributor to climate change. In our analysis, we saw how the heat island effect had the largest impact on the poorest communities in cities as it increases energy burden and decreases the available income of people living. To tackle this issue we have to find solutions to make people from lower socioeconomic status communities less vulnerable to heat island effect. The City of Baltimore already conducted a study with a similar goals and put forward new solutions that we could apply in terms of this problem in the Downtown Atlanta area.

This study found that investments in energy efficiency, renewable energy and alternative fuels save money long-term, catalyze local reinvestment and jobs, and protect human health and the environment. To ensure low-income residents are not left behind as technology advances, cities are working to lower the upfront cost of renewable energy and energy efficiency. The solutions from the *2019 Baltimore, Maryland Sustainability Report* that are applicable to Atlanta include:

1. *Increase energy efficiency across all sectors through education, efficiency retrofits, and building management systems*
2. *Increase the urban tree canopy and target areas with urban heat island impacts*
3. *Review current building codes and regulations, and adopt a residential green building code to increase energy efficiency in residential buildings.*
4. *Complete the conversion of streetlights to LEDs and pilot street lights with solar panels, temperature monitoring and sensors that can spot parking spaces and track air pollution. Ensure equitable geographical distribution.*
5. *Increase installation of cool roofs and green roofs and plant more shade trees in neighborhoods where concrete and other hard surfaces trap and collect heat, creating "urban heat islands".*
6. *Promote and expand installation of energy-efficient combined heat and power and district energy systems which capture and reuse waste heat.*
7. *Set a goal to reduce petroleum consumption and increase the use of alternative fuel vehicles and equipment in the city government fleet.*

4.3. Science Team

On March 18, 2019 the presidential administration announced plans to reform NFIP prices on flooding insurance. "FEMA's current system calculates rates based on whether a home falls in a designated flood zone, and since higher-valued properties are more likely to hit the $250,000 insurance cap, lower-value homes are paying proportionately more than higher-value homes" (Insurance Information Institute, 2019). The reform system seeks to change that by assessing homes individually using parameters such as coastal surges, proximity to bodies of water, and hurricane rainfall rather than applying a formula to an entire zone. FEMA intends to implement this system October 1, 2021.

"In 2014 Florida enacted a law that encourages private companies to offer flood insurance. The legislation permits four types of flood coverage – a standard policy, which resembles National Flood Insurance Program coverage, and three enhanced policies. To encourage market growth, the law allows insurers to file their own rates until October 1, 2019. After that, rates will be subject to regulatory approval" (Insurance Information Institute, 2019).

Policies replicating this policy can be implemented in other states to make policies more affordable (Insurance Information Institute, 2019).

Communities can also develop grassroots flooding resilience by implementing the practices recommended by the EPA. These practices include green infrastructure, land conservation along river corridors, creating a comprehensive disaster recovery plan, updating flooding building codes, and implementing watershed-wide initiatives for storm water management (Environmental Protection Agency, 2014).

4.4. Engineering Team

CAP's Downtown Master Plan proposes many technologies, policies, and efforts to improve Downtown. For the purpose of this report, the engineering team selected 26 solutions from the Master Plan that, if implemented, have the potential to mitigate Downtown's vulnerabilities. These solutions were further analyzed to determine their impact on the three specific vulnerabilities focused on in the Analysis and Discussion portion of this report. See Table 4.4.1. for this list. The following solutions specified by the Master Plan have the greatest impact on the three vulnerabilities analyzed: re-design blah-zas, best block contest, decreasing parking, bioswales, and green infrastructure.

Table 4.1.1. Master Plan Solutions and Vulnerabilities Addressed

	Science	Economic	Social
Solution	**Flooding, Small Businesses, Insurance**	**Heat Island, Energy Burden, Leisure Spending**	**Heat Island, Asthma, Unemployment**
Re-design Blah-zas	☑	☑	☑
Best Block Contests	☑	☑	☑
Decrease Parking	☑	☑	☑
Bio Swales	☑	☑	☑
Green Infrastructure	☑	☑	☑
District/Centralize Parking	☐	☑	☑
Disincentivize Parking	☐	☑	☑
Improve Curbside Management	☐	☑	☑
Limited Repair Program	☐	☑	☐
Weatherization Programs for Residents	☐	☑	☐
Revisit Street and Sidewalk Maintenance Standards	☑	☐	☐
Wayfinding Signs	☐	☐	☐
Lighting Improvements	☐	☐	☐
Ground Floor Loans	☐	☐	☐
Temporarily Closing Blocks to Traffic	☐	☐	☐
Employee Assisted Housing	☐	☐	☐
Expanded Student Housing	☐	☐	☐
Network Startups	☐	☐	☐
Revisit On-Street Parking Policies	☐	☐	☐
Create and Market Linear Experiences	☐	☐	☐
Hire a Downtown Arts Coordinator	☐	☐	☐
Shared Commercial Kitchen/Food Incubator	☐	☐	☐
Elderly Monitoring Program	☐	☐	☐
Lockers for Homeless	☐	☐	☐
Integrate Health	☐	☐	☐
Construct a Tunnel Similar to the Krog Street Tunnel	☐	☐	☐
Raise Crosswalks to Sidewalk Level	☐	☐	☐

