UNC TriCoMM 2022

Proposal for the Decrease in the Urban Heat Island Effect and Related Hospitalizations Through the Planting of Green Space

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Prompt:

Problem 1: Urban Heat Island

"Urban Heat Island (UHI) effect describes increased heat in developed urban and suburban areas due to the retention of heat by concrete. Heat is then continually released after nightfall and artificially inflates the climate of the city throughout the year compared to surrounding landscapes. UHI effects can be dangerous to human health during excessive heat in the summer months. UHI effects may be of particular concern to low income populations without reliable air conditioning, who may in turn disproportionately face heat-related hospital- ization and health concerns. Trees, grass, and other vegetation can provide significant temperature reduction to counter UHI effects, helping reduce stress, hospital admissions, and heat related mortality." (epa.gov) More background information can be found here: Environmental Atlas Article

Suppose you are competing for a government contract in Durham, NC to develop a policy plan for planting greenery to help combat UHI effects. You have been provided a data set with information about night time ambient temperature reduction, percent of green space, and demographic data for census blocks in Durham County to help inform your plan (Dataset). Important aspects related to this issue are:

- Planting trees in existing green space or developing new green space in the city will reduce UHI effects
- The city has a limited budget and time to implement a policy to address this issue and would like to find a lasting, sustainable solution
- Developing new green space or planting trees in census blocks with less than 60 percent existing green space will have additional costs.
- The city recognizes that low income populations have been disproportionately affected by this problem and would like to focus their efforts on these demographics

Your task is to develop a model to quantify how planting greenery will reduce UHI effects over time while addressing the constraints above.

Write a detailed technical report to explain your model to the analytic task force of the government of Durham who has been tasked with screening potential candidates. Make sure to highlight how your plan will address UHI effects and take into account their related concerns. In addition to this report, write a convincing one page letter to the mayor of Durham explaining the main results of your analysis, the benefits your plan will have to the city, and why you should win the contract.

Introduction:

Our goal to solve this problem is to analyze which areas are most affected by the UHI effect. In doing this, we seek a solution through the addition of ground and tree cover in low coverage areas. In the Durham County zoning laws, we quote,

> "Tree coverage serves to reduce glare, noise, air pollution, and soil erosion; to moderate temperatures; to reduce stormwater runoff; to preserve remnants of Durham's native ecology; to provide habitat for native plants and wildlife; to provide a healthy living environment; and to make Durham County a more attractive place to live." [4]

Thus we are interested in finding plant coverage for a variety of reasons specific to Durham, notwithstanding greater economic and climatic effects. We are seeking a thorough analysis of our data, from which we can draw conclusions about how best to model UHI effects relative to pre-existing data.

From this, our ideal models would take the percentage of green space in a given census block and return an amount of trees and ground cover to be used in a given area. Furthermore, we would like to develop a methodology to take the ratio of trees versus ground cover, as designated by a project manager, to a set cost for an area to improve its percentage of green space, as delineated below:

(Input: GreenSpace %
Output: # of Trees/Cover per area (find ratio but weakness actual ratio up to project manager)

Input: % of Trees vs % of Ground Cover
Output: Cost per area)

This would result in a set of models which would allow us to visualize how much any given area would cost to improve.

Considerations:

In this section, we provided an overview of the different factors and approximations we used in our model to reach our solution. It's important to note that these are all approximations that allow us to create a simpler model that we can use to come up with a general estimate for resulting costs, time, added greenery and decreased UHI effects. During the actual implementation of this project however, the area being considered will dictate the actual values.

Plant Type:

Plants fight the UHI effect by providing shade and performing transpiration. Thus we are looking for tall trees that provide lots of shade as well as fast growing ground cover that has a high rate of transpiration. Some further requirements for both plant types are that they must be native species to the Carolina Piedmont, require minimal upkeep (water, soil health, fertilization), drought resistance, and lower costs. Ideally, trees should also be long living which would allow lower annual costs. In regards to ground cover, we'd choose grass and turf alternatives that would require minimal water and upkeep. We would select a variety of plants that met these specifications to promote biodiversity.

