Adapting Tree Co-Benefit Calculators with the Greater Baltimore Wilderness Coalition

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I. Executive Summary

There are numerous tools that estimate the benefits of planting trees in their communities. However, those benefits are usually presented in the context of environmental impacts, and tools can be challenging for a non-professional to use and understand. To address this issue, our research team worked with the Greater Baltimore Wilderness Coalition (GBWC) to create a more user-friendly and personalized tool for the residents of Baltimore County, Howard County, and Baltimore City.

To meet this goal, the team took on two tasks: to explore current tree calculator tools and recommend which components of these tools are most helpful, and to characterize factors that don't exist in current calculators that would best show residents how trees could benefit their community.

By reviewing literature and case studies in economics, urban development, forestry, environmental science, epidemiology, psychology, and anthropology, we determined that a mature tree canopy is positively correlated with improvements in mental health, physical health, social cohesion, and the economy. Benefits reductions in stress levels, anxiety, and depression as well as decreased risks for asthma, heat-induced medical conditions, and lung cancer. Additionally, tree canopy may also create monetary incentives for homeowners by lowering energy costs, increasing property values and facilitating storm-water filtration.

Based on these research findings, we recommend designing an interactive webpage that combines suggested tree calculator features, along with an estimated quantitative calculation of economic benefits. Rather than quantifying mental, physical, and social cohesion factors, we suggest the site include a separate section to display these benefits in a way that is easy for the user to understand.

One possible way to present these findings is by integrating information and interactive imagery into a platform similar to GBWC's existing "Climate Resilience Map." By researching the best calculator tool components and lesser-known co-benefits, this project can be used to develop or adapt a new tree co-benefit calculator for residents of central Maryland, to aid in the GBWC's goal of increasing support and understanding of the benefits of planting trees in local communities.

II. Introduction

Since 1990, it is estimated that 420 million hectares of the world's forest have been lost due to anthropogenic influence, primarily, agricultural practices (FOA, 2020). This an area greater than that of the United States, Russia, and China combined. It's estimated that, in the past decade, Maryland has lost 4,000 acres each year to deforestation (Sierra Club Maryland Chapter, 2017). Because half of the world's forests are within just five countries, including the United States, our country has an even greater responsibility to protect and restore its forests; yet we are responsible for more than seven percent of global deforestation presently occurring (FOA, 2020). Due to the vast ecosystem services forests provide—air filtration, nutrient cycling, habitat, flood mitigation, timber, tourism, and recreational, cultural and religious importance—deforestation threatens social and ecological systems around the world (USDAFS, 2019).

While we may not be able to solve national forest degradation, targeting this issue at a regional level can contribute to large-scale changes. Consequently, the Greater Baltimore Wilderness Coalition has started the Planting the Future initiative in the Baltimore region to encourage residents' participation in tree planting. Although the City has a goal of 40 percent tree cover by 2030, canopy density has only increased one percent between 2007 and 2015 (USDAFS, 2017). Thus, additional resources should be used to help the City reach its goal.

GBWC is considering creating a tree co-benefit calculator. Tree co-benefit calculators are tools that allow users to input tree characteristics to estimate the benefits it could provide to the user and the community. These calculators provide a way for community members to learn about the importance of tree canopy. While many such calculators exist, they are commonly focused on determining the environmental benefits of trees, such as carbon sequestration, air filtration, and biomass (i-Tree Tools, 2020 & . Carbon Footprint Calculator, 2020).

Because many of the tree canopy's other benefits are difficult to quantify, current calculators have an information gap, particularly in mental and physical health, social cohesion, and economic benefits. To help the GBWC increase community involvement and appreciation of trees, this study presents features from other tools that can be useful in building a more complete tool, research on the co-benefits, and possible ways to incorporate and measure them in a new tool.

III. Goals and Objectives

The goals of this research are to:

- summarize the best features of current tree co-benefit calculators
- provide information on the co-benefits, including mental and physical health, social cohesion, and economic benefits that planting trees can provide to the Baltimore County, Howard County, and Baltimore City

- use this information to recommend features that integrate these benefits into a new calculator that encourages residents to plant trees.

These goals and end products will be accomplished in four objectives.

Objective 1: Tree Co-benefit Calculators

Research the factors in current tree co-benefit calculators/tools. We are seeking the simple, user-friendly, practical features for rural and urban residential use. Identifying these features in existing calculators can provide a framework for the less-frequently incorporated co-benefits explored throughout this project.

Objective 2: Mental and Physical Health Benefits

Find data supporting the mental and physical health benefits of increased tree density in urban and suburban areas. We are specifically looking for the benefits most relevant to residents in these areas. We are also looking for ways to quantify these benefits.

Objective 3: Social Impacts

Investigate and summarize the community impacts of tree planting. Tree planting can have a wide variety of impacts depending on population factors including age, income, and race. Specific community impacts include how tree planting can influence social cohesion and an area's crime rate.

Objective 4: Economic Benefits

Identify research that supports job opportunities in urban tree planting and maintenance. We also compare returns on investment in tree planting with investments in other sectors. Within this objective, we examined evidence of benefits for homeowners in several categories—energy cost savings, increases in aesthetic appeal, and increased property values.

IV. Methodology/Research Approach

The team divided the study of tree planting co-benefits into four categories: current tree co-benefit calculators, mental and physical health, social cohesion, and economic value. To research the useful features of current calculators, we searched for "Tree Benefit Calculators" on Google. For mental and physical health, social cohesion, and economic value, we gathered quantitative and qualitative data from reputable, peer-reviewed sources and extracted the most applicable evidence to support GWBC's mission.

Tree Co-benefit Calculators

Researching co-benefit calculators starts with gathering current calculators available on the internet. The most notable calculators came from the i-Tree series: i-Tree Design and i-Tree MyTree.

We started the process by searching the phrases: “tree co-benefit calculator,” “tree calculator tools,” and “tree forest calculations.” This results in numerous web page offerings, including tree co-benefit calculators, forest calculation reports, “how-to” websites, and R codes for programming specific tree calculations. We examined tree calculators in descending order until we found repeats. This led us to the following ten calculators: National Tree Benefit Calculator, Calculator Tool - California Air Resources Board, The Trees for the Future Carbon Calculator, and seven tools in the i-Tree domain (Projects, Landscape, County, Canopy, Planting, MyTree, and Design). Each tool was analyzed for urban/rural tree planting, a user-friendly interface, and benefits calculated.

Each tool was tested in multiple trials. For residential use, a calculator should allow the user to search and accurately locate an address, plot specific tree species, input tree characteristics, and access quantified tree benefits for their household.

Requirements for user-friendly designs included ease of access, steps needed to calculate benefits, and a comprehensive benefits spreadsheet. We focused on calculators accessible on a website from a smartphone or tablet and with nothing to download. Calculators had to have fewer than 10 steps between inputting tree information and outputting benefits. The listed benefits had to be categorically distinct, offering simple, diagramed results with easy-to-comprehend explanations.

We listed the benefits of each tested tool to evaluate their salience. The higher the salience, the more applicable they were to residential users. For example, most calculators quantified stormwater runoff, energy savings, and air quality improvements. These tests helped eliminate non-intuitive or complicated tools, and set a framework for health, social, and economic benefits.

Mental and Physical Health

Mental and physical health variables aren’t typically quantified in co-benefit calculators. Nevertheless, they are important to examine because they allow the user to connect with the tool in a more personal manner. After conducting preliminary research, we compiled possible ways to quantify these benefits. The main method we used to research mental and physical health effects was examining scholarly articles and reports on the relationship between trees and green space and well-being.

