Mitigating Urban Heat Island Effects in Washington, DC: Grant Proposal for Urban Reforestation

I. Introduction

Washington, DC's intensified and expanding urban growth has contributed to the city's urban heat island (UHI) problem. An urban heat island occurs when a city experiences much higher temperatures than the surrounding area. Importantly, UHI increases the average daily temperatures and the intensity of extreme heat events, causing decreased power plant efficiency, increased utility costs, and adverse health effects.

This is a clear market failure. UHI is a negative externality of urbanization, as resulting temperature increases do not fall exclusively on the landowners and developers, but rather the public at large. A temperature externality creates a market failure since the equilibrium price of urbanization currently does not reflect the true cost of the activity. Further, Greenstone and Jack (2015) state that the social marginal willingness to pay for environmental goods will exceed the private marginal willingness to pay for environmental goods if environmental quality investments create public goods or positive externalities.[i] This is true here; environmental quality investments for heat mitigation, such as cool roofs and tree planting, are not excludable and cause positive externalities. Additionally, this framework states that social marginal willingness to pay for self-protection will exceed private marginal willingness to pay for self-protection if self-protection mechanisms create negative externalities. Again, this is true. Self-protection mechanisms for regulating higher temperatures, such as air conditioning, create greenhouse gases, a negative externality that further exacerbates the temperature issue. In sum, individuals overinvest in the self-protection mechanisms with negative externalities (air-conditioning) and underinvest in the self-protection mechanisms with positive externalities (tree planting and eco-building). Therefore, the market does not promote an efficient and socially optimal solution, and government intervention is necessary.

Despite stated desire to reduce the risks of this market failure, successful intervention has been limited. There has been some public green infrastructure investment, such as the installation of green and cool roofs on government buildings. There is also a green roof incentive program which gives rebates of $10-$15 per square foot of green roof installed.[ii] Further, the city offers low-income residents a Utility Discount Program, providing up to $475 per year on electric bills, as well as a free Home Energy Rating Audit.[iii] In the summer of 2020, the District opened 14 public cooling centers around the city for residents to find reprieve on extreme heat days.[iv] Other potential interventions include regulatory standards mandating cooling materials and vegetation or the creation of public parks and green spaces.

And still, the heat in DC has continued to relentlessly increase, with low-income residents and renters facing the highest burdens. There are many disadvantages among the aforementioned list of programs. Both regulation and direct government infrastructure investment are costly and not well-targeted. Space, cost, and client need can preclude meeting regulatory standards, which may halt entire projects. Plus, developers with large lobbying power can be resistant to regulation. Audits likely do not provide large enough incentives to enable low-income households to invest in self-protection mechanisms. The current reforestation efforts in DC are limited to public property and do not target residential buildings. Utility assistance programs and cooling centers, while necessary to provide immediate relief, do not solve the root causes of the market failure. Public green spaces often induce gentrification. Finally, all of these interventions are not the most cost-effective solution.

Alternatively, the District should adopt a policy to incentivize firms and individuals to incorporate urban reforestation into their development projects and/or existing infrastructure through subsidies and technical assistance for tree planting. This program helps significantly mitigate UHI, as well as contributes to beautification and air pollution reduction. Consequently, this solution has the highest net benefit and is most cost-effective. Researchers at the Nature Conservancy have documented this fact— the median net cost of tree planting is less than every other strategy considered, once accounting for both temperature and particulate matter concentration reductions.[v] The EPA noted that $1 invested in tree planting translates to between $1.50 to $3.50 in benefits.[vi] The structure of the program allows for low-cost tree planters to have the highest take-up rates. This is critical for tree planting, as those with low costs and high benefits will be invested in the program and become more likely to ensure that trees survive. Hence, the program's success becomes self-reinforcing, and there is a high likelihood for lasting temperature decrease.

The outlined tree planting incentive scheme is efficient. Under this program, landowners may plant an additional tree up to the point in which the resulting temperature reduction (marginal benefit) is equal to the cost of planting that tree (marginal cost), satisfying the first equimarginal principle. At present, there is an inefficiently low number of trees in DC, as the marginal cost of planting an additional tree is much higher than the benefit it brings to the landowner/landlord. By both reducing the marginal cost and emphasizing the benefits of reforestation through outreach, the marginal cost will equal the marginal benefit at a socially optimal level.