Both flooding and the heat island effect can be mitigated by reducing impervious surface area and replacing these areas with greenery. Blah-zas, which are large, underutilized areas of impervious cover, are a key source of potential in mitigating both flood risks and the urban heat island effect. Other technologies such as bioswales and green infrastructure can be incorporated into these blah-zas to turn them into more environmentally friendly and aesthetically pleasing spaces. These technologies can just as easily be incorporated into other public and private spaces Downtown. The goal behind Best Block contests is to improve an individual block's aesthetic through greenery, lighting, and landscape. These contests are a great way to indirectly encourage residents and corporations to plant greenery and increase permeable surfaces on their respective city blocks. Increased amounts of greenery would be a natural side effect of holding these contests.

Another key source of potential land for positive redevelopment in Downtown is the substantial amount of parking in the district. According to CAP's Downtown Atlanta Master Plan, there are 147 acres worth of unused parking spaces even at peak times (2019). Decreasing the parking supply, districting/centralizing parking, and disincentivize parking are all strategies that can be implemented to help convert some of this wasted space Downtown into activated, environmentally beneficial space that would also help reduce flooding risk and the heat island effect. Immediately removing the unused spaces would contribute to this mitigation strategy, and centralizing and disincentivizing parking would both help create a system wherein the demand for parking is further reduced, allowing more spaces to be converted to other uses. Having a more centralized, efficient parking system in Downtown also helps reduce total vehicle miles traveled (VMT) which decreases emissions, congestion, and asthma triggers. Disincentivizing parking through increasing its costs or providing stipends to those who do not drive is also known to reduce VMT and emissions (Johnston, 2006). Similar to decreasing parking supply, improved curbside management will reduce Downtown's VMT. According to Ali Vahabzadeh, founder of curbFlow, San Francisco and Washington, D.C. are both making an effort to better manage their curbsides to "improve metrics around congestion, safety, and sustainability with less vehicle miles traveled from circling looking for parking and drop-off space" (Descant, 2019).

Limited Repair Programs and Weatherization Programs both have the same goal: to improve dwellings of vulnerable populations. Limited repair programs focus on home repair for older adults or persons with disabilities for little or no cost (City of Atlanta, 2019). Weatherization programs focus on increasing energy efficiency of homes for low-income families (US Dept. of Energy, 2019). Efficient and maintained homes waste less energy than homes in disrepair. By helping families maintain and weatherize their homes, the energy burden for that family will decrease.

5. Conclusions

5.1. Existing Conditions & Recommendations

According to our analyses, areas with higher prevalence of asthma are more vulnerable to the effects of climate change. An increase in overall temperatures can exacerbate the urban heat island effect, increasing the number of low air-quality days and the health impacts of asthma. Populations who already live with asthma will face a decrease in productivity and a rise in costly unnecessary hospitalizations. Asthma can be debilitating to workers who primarily labor outdoors, and therefore face much higher exposure to pollutants and allergens. While higher-precision community-level air quality monitoring will not directly impact air quality, by closely monitoring air quality at the parcel level and keeping the public informed, policymakers, area residents, employees and employers could better prepare for the day with mitigating solutions.

The high heat island effect in downtown Atlanta also creates an increase in energy burden because some houses consume more energy due to their lack of energy-efficient fittings and, thus, pay more in energy bills. The heat island effect has a prominent influence on the energy burden for low and middle-income communities living in the area. As the energy burden becomes heavier, the income allocated to energy consumption grows, preventing people from lower socioeconomic status from adapting to higher temperatures. Retrofitting low-income houses and buildings will help these residents to spend less of their income on energy and bolster the economy. This extra income can help these communities to spend more in businesses such as food consumption, restaurant visits, and investing back into their communities.

The overlapping of the flood maps with both the uninsured individuals and small business maps revealed where the most vulnerable individuals and businesses in the downtown area are concentrated. Using this information, we were able to conclude that flood insurance is not comprehensive nor is it accessible to all. While the Downtown area is a local high point, we can still make efforts to reduce the effects of flooding within downtown as well as the externalities faced by locations downhill from the area. FEMA flooding zones need to be updated to cover a broader span of residents that need insurance due to their risk of flooding and flood insurance must be made more affordable. The high cost of insurance makes lower socio-economic groups more vulnerable to the costly effects of flooding. Flood insurance must be more heavily subsidized for those in need, and more private flood insurance companies should be encouraged to enter the market to drive down prices. Flood insurance should be included in homeowner’s insurance in areas detected in the flood map.

5.2. Recommendations for Future Studies

This sustainability and climate vulnerability assessment can provide support to the sustainability report, which is being created by CAP. Our team strongly recommends that this sustainability report be completed to provide a more comprehensive view of the vulnerabilities in the area.

Our analysis was done in present time (i.e., 2019); as such, we recommend an update to these maps with the new census coming in 2020. We also recommend the implementation of a similar study taking into consideration the IPCC's projections using climate models that include higher resolution data to the parcel level, statistical analysis, and include more social data that can provide a better detection of vulnerable areas and populations.

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