We entered keywords such as “urban,” “health,” “greenspace,” “forests,” “mental health,” “psychological distress,” “trees,” “physical health,” “asthma,” “respiratory,” “well-being,” “activity,” and “exercise” into commonly used databases, including Google Scholar, JSTOR, and Web of Science. Accordingly, the journals and reports we used were broad, and included public health, landscape and urban planning, environmental health, environmental psychology, social science and medicine, and comprehensive physiology. Another important piece of the research was the mental and physical health benefits most applicable to the average urban resident. We were able to narrow our variable list based on the most prominent categories in the existing research.

Social Impacts

The community impacts of tree planting are also significant, but not often quantified in typical tree co-benefit calculators. To research community impacts we examined various scholarly articles and journals, including ones focused on public health and urban planning, discussing how green space and tree planting can impact people and communities. These papers were found using keyword searches on both the University of Maryland Libraries' website and Google Scholar. Some keywords used included "urban green spaces" and "social impacts of urban forests," as well as "tree canopy and crime."

After research, we determined that the best way to quantify this information would be to discuss all the community impacts we discovered. We examined how green spaces can impact community cohesion among different populations, the impact of accessibility in different types of communities, and how tree planting impacts crime rates. Finally, we examined how environmental justice plays a role in the distribution of green spaces and tree planting in communities.

Economic Research

Sources for economic research were found using Google Scholar and focused on three categories: benefits to individual homeowners and urban residents, benefits to employers and employees, and benefits to governments and taxpayers. Different keywords narrowed the search in each of the three categories.

Key phrases for information about potential benefits to individual homeowners and residents included: "urban tree planting homeowner benefits," "urban tree density energy savings," "urban trees shading benefits," "urban trees property values," and "quantifying aesthetic benefits of urban trees." Key phrases for information about the benefits to employer and employees included: "tree-planting job creation," "urban forestry management jobs," "sustainable urban greenscape jobs," and "urban tree-planting return on investment." Finally, for information about governments and taxpayers, specifically, potential economic benefits in the current economic downturn, we used the key phrases: "economic stimulus through urban forestry 2020," "green economy," "urban tree planting 2020" and filtered our results for publications within the last year.

From the results, we selected sources from scholarly articles in reputable journals such as *Ecological Economics*, *The Journal of Environmental Management,* and *Urban Forestry & Urban Greening*. For data on health care savings, we also used governmental organizations such as the Centers for Disease Control and Prevention and Centers for Medicare and Medicaid Services. To supplement our findings on urban greening's relationship to property values, as well as the comparative costs of carbon capture and storage-based carbon sequestration, and sustainable urban forestry programs, we relied on data from non-governmental research and advocacy organizations such as the Center for Climate and Energy Solutions, Pew Center on Global Climate Change, World Resources Institute, and the Institute for Environmental Solutions.

V. Findings

Tree Co-benefit Calculators

The internet hosts a plethora of tree calculators or tools for individual, business, and global use. However, most offer the same benefit categories, and many are out of date in what they offer to residents. Based on our research, the most extensive and up-to-date tools are from the i-Tree domain. i-Tree has fifteen different tree tools, with calculations based on peer-reviewed, USDA Forest Service research (i-Tree, 2020). Two of their tools are designed for residential tree planting—i-Tree Design and i-Tree MyTree—and allow the user to input location, describe tree species, and determine common quantified benefits. MyTree doesn't allow continued map use after calculations and is designed for small calculations of single trees. The i-Tree Design tool seems a more ideal design structure for GBWC.

Furthermore, although it doesn't fit the criteria, we assess The Trees for the Future Carbon Calculator as an option for residential users who don't wish to plant trees on their property. This calculator allows individuals and businesses to offset their carbon footprint by donating to a tree planting program. An offset program would allow GBWC to increase funding for their green infrastructure planting goals and allow users to reduce their carbon footprint without altering their property.

i-Tree Design

Tree Design allows users to calculate the approximate benefits that individual or multiple trees provide to any address on their map and is well-suited for residential use. First, residents enter their location then choose whether to calculate the impact of trees on their utility bills by outlining a building of their choice. Users can add additional buildings not found on the i-Tree Design map. (Image 1 shows the University of Maryland's McKeldin Library.)

Then, users enter existing or desired tree species, diameter, condition, and sunlight exposure. In Figure 1, we've entered a Northern red oak with sample specs. Users can place one or more trees in Tree Benefit Zones, the green buffers surrounding the building. As they place a tree, the calculator shows the value of energy savings the tree would provide in each zone: less in lighter zones, more in darker zones. This helps users pick planting locations to maximize benefits. The calculator also shows the latitude, longitude, and relative distance from the selected building and users can choose the lifespan of the estimate, up to 60 years.

Figure 1: McKeldin Library at the University of Maryland, displayed on the i-Tree interface (i-Tree Tools, 2020)

Once the user enters in the years to calculate benefits, a summary page lists co-benefits such as stormwater runoff, energy savings, air quality, and carbon reduction on the x-axis. The y-axis shows current and future benefits over time. These can be adjusted to find the desired co-benefit and time period. Simple images and diagrams also accompany the text, explaining the benefits of the current selection (Figure 2). These projects can be saved and downloaded for use at any time.

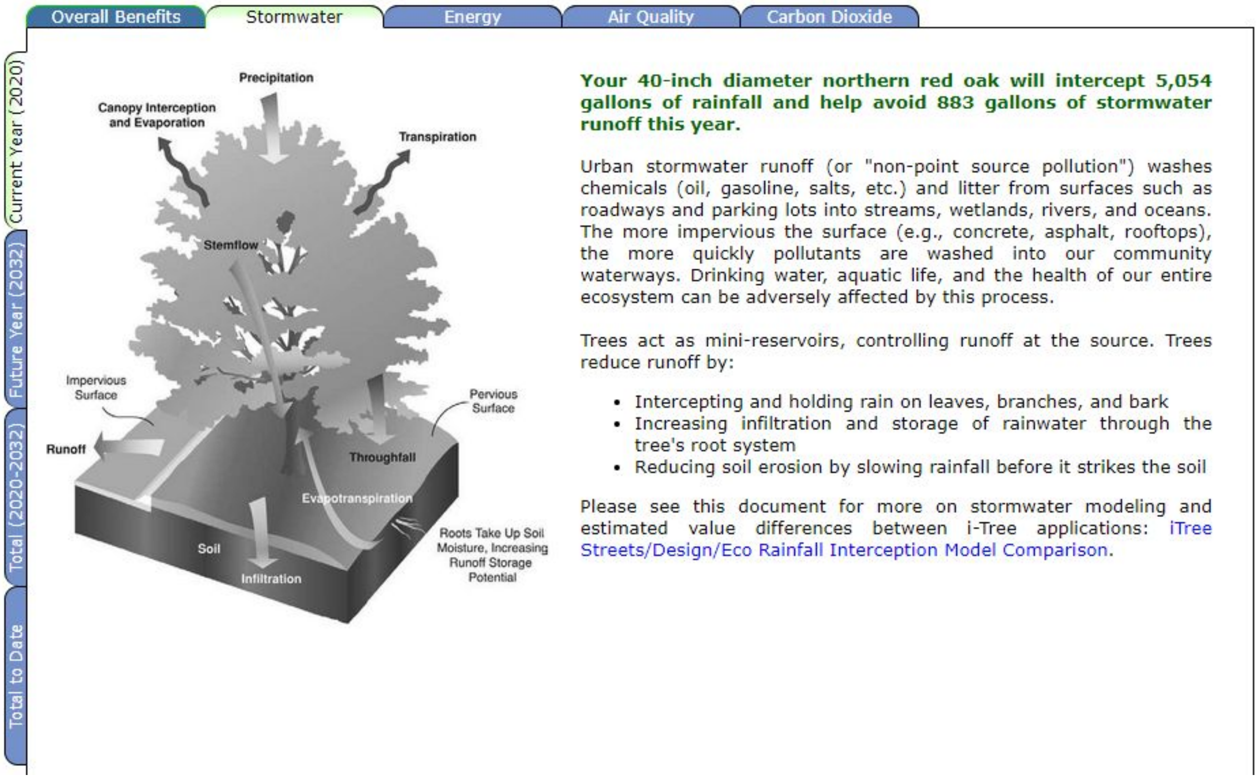

Figure 2: Typical summary page of i-Tree Design benefits spreadsheet (i-Tree Tools, 2020)

<u>Trees for the Future</u>

Trees for the Future is a nonprofit organization that creates forest gardens to sequester and store carbon dioxide. Projects are funded through individual and business donations aimed toward offsetting the users' carbon footprint (Image 3). The user inputs their estimated annual carbon emissions through different usage factors. For individuals, factors include estimated gallons of gasoline used, miles traveled by plane, miles traveled by bus, miles traveled by subway, and home energy use. For businesses, factors include electricity used, natural and propane gas used, employee commutes, and supply chain emissions. The program then calculates the donation that will offset the individual's or business's carbon footprint. A receipt is sent to the user's email as a record for tax credit.