Moreover, the outlined tree planting incentive scheme is a cost-effective solution. The second equimarginal principle states that equating the marginal cost of abatement across firms and industries will achieve cost effectiveness. Landowners, developers and firms can abate (tree plant) up to the point at which each additional unit of cost equated across project sites because the program is an incentive scheme designed to allow for this flexibility. Rather than requiring a mandated standard, which would not allow for equal costs across landowners and firms, the voluntary take-up will ensure cost-effectiveness.

II. Problem Description

Urbanization has brought economic growth to the District, yet has also contributed to the city's urban heat island (UHI) problem.[vii] An urban heat island arises when an area experiences higher temperatures than surrounding natural landscapes, due to higher concentrations of paved surfaces and infrastructure that absorb and re-emit solar energy at higher rates than natural vegetation. In 2014, DC was cited as the sixth most intense urban heat island in the US, with an average temperature difference of 4.7°F between the city and surrounding rural areas.[viii]

There currently exists a highly unequal distribution of shading in DC due to redlining and historically discriminatory housing practices. Data show that high-income, predominantly white neighborhoods in DC have lower heat vulnerability indexes (e.g., 0.253 in Cleveland Park) than low-income, predominately non-white neighborhoods (e.g., 0.706 in Anacostia).[ix] UHI exacerbates these existing inequalities, and low-income residents bear the highest burden.

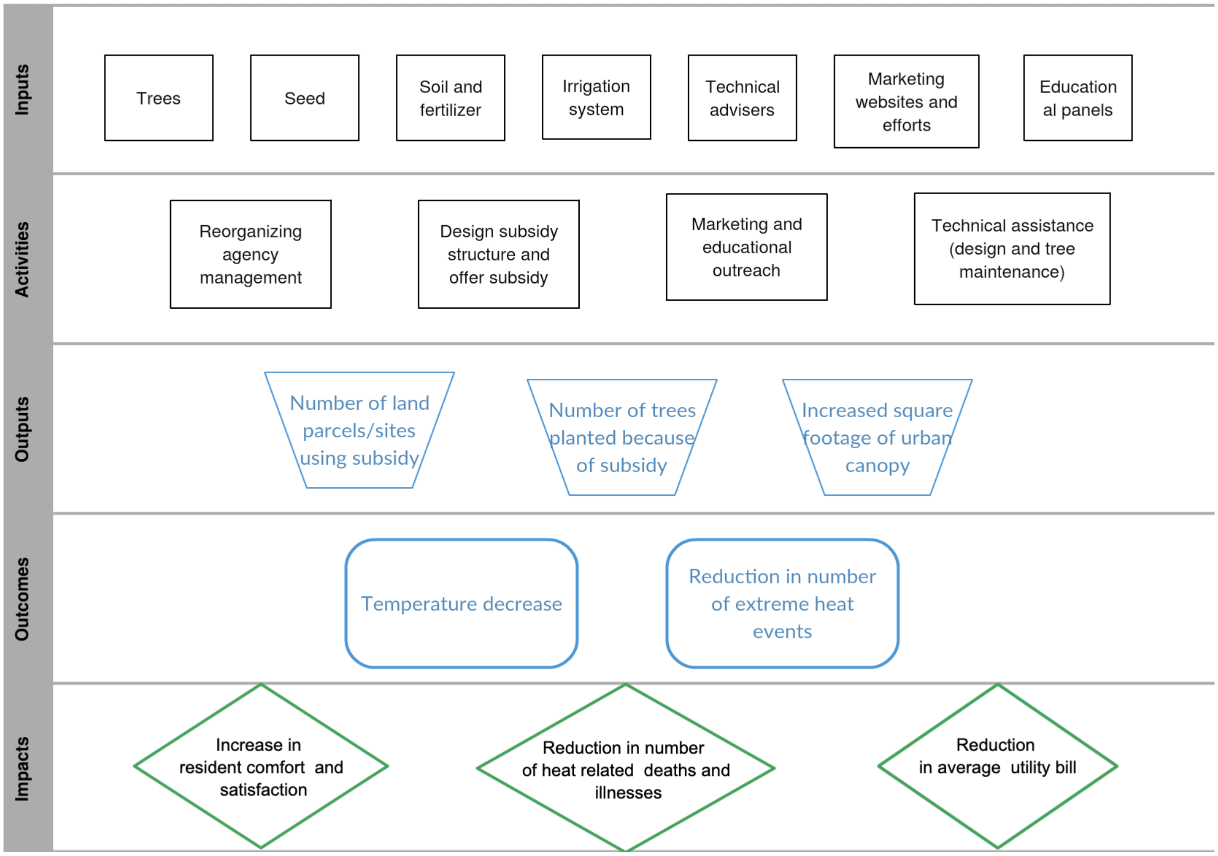
Higher temperatures increase the cooling demand of buildings. A meta-analysis of the present literature determined that cooling energy demand increases approximately 12 percent, on average, from UHI.[x] High demand for cooling services can cause suspension of electricity services during peak temperature events in an attempt to avoid blackout. Furthermore, high temperatures decrease the efficiency of power generation plants, increase costs of adaptation services and decrease the lifetime of capital stock.[xi] Increases in input costs and aggregate demand thus increase consumer prices. Low-income residents are disproportionately burdened by higher utility prices, since a larger share of their budget is spent on electricity.