- **Examples of Plants that might be selected:**
    a. American Elm (Ulmus americana)
        - Deciduous
        - Height: 100+ ft, canopy spread: 60-100 ft
        - Drought and disease resistant
        - Life span:175-200 years
        - Cost: $7.95 per 1-2 ft sapling [1]
    b. Loblolly Pine (Pinus taeda)
        - Coniferous
        - One of the highest tree growth rate
        - Tolerates moderate drought and flooding
        - height: 60-100 ft, canopy spread: 25-35 ft
        - Cost: $8.95 per 1-2 ft sapling [1]
- Approximations:
    a. Taking into account a preference for large canopy, high shade trees, we will be approximating the average tree coverage span to be 40 ft at full growth. To simplify the model, each tree will cover a square area of 1600 square ft.
    b. Generalize: 1 ground cover grouping will spread to cover 10 square ft.

Time:

Ideally, it would be possible for our policy proposal to be enacted immediately and create immediate effects to prevent heat related illnesses. Unfortunately, there are a number of time dependent factors that will be outlined and considered below. Despite this, we are still trying to model a **five year** goal that could make a noticeable impact on the reduction UHI effects.

- Plant Growth:
  - Trees: Fast growing trees can reach their full height in 10 years while a general growth time is about 20 to 30 years [5].
    - As we are looking for faster growing trees, we will approximate the average growth time to be **15 years.**
  - Groundcover: We will be choosing fast growing ground cover that will be able to establish itself and begin spreading within a year. Thus we will approximate the average time needed for the ground cover to fill the assigned space to be **2 years.**
- Time to Open-up Available Land:
  - Will take immediate (<1 year) action to find available plots to overturn, and will likely find about 50% of available, enactable land in this period.
  - After 1 year, more sustainable goals will be put in place.
    - Should implement practices to develop more forested plots as time goes on
    - Business failures/home foreclosures can lead to potential UHI development targets

Costs:

There are many hidden costs that may not be discovered until the project is actually being implemented. Furthermore, we can't know the exact cost of labor, tools and transportation, so we decided on a general approximation.

- Groundcover:
  - The cost of inexpensive ground cover options can range from $1-4 per plant. We will approximate this to be $2.50.
- Trees:
  - While seedlings are cheaper and easier to transport than saplings, they have a much higher mortality rate. Thus, we will be choosing to plant 1-2 ft tree saplings as they are still relatively cheap and easy to transport. We will approximate the cost of these saplings to be about $9.00.
- Labor:

- Both trees and groundcover require labor, transportation and further materials to be installed. We could potentially decrease labor costs by presenting this as a community outreach and service project and utilize volunteer services. Furthermore, adding more plants at one time can also decrease costs. Thus we will approximate these costs by doubling the cost for trees and ground cover.
- $18 per tree planting, $5 per ground cover planting

- Planting Land:
  - There will be a cost associated with finding land to plant on. This cost will also increase as we move into more developed areas with a lower percent greenery because those areas are already developed.
- Developers:
  - Incentives:
    - Another idea is to incentivize developers to increase green space by adding tax benefits to buildings with green roofs or higher levels of ground/tree cover
  - Laws:
    - Current zoning laws only require [4]:
      - 20% preserved tree cover in suburban residential spaces
      - 10% preserved tree cover in suburban nonresidential spaces
      - 7% preserved tree cover in urban residential spaces
      - 3% preserved tree cover in urban assorted spaces
      - There is also a stipulation that roadways have the “right of way” over tree coverage, and that the roads can be expanded (by Durham) without changing overall tree coverage requirements.
  - Maybe a future model could look at how incentivising developers or creating new laws can affect increased greenery.

Data Analysis:

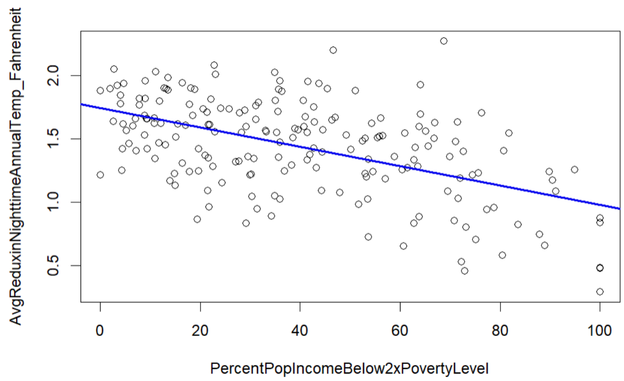

Figure 1.1

Showcases the variable PercentPopIncomeBelow2PovertyLevel against AvgReduxinNighttimeAnnualTemp_Fahrenheit. There is a clear negative linear correlation, where the average annual nighttime redux in temp decreases as the % of the population's income below 2x the poverty level increases. We also solved for the trendline, written below, as well as the correlation coefficient, R^2, which showed statistical significance for the correlation.