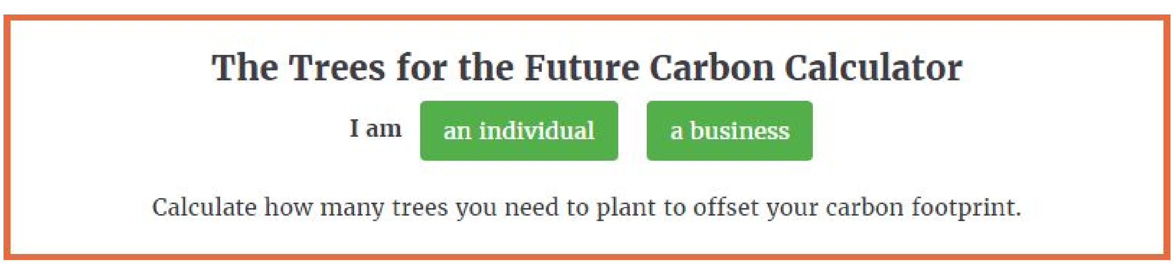

Image 3: Trees for the Future carbon calculator model: individual vs business (Carbon Footprint Calculator, 2020)

Mental Health

Research has consistently demonstrated that green space is positively correlated with improved mental health (Beyer et al., 2014 & Wood et al., 2018 & Hedblom et al., 2019). Because cities have less canopy than suburban and rural areas, the need for increased tree planting is not only more extensive but has the potential to impact residents in areas where green space is scarce or limited to low-lying vegetation and grass (Astell-Burt & Feng, 2014). While some studies purport that exposure to urban vegetation can improve spatial memory (Flouri et al., 2019), three benefits have clearly emerged in the past decade to suggest an association between tree canopy and improved mental health: reduced reports of depression, anxiety, and stress.

In 2014, researchers utilized data from a Wisconsin state-wide survey to analyze the correlation between the proximity of forests and green space for citizens and their prevalence of mental health issues, including depression, anxiety, and stress (Beyer et al., 2014). The study states “results indicate that the difference in depressive symptoms between an individual living in an environment with no tree canopy and an environment with 100% tree canopy is larger than the difference in symptoms associated with an individual who is uninsured compared to an individual with private insurance” (Beyer et al., 2014).

Similar relationships between improved mental health and the presence of tree canopy and greenspace are found in international studies as well. A 2015 Toronto study estimated that the benefits for residents in areas with high tree density was comparable to the health benefits (including depression and anxiety) one would expect to find in the next higher income bracket (Kardan et al., 2015). A 2017 Korean study found that adults who lived near the most parks and green areas were 16 to 27 percent less likely to report feeling depressed or suicidal (Min et al., 2017). In Auckland, New Zealand, proximity to urban greenspace resulted in decreased reports of anxiety (Nutsford et al., 2013). Respondents in Denmark who lived more than one kilometer from green space were found to have “1.42 [times] higher odds of experiencing stress…[compared to]...respondents living less than 300m away from a green space” (Stigsdotter et al., 2010).

While there is a strong correlation between improved mental health and urban greenspace, these findings are hard to convert into a quantitative format in a tree-canopy calculator. We found only two such studies, in which researchers attempted to address this challenge by associating levels of depression, anxiety, and stress with the density of and proximity to trees.

A 2019 study of three Australian cities (including Sydney) found that residents in areas with dense low-lying vegetation were 71 percent more likely to self-report psychological distress compared to residents living in neighborhoods with moderate to heavy tree canopy (Astell-Burt & Feng, 2014). Results were collected after participants filled out the Kessler Psychological Distress Scale, a questionnaire that assigns points based upon the level of anxiety and depressive symptoms reported; in this study, results over 22 points were indicative of psychological distress.

In the Toronto study, researchers attempted to break down the benefits associated with each tree. They stated, "...having 10 more trees in a city block, on average, improves health perception [including depression and anxiety] in ways comparable to an increase in annual personal income of $10,000 and moving to a neighborhood with $10,000 higher median income or being 7 years younger" (Kardan et al., 2015). Data informing this assertion was based on self-reported questionnaires retrieved from the Ontario Health Study (Kardan et al., 2015). Since the Normalized Difference Vegetation Index (NDVI) and satellite imagery are easy to access and were both used to determine canopy cover in the two aforementioned studies, this could be an option for a tree calculator (Jiang et al., 2020). However, research does not presently exist to accurately support such an addition.

Physical Health

Physical health is extremely important to most people, which is increasingly apparent in a world reshaped by the ongoing COVID-19 pandemic. What most individuals might not realize is that time spent outdoors, surrounded by green infrastructure, can benefit physical health in ways beyond exercise. Spending time outdoors in an urban area with a significant number of trees can reduce the risk of asthma, the chance of experiencing a heat-induced medical condition, the risk of being diagnosed with lung cancer, and more (Wolf, et al., 2020). Exercise is also a factor. The presence of trees in an urban area encourages physical activity by creating a welcoming, safer, and healthier environment (Turner, et al., 2019). Each of these aspects are a compelling reason for urban residents to plant trees in their yards or in the sidewalk tree boxes.

One study found that tree orientation and type can decrease the risk of heat-related medical incidents because the trees create sidewalk shade during peak sun hours (Sanusai, et al., 2016). Residents could be intrigued by the thought that planting a tree at the sidewalk in front of their home will provide shade and protection during the sun's harshest hours. The key to this, however, is the type of tree planted. Researchers considered leaf size, transpiration rate, and the tree's orientation (Sanusai, et al., 2016). This study used the London plane tree, but with further research and evidence, other trees could be used.

One of this project's goals is to quantify the research so it can be used in a calculator. One group of researchers approached the issue of quantifying physical health impacts by comparing green land cover to life expectancy in Baltimore (Tsai, et al., 2019). They used remote sensing and spatial resolution techniques to determine whether the relationship between the two variables was positive, negative, or neutral (Tsai, et al., 2019). Results showed that different spatial resolutions and different vegetation types changed with life expectancy rates (Tsai, et al., 2019). Examining this research further could provide insight into quantifying this information.

Social Impacts

Community Cohesion

Tree planting has numerous physical and mental benefits for individuals. For an entire community, even greater benefits can be recognized (Hanson & Frank, 2016).

One of the greatest impacts tree planting can have on communities is improved community cohesion. That is, tree planting can help strengthen community bonds among residents. Greater access to green spaces in communities has been found to be strongly associated with a sense of community among nearby residents (Jennings & Bamkole, 2019). Through surveys of residents, this sense of community can be identified in a number of feelings, such as trust, belonging, and connectedness. One way green spaces strengthen communities is as local gathering places Activities that encourage social interaction, such as walking, biking, and attending community events take place. Less green space can discourage community cohesion. Areas that have fewer green spaces can lead residents to feeling isolated and less like they belong (Hanson & Frank, 2016). This study also notes that feeling isolated can have negative health impacts. This further shows that social ties act as a connector between green spaces and health.