Moreover, extreme heat exposure can cause heat illness (dehydration, heat cramps, heat stroke), accelerated death from respiratory, cardiovascular and other underlying conditions, and a rise in hospitalizations.[xii,xiii] Between 2004 and 2018, there were an average of 702 heat-related deaths in the United States per year.[xiv] Also, heat can cause distressed mental states, from irritability to the inability to complete skilled tasks, to increases in conflict.[xv] Notably, these health effects disproportionately affect vulnerable populations such as low-income households, the disabled and chronically ill, and the elderly.[xvi,xvii]

Finally, high temperatures of roofs and paved surfaces increase runoff water temperatures, which negatively impacts surrounding aquatic ecosystems, such as the Anacostia River.[xviii]

III. Theory of Change

The figure below details the theory of change framework.



The short-term objective is for 50 percent of new development projects and 10 percent of existing low-income households in DC to use the subsidy within the first two years. The goal is for this level of take-up to translate to a 20 percent increase in DC's urban canopy.

The efficacy of reforestation in mitigating UHI is well documented. Researchers found that a single tree's evapotranspiration can offset the heat equivalent to that produced by one hundred 100-watt lamps, burning 8 hours per day.[xix] Another study found that greater tree cover decreased temperatures significantly (over 40%), within the precision of a city block.[xx] A global analysis of 245 cities showed that current tree stock in cities provides nearly 70 million people with a reduction in maximum summer temperatures of roughly 0.9 to 3.6° F.[xxi] Beyond a direct causal link to the output of temperature reduction, reforestation translates to improved outcomes and impacts. One model estimated over $70 million in energy cooling savings from a tree planting and reflective roofing scheme in LA.[xxii] In Texas, tree planting in certain areas reduced deaths by more than 20 percent due to temperature reductions.[xxiii]

The success of the program in transforming inputs to outputs is contingent on four assumptions.

1. Educational and marketing outreach reaches a large population of landowners, and landowners understand and value the long-term benefits of the program.
2. Space constraints on project lots are not a major limiting factor to the incorporation of tree planting.

3. Tree planting failures are minimized and trees survive for several years due to proper maintenance.
4. It is assumed that subsidization is set at a level that sufficiently offsets costs and risks associated with incorporating reforestation into development sites.

Technical maintenance employees, coordinated and targeted outreach, and varied and thoughtfully designed subsidy structures all help ensure the validity of these assumptions.

IV. Stakeholder Assessment

The nine most relevant stakeholders of the urban reforestation subsidy program are listed below.

Direct beneficiaries

1) Residents of heat vulnerable areas
2) Small businesses in heat vulnerable areas (shading increases walkability and foot-traffic)
3) Construction and development firms with projects in heat vulnerable areas

Indirect beneficiaries

4) Nurseries and vendors trees, soil, fertilizer, and irrigation systems are purchased from
5) Individuals trained and employed as tree planting and maintenance technicians
6) Individuals employed as urban planners who engage with enrolled developers to redesign blueprints so that project sites effectively integrate tree planting
7) Program office employees (working in administration, application management, and educational and promotional outreach)

Resistant actors due to negative impact and/or exclusion from benefits

8) Landowners and development firms with property and projects in already shaded areas

Resistant actors who may view the program as a threat to their power and opportunity

9) Canopy 3000 (group of DC government agencies, companies and nonprofits working on a tree planting campaign in DC)

Gathering information from residents, landowners and urban reforestation experts before the program is launched can help the program run more smoothly. Focus groups with residents can help inform the needs assessment and targeting efforts, as residents of heat vulnerable neighborhoods can help highlight the hottest areas and where tree planting may have the highest marginal utility. Second, polls and focus groups with landowners (which may not be the same as residents, as many residents are renters) can inform strategies to maximize take-up and buy-in. Understanding how landowners currently consider tree planting in their projects (if at all) can inform outreach efforts. Is it cost, lack of maintenance skills, or a desire to have low-maintenance sites, or rather a lack of awareness and understanding of the benefits of urban reforestation that mainly inhibit tree planting? Third, consultations and focus groups with urban planners and input vendors can help inform the program's implementation strategies, as these individuals possess specialized knowledge on successfully designing and maintaining urban tree spaces.