Solution: Y = MX+B

M = -0.0076289

B = 1.7437612

R^2 = 4.43e-15

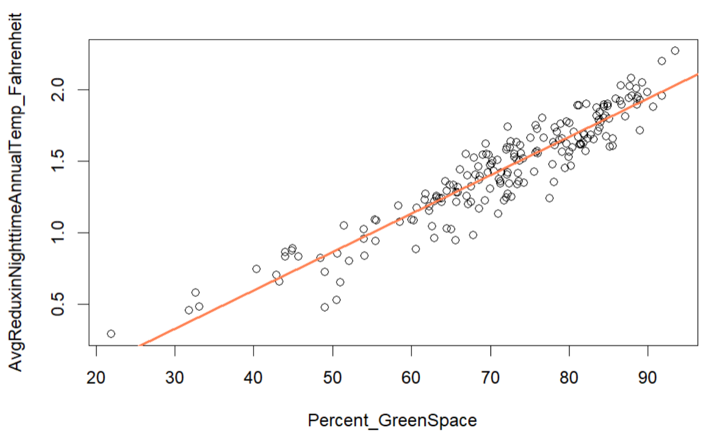

Figure 1.2

Showcases the variable Percent_GreenSpace against AvgReduxinNighttimeAnnualTemp_Fahrenheit. There is a clear positive linear correlation, where the average annual nighttime redux in temp increases as the % of greenspace increases. We also solved for the trendline, written below, as well as the correlation coefficient, R^2, which showed statistical significance for the correlation.

Solution: Y = MX+B

M = 0.0267831

B = -0.4715971

R^2 = < 2e-16

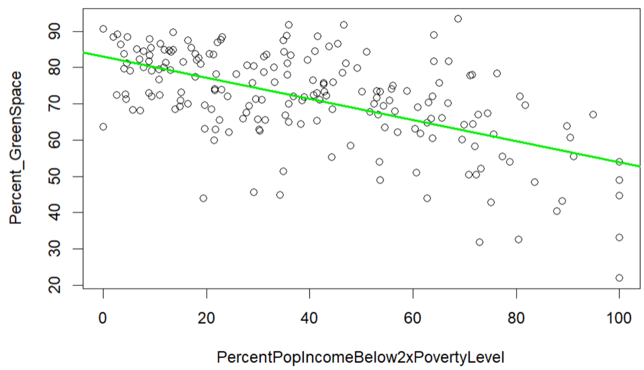

Figure 1.3

Showcases the variable PercentPopIncomeBelow2PovertyLevel against Percent_GreenSpace. There is a clear negative linear correlation, where the % of the population's income below 2x the poverty level increases as the % of greenspace increases. We also solved for the trendline, written below, as well as the correlation coefficient, R^2, which showed statistical significance for the correlation.

Solution: Y = MX+B

M = -0.29186

B = 82.99383

R^2 = < 2e-16

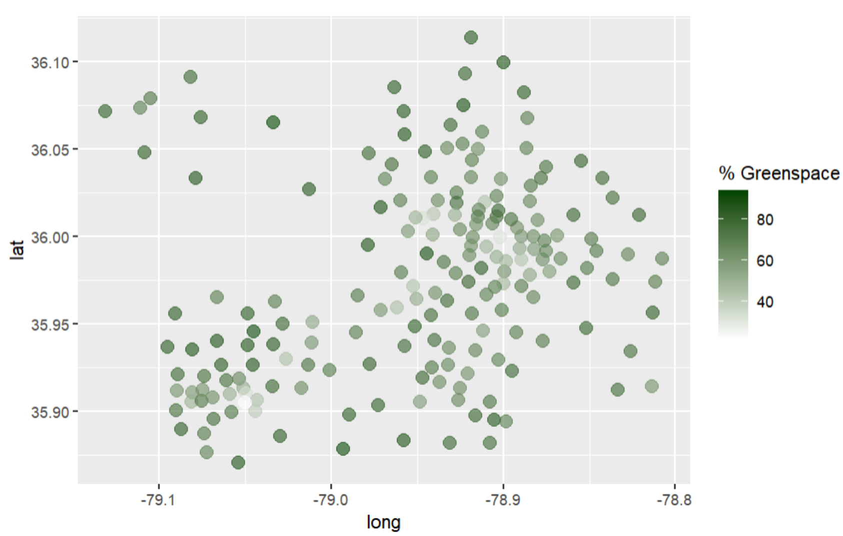

Figure 2.1

Showcases the locations of each datapoint, using latitude and longitude, along with shading to indicate the % of greenspace at each point.