Green spaces can also provide a way for residents to become invested in their communities. One example of this is tree planting programs. In this type of activity, residents help improve their communities and see the long-term impacts of their labor (Hanson & Frank, 2016). By becoming more involved in their communities, residents are likely to experience beneficial feelings of belonging and connectedness. In addition, tree planting can encourage further environmental development in communities, such as community gardens and community-designed parks (Sommer et al., 1994). Community involvement is crucial to resident satisfaction and programs and projects should actively encourage it. The study that found this correlation notes that residents who planted their own trees were far more satisfied with the tree's attributes, including its location and quality, than if it had been planted by someone outside the community. Projects that bring in outside providers actually can create feelings of hostility toward the outcome (Sommer et al., 1994).

The impacts of community cohesion that green spaces provide are not uniform among all age groups. Different age groups experience the impacts of urban forests differently. For children in urban environments, green spaces have been shown to be important for their development (Taylor et al., 1998). Urban forests promote meeting and playing with other children. This study found that, compared to children who played in areas with low vegetation, children who played in areas with high vegetation played "more creatively." Children with access to highly vegetated areas were also seen to have greater access to adults. Both of these factors can help influence a child's development. The impacts of green spaces on community cohesion are experienced differently by adults (Hanson & Frank, 2016). While older members of the community did not particularly report better physical health, they did experience improved social ties, which can be vital for social support and reducing loneliness.

Crime Rates

Tree planting in an area can impact on the local crime rate. Multiple studies have found an inverse relationship between tree cover and crime rate—as tree cover increases, crime rates decrease. One study found a strong negative association between crime and tree cover in Baltimore County and Baltimore City (Troy et al. 2012). As this paper focused specifically on the Baltimore region, it is extremely relevant to this project.

This paper found that tree canopy ranges from zero percent to 87 percent and crime rates ranged from “among the highest in the nation, to near-zero.” Statistical models tested relationships between the percentage of tree canopy cover and crime (Figure 4). These models also considered socio-economic factors such as race, income, and housing type—all factors associated with urban green spaces (Troy et al. 2012). Through these models, it was determined that, after accounting for various socio-economic factors, a 10 percent increase in tree cover would be associated with an 11.8 percent decrease in the crime rate (Troy et al. 2012). These models also suggest that planting trees on public areas may reduce crime more than planting trees on private land. It’s important to note that this study recognizes these results don’t reflect causation between vegetation and crime rate, but instead suggest that further research might determine the specific ways vegetation can decrease crime.

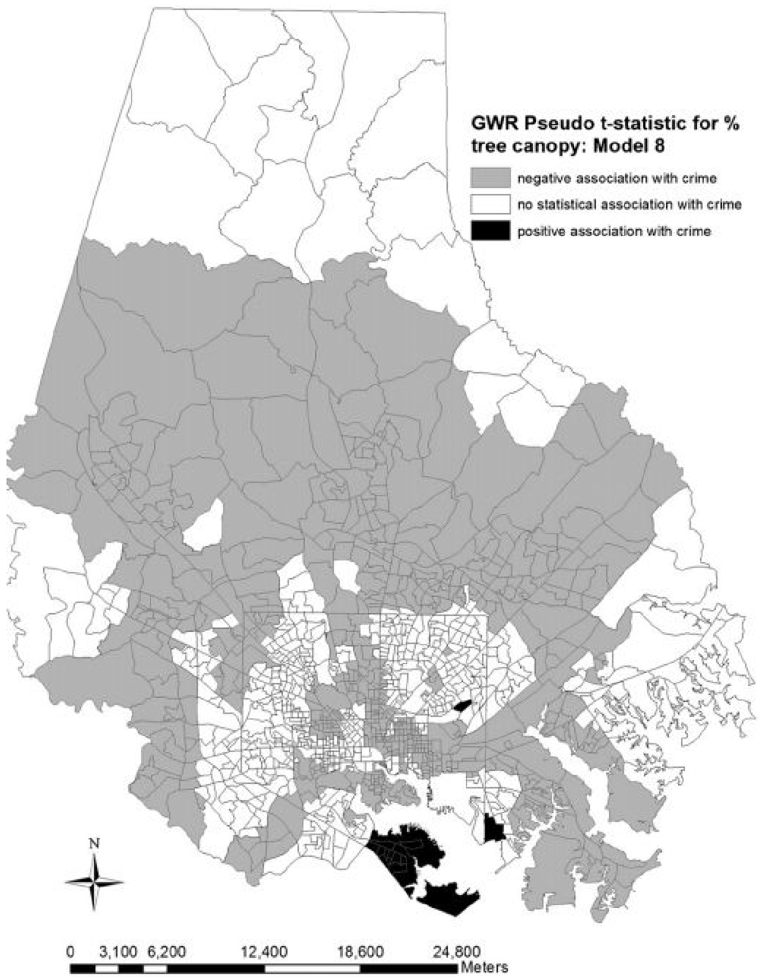

Figure 4: Mapped model results determining the relationship between canopy cover and crime rates by census tract in Baltimore County and Baltimore City (Troy et al., 2012)

A Chicago study of the relationship between vegetation and crime rates analyzed the types of crimes impacted by vegetation rates using methods similar to the Baltimore study. The researchers used statistical models to determine the relationship between vegetation cover and crime rates. Additionally, this study accounted for other factors that impact crime, such as income and employment.

The Chicago study also found that fewer crimes were reported when buildings were surrounded by more greenery (Kuo & Sullivan, 2001). It found that buildings with high vegetation had an overall 52 percent decrease in crime—particularly 48 percent fewer property crimes and 56 percent fewer violent crimes. This study defines property crime as theft or arson, while violent crime is defined as acts such as assault or homicide.

Kuo and Sullivan (2001) studied greenery and the perception of fear, noting that dense vegetation has been linked to a fear of crime. How is it possible that vegetation has been shown to decrease crime, but it can also cause a fear of crime? This study notes that vegetation can lower visibility, therefore making an area appear to be a more appealing location for crime. It also noted that residents perceived properties with trees and shrubs to be safer than those that did not. This shows that while higher levels of vegetation can create a more comforting environment, in order to do so, it should be planted in a way that doesn't impact visibility, such as high canopy trees and low growing shrubs (Kuo & Sullivan, 2001).

Overall, tree planting and green spaces can be useful tools to help communities reduce crime. It is important to note that many factors influence an area's crime rate, and that planting trees is not a panacea. However, with proper planning and planting, vegetation can both reduce crime and create a greater perception of safety in a community.

Distribution of Green Space

Access to green space shows a strong association with social cohesion and decreased crime rates, but green space is not evenly distributed among communities. This is an issue of environmental justice. Often, communities of primarily low-income or minority residents have less access to green space compared to wealthier, whiter communities (Sister et al., 2010). This disproportionate access ranges from poorly maintained parks to areas that are simply dangerous. Marginalized communities already bear a disproportionate weight of environmental stressors, such as pollution and unwanted industry; limited or no access to green space can amplify negative personal or community health impacts.

Zhou and Kim studied this issue by assessing tree canopy area and park access in six mid-sized Illinois cities. In four of the six cities, neighborhoods with large African Americans populations had significantly less tree canopy (Zhou & Kim, 2013). There was also a slight decrease in the amount of tree canopy in neighborhoods of other minority groups. Sister et al. (2010) found an inequitable distribution of public parks in Los Angeles, noting that many properties close to large parks are expensive, so only residents who can afford to live there have access. Most wealthy residents have access to green space in their own backyards, while low-income and high-density neighborhoods are more likely to rely on public green spaces. This study also found that Latino and African American populations were likely to live close to parks that were overcrowded or overused. With limited access to parks and other green spaces, these communities can't experience their social and physical benefits.