In addition to consulting stakeholders to utilize pertinent information, it is important to address potential project stakeholder resistance upfront to ensure that stakeholder needs are met. First, residents may be concerned that the maintenance burden may fall on them. Reassuring residents that tree technicians will follow-up with and maintain each site is essential in ensuring resident investment in the program. The program may even consider paying residents to help care for trees, or consider training and employing them as the tree maintenance technicians themselves. Local residents likely have greater investment in keeping trees alive in their neighborhoods, so this strategy may even cause better tree survival outcomes. Second, residents may be resistant to the program if they believe it will induce gentrification. As such, the program should assume the "just green enough" strategy, which couples environmental justice and sustainability goals as defined by community leaders in order to green neighborhoods without pricing out existing residents. Additionally, targeting the subsidy at low-income housing and rent-controlled units will inherently mitigate concerns of gentrification. Lastly, in order to ensure that established reforestation efforts (e.g., Canopy 3000) do not perceive the new program as undermining their own efforts, communication with this group is critical.[xxiv] The two program efforts are not mutually exclusive, as this intervention effort targets privately owned land, whereas Canopy 3000 has access to publicly owned land through its partnership with the District government. Meetings to keep Canopy 3000 informed may overcome this potential resistance.

V. Log Frame

Objectives Hierarchy	**Indicators**	**Sources of Verification**	**Assumptions/Threats**
Objective: Decrease in temperature of high heat vulnerability index areas	Temperature	Temperature readings (°F)/ historical weather data	Other confounding factors do not simultaneously change temperature dramatically
Outcome: Increase in tree canopy	(Δ in) tree cover	Satellite imaging	Majority of trees survive once planted, sufficient maintenance practices employed, no major deforestation on sites for other reasons
Output: More trees planted	Number of trees planted on sites of subsidy participants	Site visits	Adequate compliance and follow-through with planting

Input: Number of subsidies offered	Number of individual projects that use the subsidy	Office records/site visits	Sufficient interest at given subsidy levels, Sufficient buy-in by landowners on the benefits of tree planting

VI. Evaluation Goals

The main evaluation goals of the project are:

1. Measure the total amount of trees planted as a result of the subsidy program.
2. Measure a reduction in the average temperature in areas where planting occurs.
3. Assess the total and average program cost per degree of temperature reduced.

All three of these evaluation goals can be assessed within the first three years of the program. The long-run impacts of utility bill reduction and health improvements may be assessed on the 5-to-10-year timeframe. The first two evaluation goals are directly tied to the outlined results framework and desired, tangible outcomes of the program. If trees survive after three years (as will be assessed by the first evaluation goal) and temperatures are reduced (assessed by the second evaluation goal), utility and health improvements will follow as a natural consequence, as the scientific literature quite clearly links reforestation to shading and temperature reduction.[xxv]

Consequently, the central question of interest is less a matter of causal impact, but rather a question of cost-effectiveness and scalability of a city-wide program. The third evaluation goal attempts to measure cost per degree of temperature reduced in order to contextualize the cost-effectiveness and scalability of the program and allow for comparison across other methods.

VII. Evaluation Plan

The roll out of the program will randomly assign subsidization amounts to interested participants. Once a landowner or developer shows interest, they will randomly be offered a subsidization level of either zero percent of direct costs, 50 percent or 90 percent. This randomization will allow for causal measurement of take-up and number trees planted per subsidy level. Note that all interested participants will receive free technical assistance in designing the landscape and maintaining trees. Thus, randomization across subsidization amounts allows us to evaluate if knowledge and maintenance assistance itself are enough of an incentive to plant trees, or if direct costs are a barrier to planting. From this, we can trace out a demand curve for tree planting, which will be immensely useful in determining an optimal long-term subsidy amount (maximizing take-up per marginal cost) in later program stages.

Consideration was given to randomizing subsidy amounts by geographical zones, rather than at the participant level. There were two major reasons why this level of randomization was not chosen. First, the impact of shading is highly localized to specific property sites and temperature readings can precisely measure differences within a one block radius. As such, spillover effects are not a major concern for measuring the direct impacts. Second, there is limited space in DC to create a sufficient sample size of control and treatment zones.