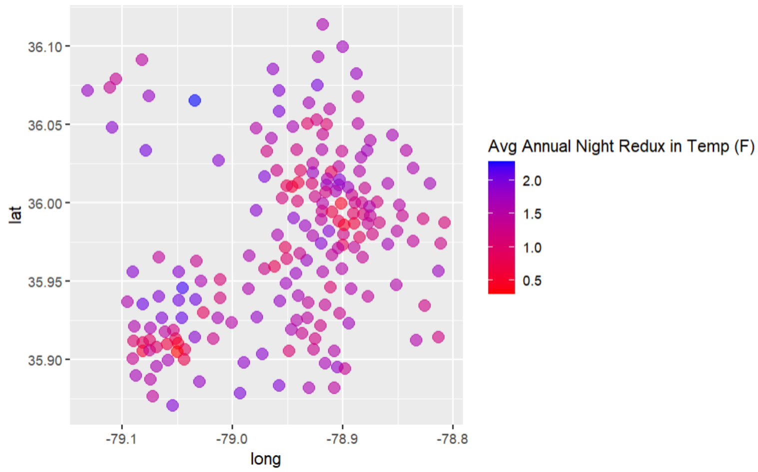

Figure 2.2

Showcases the locations of each datapoint, using latitude and longitude, along with shading to indicate the average annual nighttime redux in temp at each point.

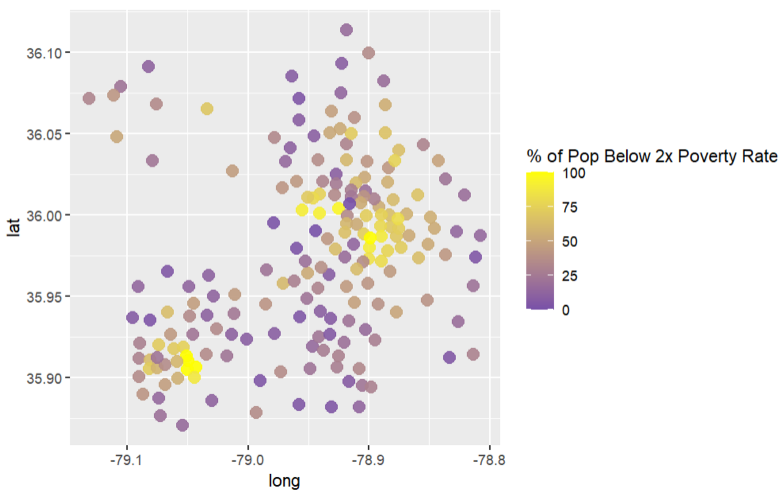

Figure 2.3

Showcases the locations of each datapoint, using latitude and longitude, along with shading to indicate the % of the population's income below 2x the poverty level at each point.

Figure 3.1

```
        Welch Two Sample t-test

data:  poverty_above_50$AvgReduxinNighttimeAnnualTemp_Fahrenheit and
poverty_below_50$AvgReduxinNighttimeAnnualTemp_Fahrenheit
t = -6.5206, df = 104.99, p-value = 2.507e-09
alternative hypothesis: true difference in means is not equal to 0
95 percent confidence interval:
 -0.4717853 -0.2517636
sample estimates:
mean of x mean of y
 1.204432  1.566206
```

Here we performed a Welch Two Sample t-test to determine that areas with more than 50% of their population below 2x the poverty level have lower average annual nighttime redux in temp to a statistically significant level (R^2 = 2.507e-09).

Figure 3.2

```
        Welch Two Sample t-test

data:  poverty_above_50$Percent_GreenSpace and poverty_below_50$Percent_GreenSpace
t = -6.9928, df = 100.99, p-value = 2.98e-10
alternative hypothesis: true difference in means is not equal to 0
95 percent confidence interval:
 -17.33288  -9.67203
sample estimates:
mean of x mean of y
 62.58119  76.08365
```

Here we performed a Welch Two Sample t-test to determine that areas with more than 50% of their population below 2x the poverty level have lower % of greenspace to a statistically significant level (R^2 = 2.98e-10).