Both of these studies recommend remedies to enhance access to green space for these populations. For example, city officials should use decision-making tools to determine areas that need parks and direct funding and resources to those areas (Sister et al. 2010). Developers and urban planners should be informed about ways to distribute tree planting that help ensure equal distribution of green space (Zhou & Kim, 2013).

Economic Findings

For those advocating increased public and private investment in urban forestry, a frequent hurdle is that the cost of tree planting is easier to quantify than their benefits. This is partly because those costs are directly borne by the land manager (Nowak, 2017); planting, removal, pruning and maintenance, repairing lifted sidewalks, damage from fallen branches, damage and injuries from forest fires, and more. Meanwhile, the economic value of those trees don't directly affect the land manager's bottom line, but instead indirectly and gradually accrue to the individual who bears the cost as well as to surrounding residents by providing ecosystem services and improving their health and well-being (Nowak, 2017).

Some of the economic values of trees are difficult to quantify, such as increased tourism, improved recreation, aesthetics, and social and psychological benefits. However, methods to infer and estimate these values exist and are addressed in this and other sections of this report. This section largely focuses on describing the economic benefits and services that have been thoroughly established in the literature based on calculations derived from multiple studies of environmental, economic, and human population data.

The economic benefits are sorted into categories based on who benefits—homeowners, renters and multi-family buildings, employers and employees, government and taxpayers. This approach eliminates a deficiency in existing models and tools—their failure to frame findings in terms of *who specifically* benefits from urban forestry services.

<u>Homeowners</u>

The first category is economic benefits derived by individual urban and suburban homeowners. The principle returns on investment highlighted here are observed property value increases associated with increased urban tree cover. A great deal of research, over several decades, has substantiated this link, by comparing property values with tree cover in US and international communities and across different strata of the real estate market (Dimke, 2008; Morancho, 2003; Martin, 1989; Morales, 1983; Morales, 1980;). What follows is not an exhaustive list, but a few key examples of findings that best illustrate the correlation between urban trees and significantly increased property values and descriptions of methods to quantifying the influence of trees on those values.

For a study of six Cincinnati neighborhoods of varying socio-economic levels data was collected for estimated tree cover, overall property values and overall maintenance costs. A hedonic cost-benefit analysis of 600 sites revealed a marginal benefit of $783.98 per percentage increase in tree cover, and an average value of tree canopy of $20,226, or 10.7 percent of the sale price of the home. The hedonic method is used to evaluate the value of different characteristics of a market good based on the assumption that the sale price of that good represents the sum of the price paid for each of these characteristics. The value of each characteristic can be isolated by observing differences in sale prices of commodities with overlapping attributes (Dimke, 2008).

A 1989 Austin study sought to estimate the financial impacts of *Ceratocystis fagacearum*, the oak wilt fungus, which at the time was affecting trees in 35 Texas counties (Martin et al., 1989). Seeking to assess the costs and benefits of different disease control methods, the researchers used two methods of tree valuation on 120 residential properties. The first, the International Society of Arboriculture (ISA) replacement cost formula from its tree valuation guide, is the most widely used way to determine the monetary value of amenity vegetation. Developed in 1951, the formula incorporates four factors: tree size, species, condition, and location. Location is the most subjective and difficult to evaluate, including aesthetic, functional, and site variables (Tate, 1989). The second method was multiple regression predictive analysis using residential property value as the dependent variable with lot and house characteristics (including tree cover) as independent variables.

The ISA method found tree values to be 13 percent of the appraised property value, while predictive modeling approach found tree value to be 19 percent of appraised value. It should be noted that these findings held true across widely ranging socio-economic levels, with increases in property values observed for properties valued from $30,000 all the way up to $600,000 (Martin et al., 1989).

This correlation is not limited to the United States. Research in Castellón, Spain evaluated 810 residential properties using the hedonic method and found that every additional 100 meters from a “green area” (park or public garden) lowered the value of a property by 1,800 euros. In this study, green space was not found to be a relevant factor in influencing the increase in value (Morancho, 2003), which suggests that homeowners can significantly raise property values by planting trees around their homes.

Renters and Multi-family Buildings

The benefits of increased property values don’t help all urban residents and can be a liability for some low-income renters. To appeal to a wider population, we suggest highlighting the beneficial influence of urban trees on reducing energy costs for heating and air conditioning through ambient temperature regulation. These benefits are well documented in the literature (Sanusi, 2016; Pandit, 2009; McPherson, 2003; McPherson, 1993; Meier, 1991).

On a large scale (city or state), studies have shown trees are cost-effective cooling agents. For example, a California study showed that the state’s existing trees saved a cumulative wholesale value of $485.7 million annually, as well as utility savings of approximately $778.5 million by reducing peak loads by 10 percent annually. Based on these findings, researchers further projected that planting an additional 50 million trees to shade the east and west walls of residential buildings, could realize annual cooling reductions of $3.6 billion over a 15-year period at a $63/kW cost of peak load reduction, less than half the $150/kW benchmark for cost-effectiveness (McPherson, 2003). Estimates of energy saving from urban trees nationwide are approximately 38.8 million Mwh and 246 million MMBtus, which equates to a 7.2 percent reduction in building energy use (Nowak, 2017).

Research substantiating energy savings at the scale of residential buildings is equally if not more abundant. Studies of heating savings from wind speed reduction date to the 1930s and findings range from three to 40 percent. McPherson and Rowntree's (1993) computer monitoring and simulation studies found that a single 25-foot tall tree can reduce heating and cooling costs by eight to 12 percent. Meier (1991) found air-conditioning savings as high as 80 percent, though more commonly 25 to 50 percent.

The amount of energy savings in cooling, and of trees cost effectiveness for this purpose, varies based on a number of factors, including tree placement (west shade is optimal), crown shape and density (greatest savings with broad-spreading crowns and density to cause at least 75 percent light attenuation), and growth rate and longevity (McPherson and Rowntree, 1993). Nonetheless, savings are observed in both dry and humid locations (Meier, 1991), and from both moderate and dense tree cover, though the shading benefits of dense cover are considerably greater; 19.3 percent shading of a residential structure equates to roughly 9.3 percent monthly savings in electricity costs (Pandit & Laband, 2009).

Large amounts of money are at stake here, for communities and individual buildings. If urban residents are more aware of the financial benefits in the form of energy cost savings, they may be moved to more strongly support urban tree planting efforts.

Employers and Employees

This category encompasses benefits to individuals in the workplace, and partly overlaps with the benefits to governments and taxpayers. The most significant overlap is in the job creation potential of urban forestry. A study of economic impacts of the 2009 American Recovery and Reinvestment Act (ARRA), was a cross-industry comparison of job creation per investment, found that "reforestation, land and watershed restoration and sustainable forest management" yielded 39.7 jobs per $1 million investment (17.65 direct, 12.95 indirect, and 9.2 induced). That's more than any of the 20 other industries examined, almost two times greater than the runner-up (crop agriculture, at 22.8) (Edwards, et al., 2013), and almost eight times greater than the number of jobs created per equal investment in the oil and gas industry.

These sustainable urban forest management jobs—foresters, nursery botanists, machinery technicians, or laborers to transport and plant new trees (Rudee, 2020)—represent long-term, semi-permanent and permanent additions to the workforce, as opposed to the limited timelines typical of other infrastructure projects (Edwards et al., 2013). In total, the World Resources Institute projects that 150,000 new jobs could be created every year by a $4-4.5 billion annual investment in tree restoration and maintenance (Rudee, 2020).