The evaluation goals focus largely on carefully and accurately measuring uptake, scale and project costs. Temperature reduction can be directly measured, and prior literature has recorded that temperature effects can be recorded within single block radii, so causality can likely be established by a simple difference-in-difference of precise temperature readings on shaded versus non-shaded areas in close proximity. Hence, the following evaluation methodologies focus on effectively capturing the scope and cost-effectiveness of the program's impacts.

Finally, evaluators can calculate total costs in relation to average temperature reduction using data on temperature readings and office records of costs. This cost calculation can also be averaged by neighborhood, project site size, and average subsidy level, to help understand the differential impacts of the program. Another interesting evaluation metric is the percent of surviving trees based on subsidy rate. Then, the program can assess if individuals with the lower subsidy rates (those who paid more for tree planting) take better care of them. These evaluations help to answer the third evaluation goal of cost-effectiveness.

VIII. Data Collection Plan

All factors detailed in the Theory of Change are quantifiable. Data should be monitored and collected on the following metrics:

- Number, location and level of all distributed subsidies
- Number of trees planted as a result of the subsidies (total and per each subsidy level)
- Number of surviving trees (total and per each subsidy level)
- Temperature readings
- Tree canopy
- Project costs

Before planting begins, a technician will collect the baseline number of trees and radar temperature readings at the project site and the surrounding area (quarter mile radius). This will allow for direct comparison between the temperature of the project site (treatment zone) and similar surrounding area (control zone). Many temperature readings should be taken in each zone so averages can be taken to minimize noise.

Next, office records will record the number of trees that are intended to be planted on each site, as well as the number of trees actually planted upon project completion. Finally, the number of trees alive will be measured by technicians during follow-up maintenance visits (monthly for the first year, quarterly for the second year, and semi-annually in subsequent years). Temperature readings will be recorded in these follow-up visits as well, at both the treatment site and the surrounding quarter mile radius zone. While there will inevitably be variation in temperature per day, the outcome of interest is the temperature at the site as compared to the surrounding (control) area, so this methodology should suffice in capturing temperature difference data.

Additionally, it is necessary to create a satellite map of current tree canopy in Washington, DC before the program's start. Satellite imaging should be conducted in the first and third years of program implementation. The first and third years are important for assessment of take-up and immediate tree survival. Yearly satellite imaging after that is costly and can likely be obtained from open-source software (e.g., Google Earth). Comparison of these annual maps are not necessarily causal, since other factors may affect urban reforestation (or deforestation). However, the precision of temperature readings and overlaying canopy imaging with maps of subsidy location sites will still provide an informative picture.

Finally, data on total project costs (e.g., subsidy costs, technical assistance, maintenance, staffing) should be detailed in each project record file.[xxvi] The program office can then aggregate the costs across sites to determine total program costs.

It should be noted that, under an unconstrained budget, the program would implement two surveys to residents in heat vulnerable neighborhoods– one prior to subsidy distribution and a second sent approximately three years after the program has been. The surveys could consist of a series of 5-10 questions related to current satisfaction of urban greenery and heat levels, 2-3 questions regarding utility payments, and several questions on key demographic variables. A simple, brief survey design increases response rates and minimizes costs and canvassing time. However, this prescribed survey design requires a budget of at least $100,000 (assuming 1,000 participants per survey). While resident comfort level and utility bills are two critical long-term objectives of this program and surveys could help close current data availability gaps, it is likely not a priority of this plan, as compared to the measurements of scope, take-up, tree survival and cost-effectiveness. If budget permits, this feature can be added to supplement understanding of program impact, though it should not be a priority evaluation metric.

IX. Conclusion: A Solution for All

UHI is a well-documented problem afflicting countless cities across the US, almost always concentrated in low-income and non-white neighborhoods. The research concludes that urban reforestation successfully reduces temperatures. Yet, there are currently very few (if any) city-wide monitoring and evaluation tree planting programs in the US. Hence, answering the question of how to cost-effectively implement city-wide tree planting has large generalizability. A tree planting subsidization program in DC can become a model for many US cities. Moreover, the salient issue of temperature increase is exacerbated and made all the more urgent as the climate crisis continues to escalate. There is no time to waste in adopting an efficient, equitable and cost-effective solution to heat mitigation. The consequences of inaction will result in higher UHI, wildly unaffordable utility bills, and additional human suffering and mortality.

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