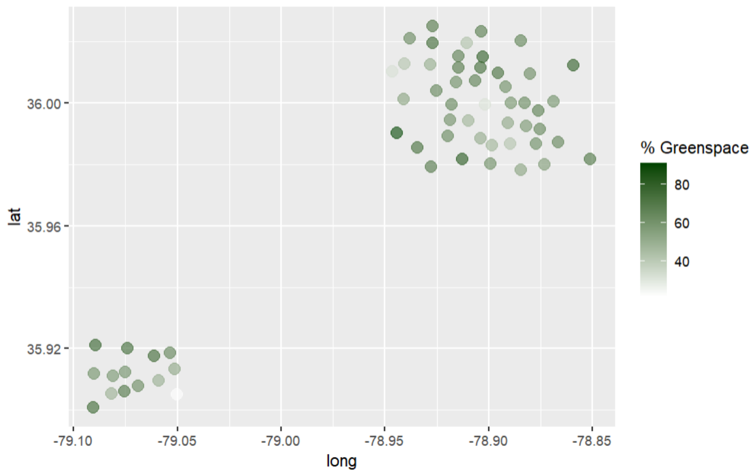

Figure 4.1

This is a rendering of the targeted areas, which have lower % of green space and a higher data density than other locations. This area also experiences statistically higher UHI effects and has a poorer population than the whole.

```
        Welch Two Sample t-test

data:  target_areas$Percent_GreenSpace and df$Percent_GreenSpace
t = -3.9778, df = 97.644, p-value = 0.0001336
alternative hypothesis: true difference in means is not equal to 0
95 percent confidence interval:
 -11.667944  -3.900595
sample estimates:
mean of x mean of y 
 63.61200  71.39627 
```

Figure 4.2

This Welch Two Sample t-test shows that in our targeted areas, the % of green space is significantly different, being less than the typical value from the whole dataset. This is statistically significant (p = 0.0001336).

```
        Welch Two Sample t-test

data:  target_areas$PercentPopIncomeBelow2xPovertyLevel and 
df$PercentPopIncomeBelow2xPovertyLevel
t = 4.5311, df = 101.01, p-value = 1.613e-05
alternative hypothesis: true difference in means is not equal to 0
95 percent confidence interval:
  9.528549 24.369185
sample estimates:
mean of x mean of y 
 56.68544  39.73657 
```

Figure 4.3

This Welch Two Sample t-test shows that in our targeted areas, the % of the population below 2x the poverty level is significantly different, being greater than the typical value from the whole dataset. This is statistically significant (p = 1.613e-05).

```
       Welch Two Sample t-test

data:  target_areas$AvgReduxinNighttimeAnnualTemp_Fahrenheit and
df$AvgReduxinNighttimeAnnualTemp_Fahrenheit
t = -3.5738, df = 93.913, p-value = 0.0005578
alternative hypothesis: true difference in means is not equal to 0
95 percent confidence interval:
 -0.32337778 -0.09238453
sample estimates:
mean of x mean of y
 1.232735  1.440616
```

Figure 4.4
This Welch Two Sample t-test shows that in our targeted areas, the average annual nighttime temperature reduction is significantly different, being less than the typical value from the whole dataset. This is statistically significant ($p = 0.0005578$).

Calculations:

Looking at Figures 2:1-3, we found the areas that had the highest level of poverty, smallest reduction in ambient temperature and lowest level of greenery. We used the corresponding latitude and longitude lines to find the area we wanted to plant greenery within which is displayed in Figure 4.1.

Convert long lat to square miles and figure how much space we need to cover with greenery

c. Make a equation using greenery

- One degree of latitude equals approximately 364,000 feet (69 miles)
- One-degree of longitude equals 288,200 feet (54.6 miles)
- One target area is roughly 4.7 square miles
- The other target area is roughly 18.8 square miles
    - Total target area is 23.5 square miles

Next, using the area found we calculated how many plants we would need to cover this area using 60% trees and 40% ground cover to increase the greenery level by our goal of 10% increase in greenery.

- 10% of 23.5 square miles = 2.35 square miles
- 60 % tree cover = 1.41 square miles of ground cover = 3.03E7 square ft = 18,938 Trees
- 40 % ground cover = 0.94 square miles of tree shade = 2.62E7 square ft = 2.62E6 plants

Then we calculated the costs of planting and how much finding land for planting would cost in the specified areas taking into account the average poverty level.