One lesser-known benefit of urban trees, but one of significant interest to business owners and retail workers, is their documented effect on consumer behavior. Psychometric and econometric surveys analyzing consumer responses to tree densities in business districts show significant increases in "shopper patronage behavior," a variable aggregating willingness to travel to business districts, visitation pattern, and willingness to pay (both for parking and consumer products) (Wolf, 2005). A survey study of Los Angeles, Washington DC, Chicago, Portland, and Pittsburgh found consumers were willing to pay an average of 40.9 percent more for three classes of products and services (convenience goods: 38.5 percent; shopping goods: 49.7 percent; specialty goods: 34.5 percent) in districts with trees vs. those with no trees (Wolf, 2003).

Consumer purchases represent about two-thirds of the US economy (Wolf, 2003), and these findings suggest that urban forest canopy should be viewed as a central component of that market. In the same way retailers invest in product packaging and placement inside their stores, they should be made aware of the benefits of investing in more natural settings that also influence the perceived value of their products.

Another benefit of urban trees that is indirect but has massive financial implications for businesses and employees (as well as for the national budget) is the reduction of healthcare costs. The US spent approximately $3 trillion on healthcare expenses in 2014 (Centers for Medicare and Medicaid Services, 2014). In perspective, a one percent reduction in healthcare costs (a $30 billion savings) would match the savings achieved by a 22 percent marginal reduction in residential heating and cooling costs and a 53 percent reduction in stormwater management costs (Donovan, 2017), two other prominently cited benefits of urban trees.

There are four primary ways trees improve public health: improved air quality, increased exercise, reduced stress, and improved social connections (Hystad et al., 2014). The effects of the first three can be objectively quantified.

Trees remove air pollution through their leaf stomata and by intercepting particles on leaf surfaces. A 2010 estimate of these effects found that US urban forests removed 651,000 metric tons of air pollution (Nowak, 2017). A review of 14 cross-sectional and modeling studies of the impacts of urban trees and forests in reducing harmful health effects of air pollutants (such nitrous oxide, ozone, sulfur dioxide, cadmium, PM2.5, and others) found positive health outcomes in all cases, and associated health-care cost-savings. These outcomes included reduced mortality, lower incidences of lung cancer, lower prevalence of childhood asthma, and reduced incidences of asthma hospitalization (Wolf et al., 2020).

Urban tree impacts on stress levels have been documented by sampling of cortisol levels of urban residents as a biomarker of stress. An exploratory study by Thompson et al. (2012) took saliva samples from urban residents in under-served communities and found significant relationships between self-reported stress ($P<0.01$), diurnal patterns of cortisol secretion ($P<0.05$), and the amount of green space in subjects' living environments. They also found the percentage green space was a significant independent predictor of subjects' circadian cortisol cycle. These results are supported by other studies finding positive associations with increased green space and restorative mental health effects (Hartig & Staats, 2006, Roe & Aspinall, 2011).

The association of greater urban greenspace with increased proclivity for exercise has also been replicated in several studies. A Bristol, England study measured access to green space and frequency of use, physical activity, and probability of being overweight and found that respondents living closest to green spaces were most likely to achieve the recommended levels of physical activity and least likely to be overweight or obese (Coombes et al., 2010). Hartmann et al (2007) surveyed residents of Zurich, Switzerland to assess the restorative effects of urban forests and city parks and found exposure to these spaces was associated with significant decreases in headaches and stress (87 percent and 52 percent respectively). These positive effects were magnified by increased participation in sports and, to a lesser degree, in less strenuous forms of exercise such as walking.

To connect these findings of reduced stress and increased exercise to their financial and healthcare implications, it is well established that a lack of exercise is a major cause of chronic diseases, including but not limited to sarcopenia, metabolic syndrome, obesity, insulin resistance, prediabetes, type 2 diabetes, non-alcoholic fatty liver disease, and coronary heart disease (Booth et al., 2012). In 2014, the CDC reported that approximately 655,000 Americans were dying each year from coronary heart disease. Approximately $219 billion was spent combating the disease that year alone. By 2020, annual direct medical costs associated with cardiovascular diseases are projected to reach $818 billion, with productivity losses exceeding $275 billion (CDC Foundation, 2015). Even marginal reductions in these figures would represent huge decreases in loss of life and cost savings for individuals and the country as a whole.

Governments and Taxpayers

The biophysical benefits of trees, such as carbon sequestration and stormwater management, are the most frequently cited justifications for investment in urban forestry. They are so frequently invoked because they're understandable and easy to quantify. But they've been so widely publicized (e.g., i-Tree platform) that repeating them may lack persuasive force. Nonetheless, the financial benefits in this area can't be ignored in any comprehensive cost-benefit analysis or marketing campaign for urban forestry.

There is broad scientific consensus that humans need to significantly reduce concentrations of atmospheric and oceanic carbon dioxide (commonly referred to "drawdown") to avoid the most dangerous and costly consequences of climate change (IPCC, 2014). Toward that end, a multitude of technologies have been deployed and billions of tax dollars spent, with varying success. The most effective technological alternative to tree-planting for drawdown is Carbon Capture and Storage (CCS), which consists of three steps: separating CO2 from other gases in electricity generation, transporting the CO2 via pipeline or ship, and sequestering it as liquid in porous geological formations typically located several kilometers below the earth's surface. This process is extremely expensive. There are about a dozen large-scale CCS facilities in the US, and although the technology effectively reduces carbon emissions—coal-fired generators retrofitted with CCS emit approximately 90 percent less carbon dioxide (Irlam, 2017)—they are not the most cost-effective solution.

A single CCS facility can cost more than $7.5 billion (Irlam, 2017) and in combination, all the CCS facilities in the US can only capture 25 million tons of CO2 per year (Beck, 2020). By comparison, the World Resources Institute projects that a $4-4.5 billion annual investment in reforestation and sustainable forestry management could remove up to 540 million tons of carbon dioxide per year. That translates to removing approximately 10 percent of annual US emissions at a cost of less than $10 per ton (Rudee, 2020).

Benefits in stormwater flow and water quality are more modest, but not insignificant. Historically, green infrastructure has focused on infiltration-based solutions such as rain gardens, bioswales, and permeable pavements. While soil provides the majority of stormwater volume control by storing water temporarily in micro and macro-pore spaces, trees play a key role by intercepting, retaining, and transpiring significant amounts of rainfall in their canopy, helping reduce rainfall intensity, delaying peak runoff rates, and preventing the soil and reservoirs from being overwhelmed (USDA, 2020). A medium-sized tree intercepts an average of 2,300 gallons of stormwater runoff per year, absorbing about a third of the precipitation from a typical rain event in their leaves and trunks alone (Moore, 2009). Moreover, tree roots mechanically, biologically, and chemically condition the soil to increase its storage capacity (USDA, 2020). Treed landscapes can have infiltration rates 10 to 15 times greater than those without trees (Moore, 2009). These hydrological effects can also improve human health by reducing illness related to sediments and reducing chemicals and pathogens entering waterways; trees remove metal, nitrates, phosphorus, and potassium from polluted runoff (Moore, 2009).

Numerous studies have quantified the financial benefits of urban trees in stormwater regulation, usually as part of a cost-benefit analysis incorporating other biophysical benefits and ecological services. A Washington, DC study found the city saves $3,695,873 annually as a result of urban trees role in stormwater mitigation, with models showing they could save an additional $1.4 to $5.1 million annually in reduced sewage pumping and treatment costs by implementing additional urban forestry practices (Foster et al., 2011). A Modesto, California study examined whether the city's annual investment of approximately $2 million in planting and maintaining its urban forests was justified by the benefits those trees provided (McPherson, 1999). Researchers found that the market value of the ecological services exceeded the planting and management costs by a factor of nearly two to one, with total annual benefits of $4.95 million ($27.12/resident, $54.33/tree) of which $7/tree resulted from reductions in stormwater runoff ($616,000 total, 845 gal/tree).

Quantifying Non-Market Values

As described in the introduction, some benefits of urban tree planting, such as aesthetic benefits, are difficult to convey in monetary terms. Here we provide an overview of various approaches researchers take to measuring the market benefits of non-market values (Figure 5).

	Market	**Consumer**	**Method**
Contingent Valuation	Hypothetical	Hypothetical	Quantifies through surveys of willingness to pay for or to accept changes in levels of environmental goods and services
Travel Cost	Hypothetical	Real	Quantifies by observing willingness to pay costs associated with obtaining environmental goods and services
Hedonic Pricing	Real	Real	Uses multiple regression analysis to estimate implicit values of different real estate attributes

Figure 5: Three methods of estimating the monetary value of non-market goods and services or non-market attributes of market goods and services.

However, much of the historical application of these methods to urban tree valuation has been in the context of court cases and insurance claims, to determine compensation for damage or removal of amenity trees. Understandably, they've often failed to capture the value of ecological services and other benefits of urban trees.

Other systems have been developed specifically to capture these benefits and provide a holistic valuation of each tree's dollar value to a city (Figure 6).

Method	Description
Helliwell System	Used to estimate the monetary value of amenity trees, it simplifies valuation by allocating arbitrary point scores to attributes such as tree size, life span, suitability, and setting and using a monetary conversion factor to derive a price per tree from the scores. It caps the value of a single tree at 127,590 GBP
CAVAT System (Capital Asset Valuation of Amenity Trees)	Calculated based on a tree's trunk area, nursery price, planting costs (transport, planting, materials, care, and management), population density, (how many people will benefit), public accessibility, crown health, and assumed life span.

Figure 6: Methods used to estimate the value of individual amenity trees

Unfortunately, these models introduce their own blind spots by relying on generic measurement systems or fixed parameter averages.

VI. Recommendations

Tree Co-benefit Calculators

To successfully use the i-Tree Design model, it needs to fit within the GBWC framework. We recommend integrating the tool within GBWC's regional green infrastructure map. The model could be located on the left panel, next to resilience maps, or embedded within the resilience maps. A drop-down menu of community tree planting locations could be updated and used by residents and GBWC to track tree growth and benefits.

We recommend that GBWC use or base their tree calculator model on i-Tree Design for residential tree planting records and benefit calculations. i-Tree products are the industry standard and encompass a majority of the market. They are a simple and efficient tool for homeowners to easily quantify both new and old trees. Digital trees can be placed in community locations to illustrate strengthened social cohesion and awareness.

Unfortunately, tree co-benefit calculators don't cover difficult-to-quantify benefits such as economic benefits, physical and mental health, and community benefits. We propose three solutions. First, these benefits could be added to either the "Our Approach" or "Get Involved" sections on GBWC's main page. Second, they could be listed on the side panel of the regional green infrastructure map inside the "Background and Definitions" tab. Third, they could be listed but not quantified on the tree benefits spreadsheet.

Not everyone is willing to or able to enhance their surroundings with green space. To overcome this, we suggest using a donation feature, similar to Trees for the Future, to help individuals offset their carbon footprint. This would not only increase funding for GBWC's regional green infrastructure goals but is a way for locals to improve the quality of life for residents and visitors in Central Maryland.

Mental Health

Because expressing health benefits in numbers may not resonate with all users, a more viable option could be to visually interpret the information. Many organizations, such as the United Nations Food and Agriculture Organization, create simple images to summarize the health benefits of urban trees; these could be adapted to focus on the non-quantifiable aspects of tree canopy (Figure 7).

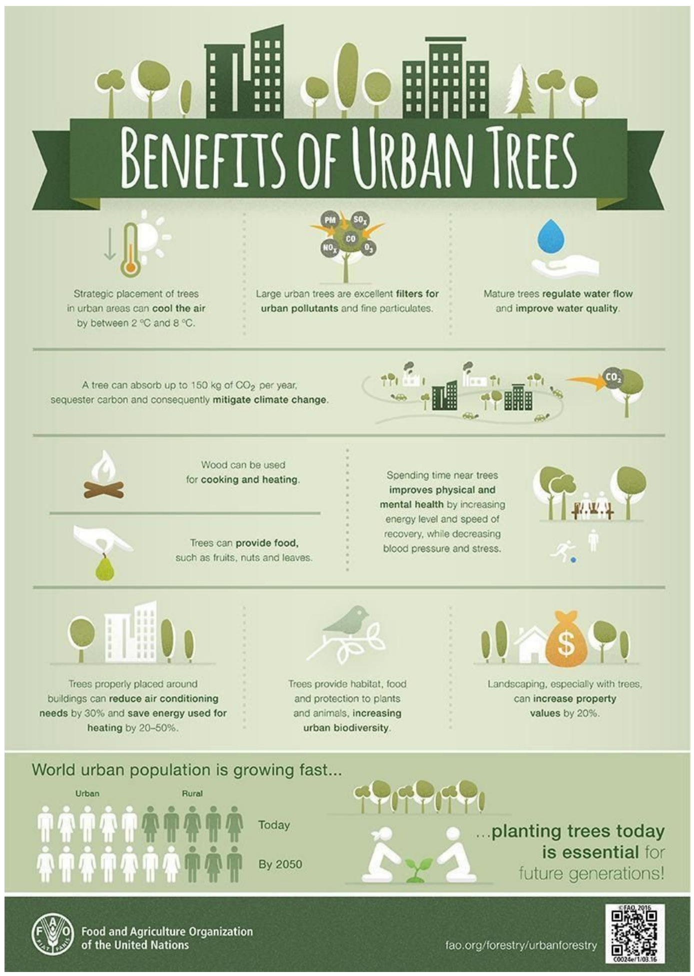

Figure 7: Diagram from the UN Food and Agriculture Organization illustrating the benefits of urban trees (FAO, 2016)

Another engaging option would be to create an interactive image that allows users to choose which information they want to learn. A photo of Baltimore, for instance, could be used along with the links to mental health and community benefit information (Figure 8).

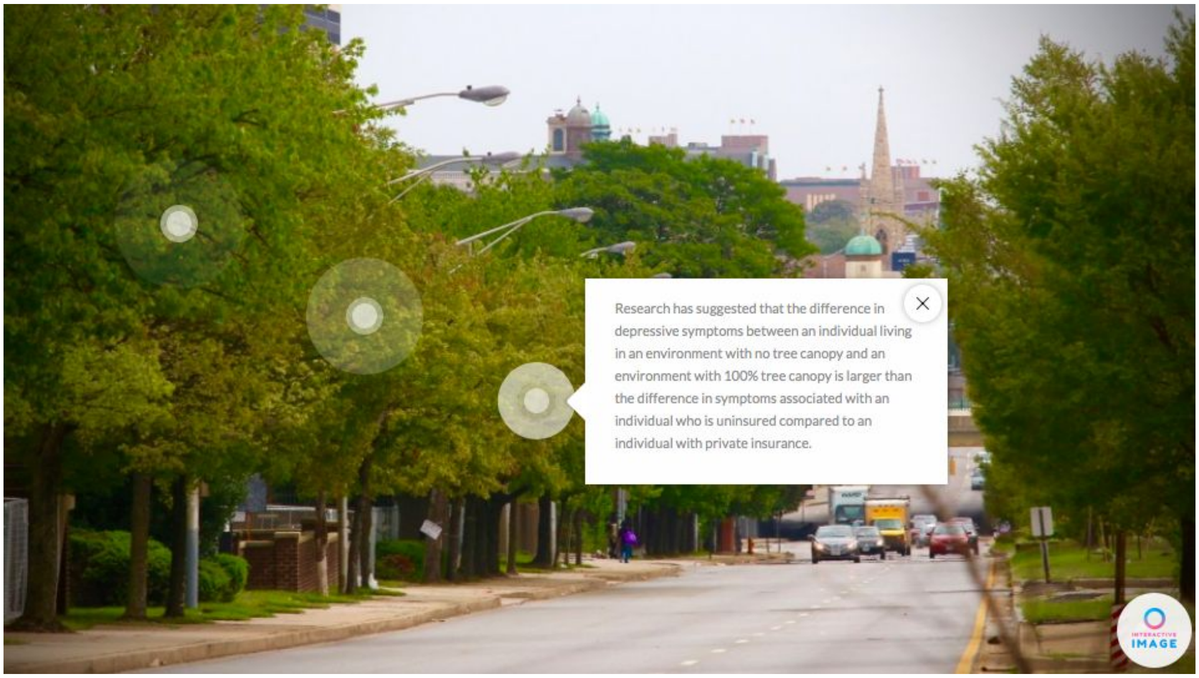

Figure 8: Original image edited to show how photos can be used to engage viewers and better convey the health benefits of urban forestry (Simon, 2015)

A final option could be to include a pictorial representation of forestry (Figure 9). For example, users are presented with a series of comparative images and asked which ones they prefer. After the slideshow is concluded, participants should be presented with information regarding the health benefits of trees.