- Cost of groundcover: 3.03E6 * 5 = 1.31E7 million
- Cost of trees: 18,938*18 = 340,884 million

After this we looked at how much the increase in greenery would decrease the UHI.

Strengths and weaknesses of the model:

- Strengths:
    - One strength of this model is the thorough analysis of the cost of implementing such a plan. This is one of the more important aspects of a plan that a city council will want to hear.
    - Another strength is that this model offers a flexible way of meeting our ground and tree cover limit allowing the project managers to more easily meet the criteria to improve greenspace through a mixed approach of ground and tree cover.
- Weaknesses:
    - One weakness of this model is that this model only considers how much money and time will be needed to complete such a project. This model does not consider how to implement our changes in a developed area, how trees and ground cover will be installed without impeding daily traffic and design of the city.

Improvements:

- If we had more time to improve our model, we would analyze the costs of land for planting and how this changes when you move into more developed areas.
- We would also look into how much time it would take to implement this plan
- Ideally, we'd also be able to take a closer look at each region and figure out what best fits that area
    - Have a project manager to provide details about what each area needs
- We would consider more how to incentivize green rooftops and gardens on private property to increase the willingness of people to adapt greenspace into the built environment.

Letter to the Mayor:

Dear Mayor O'Neal,

Our plan to decrease the Urban Heat Island Effect in Durham is to target specific areas suffering most. The urban heat island effect is caused by the retention of heat by urban building materials, such as concrete, and leads to an artificially inflated climate. These effects can be dangerous during excessive heat in the summer months, and urban heat island effects are of significant concern to low income populations without reliable air conditioning, who often disproportionately face heat-related hospitalization and health concerns. Trees, grass, and other ground cover can provide significant temperature reduction to counter these effects, helping reduce stress, hospital admissions, and heat related mortality. We want to help reduce the related hospitalizations and other negative effects by planting more green spaces in Durham.

To do this, we are prepared to plant a significant number of trees, and would like Durham to support this with public policy, which would carry out our plan. This would be complemented by more ground covering plants, which would help add to the heat island reduction plan, without needing a full-size tree. This plan would use plants native to the area, in an effort to be renewable and retain the natural ecology of the area. In doing this, we plan on creating a better, more beautiful Durham, which would be helping its neediest residents.

The primary communities of Durham we would target are shown to be significantly less wealthy than the rest, and they have less green space as well. This would help reduce the worst effects of the urban heat islands in Durham, and would lead to a much improved quality of life for, again, some of the poorest and neediest members of the community. But who would face the burden of this project?

The developers and the general population would take the brunt of the economic burden in this effective plan. This would be a reinvestment in Durham, where the population would gain as much as they spend back in more green spaces, more lush urban areas, and less climate inflation. In terms of cost, this plan would be expensive, but worthwhile. We are seeking a ten percent increase in the percentage of green space in our target areas, which would be achieved primarily in the next three years. We are also looking for an overhaul of zoning laws related to tree cover, which would help create more green developments. As the city of Durham grows and develops, more benefits would spring forth.

For one, there would be more land available for parks, greenways, and other natural areas. Of course, as time goes on, there should be lessened effects of urban heat islands as the heat islands themselves are reduced. Furthermore, the city of Durham would gain a more beautiful appeal, simply from having more greenery and fewer paved areas. We appreciate your consideration on our plan, which we think will have countless benefits as time goes on.

Sincerely,

Sam Pell, Jane Corah, and Alex Miroshnichenko

Sources:

[1] https://www.willisorchards.com

Used to find the costs of the trees

[2] https://www.gardenia.net/plant/pinus-echinata

Used to find details for types of plants

[3] https://www.marketplace.org/2014/04/29/cities-want-make-your-rooftop-gardens-profitable/

References on how to incentivize rooftop greenery

[4] https://durham.municipal.codes/UDO/8.3.1

City of Durham tree cover zoning laws

[5] https://www.gotreequotes.com/how-long-does-it-take-for-a-tree-to-grow/

Details on general rate of tree growth

Code Document:

https://docs.google.com/document/d/1xq6Z4x8i4nT31KeQbUbav6t75JLHmkdTpVxa5Q6TpJE/edit?usp=sharing