Figure 9: Indicates that different responses can exist between similar photographs based on the presence of tree canopy (Conniff, 2012)

Any of these options can be integrated into GBWC's existing platform. Similar to the "Background and Definitions" section of the webpage, mental health benefits could be integrated to display additional information alongside the tree calculator tool (Figure 10).

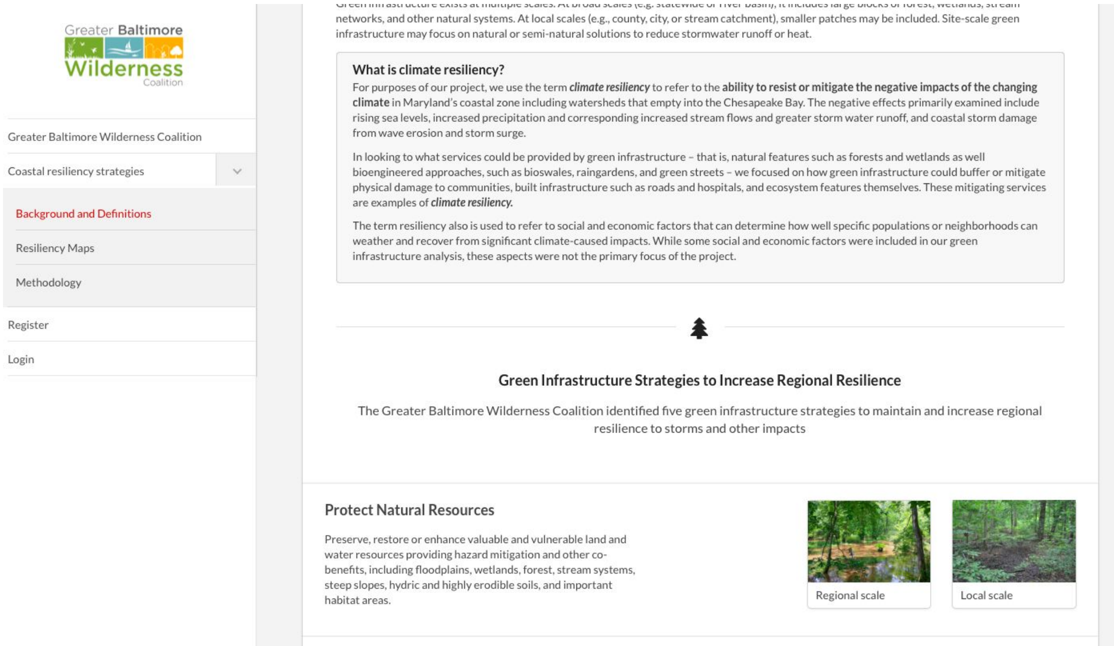

Figure 10: A mental health benefits section can be integrated into the GBWC's existing platform

Physical Health

One way to engage users in physical health issues would be to incorporate physical health facts and statistics to the tool. This is not a benefit that can be easily quantified, so drawing users in with intriguing statistics may create an incentive for them to look deeper into the tool and planting trees in general. One way to do this would be to link to a page of facts and statistics interpreted in a colorful and engaging graphic form. Also, linking to a new page will give the calculator a smoother look rather than trying to force everything onto one page and overwhelming the user. Creating an inviting, insightful section should engage users and give them a reason to use the website's resources.

Social Cohesion

Including community factors in a new calculator could be done two ways. First, as with physical and mental health, include information that engages consumers and residents. Information could include how different demographic groups experience a variety of benefits from green spaces or the varied activities that green spaces accommodate.

The second way would be to provide developers and community planners with the information to make informed decisions about tree planting and creating green spaces. Information could include how many trees would help reduce an area's crime rate. Community planners can also develop programs to increase community involvement in tree planting programs that help communities create stronger bonds between residents as well as improving overall community health.

Combining these strategies would be more effective than one alone. A well-informed population can advocate for more green spaces and programs from their governments. These governments must then make well-informed decisions that will satisfy the needs of their citizens.

Economic

Not everyone has the resources to plant or maintain green space on their property. To overcome this, we suggest using a donation feature, similar to Trees for the Future, to help individuals offset their carbon footprint. This would not only increase funding for GBWC's regional green infrastructure goals but offer a way for locals to improve the quality of life for residents and visitors in Central Maryland.

To encourage donations, it would be beneficial to incorporate a calculator of specific financial returns for individuals or groups, such as air quality improvements and stormwater management. Individuals could then point to a personal return on an investment or donation by framing microclimatic and temperature regulation benefits compared with individual energy cost-savings for residents who plant and maintain trees on their property.

The approach of reducing *all* of the diverse economic benefits of urban trees to a dollar value per tree is misguided in many cases. While "bulk-packaging" benefits may be valuable for some purposes, it fails to distinguish specific benefits to specific parties, and therefore has limited use for influencing policy or public funding allocation, or for attracting private investment from financial beneficiaries who might fund urban forestry. Unfortunately, we lack mainstream public-sector fundraising mechanisms to promote projects that consider multiple and disparate groups of beneficiaries.

Therefore, we recommend that the calculator be configured to clarify the proportion of financial benefits accruing to individual interest groups that benefit from each diffuse ecological, aesthetic, or environmental value outlined in the economic findings section of this report.

VII. Conclusion

Our research, which aimed to elicit the interest of residents in Baltimore County, Baltimore City, and Howard County about tree planting, has demonstrated that tree canopy is positively correlated with improvements to mental and physical health, social cohesion, and the economy. Consequently, all these elements should be incorporated into one tool.

An abundance of research exists that supports a positive association between mental and physical health and tree canopy, including reduced levels of depression, anxiety, stress, asthma, lung cancer, and the likelihood of experiencing a heat-induced illness, as well as an increase in an individual's reported amount of exercise. Green space can increase community cohesion and create a stronger bond through community gardens and extra space for outdoor activities. Lastly, tree canopy has been shown to positively influence the economy by increasing residential property values for and decreasing heating/cooling costs.

A tree co-benefit calculator, such as the i-Tree Design, can be used to accomplish Planting the Future's mission of increased participation. These calculators offer the best framework for residential tree benefit calculations. They generate quantified analysis of stormwater runoff, energy savings, air quality and carbon reduction that trees bring to an area. Although assigning a dollar value to a single tree may not be appropriate, the aggregate monetary benefits of tree canopy can be quantified and incorporated along with the traditional co-benefits. Since research does not yet exist which can quantify mental and physical and social benefits, these qualitative features should be separated, but added alongside the environmental benefits to augment the educational aspect of the tree calculator.

Combining these factors along with traditional features will give users the chance to explore a calculator that demonstrates all of the benefits of tree planting and may encourage them to plant some of their own.

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