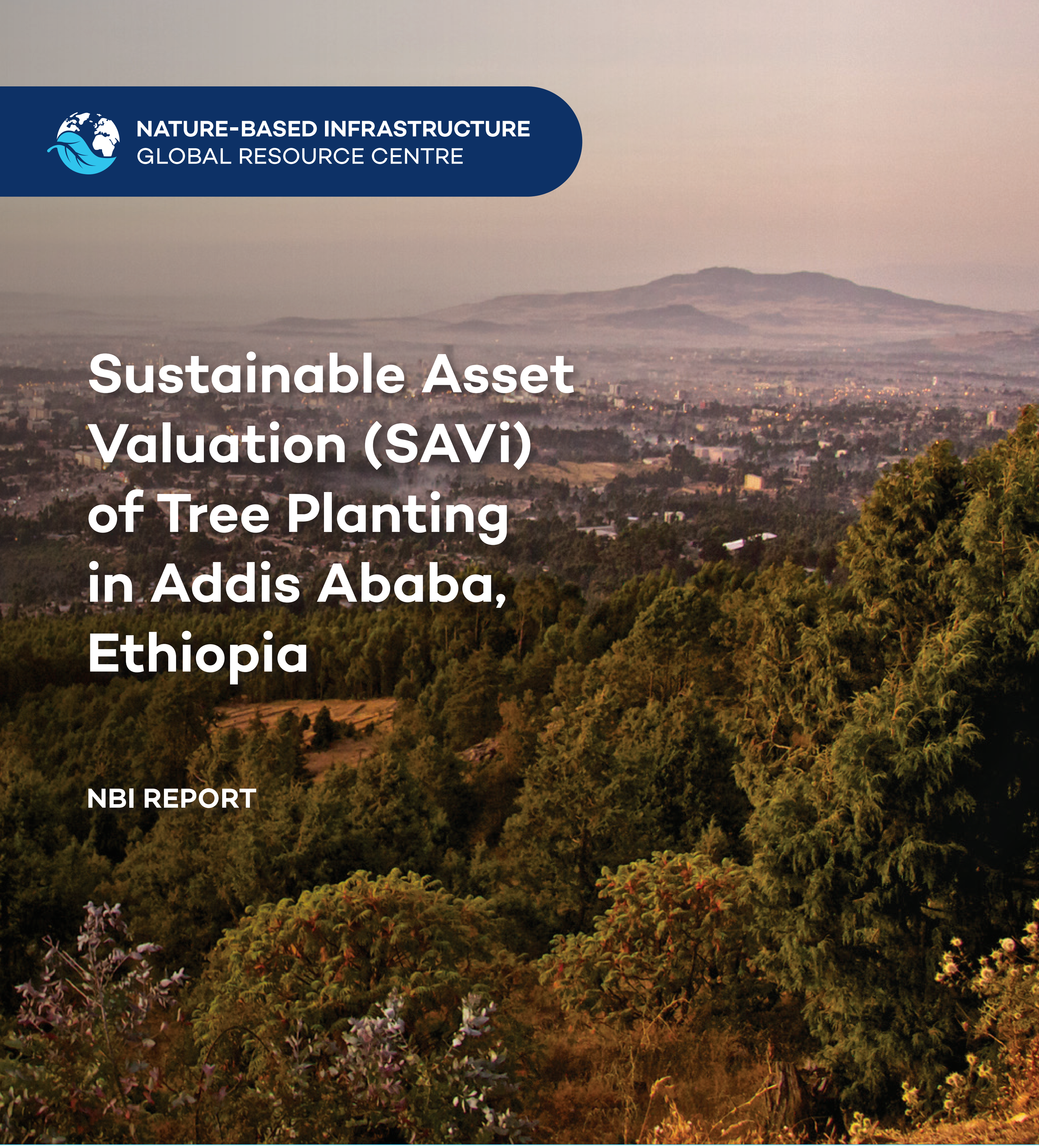

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Sustainable Asset Valuation (SAVi) of Tree Planting in Addis Ababa, Ethiopia

NBI REPORT

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Sustainable Asset Valuation (SAVi) of Tree Planting in Addis Ababa, Ethiopia

March 2022

Written by Emma Cutler, Matthew Gouett, and Marco Guzzetti

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About the Nature-Based Infrastructure Global Resource Centre

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Executive Summary

Since the 1980s, Addis Ababa has lost large amounts of vegetation as impervious surfaces have been expanded. This has created urban heat islands, made the city more susceptible to flooding, and removed a means of improving air quality. Climate change is expected to exacerbate heat and flooding, while air pollution has increased over the past 50 years and is projected to continue to worsen. In response to these environmental and climate stresses, the city plans to plant 25 million trees over 5 years starting in 2021. This effort is part of the national Green Legacy Campaign, launched by Prime Minister Abiy Ahmed with the goal of planting 20 billion seedlings in urban and rural locations over 4 years (Getahun, 2020).

This report presents the results of a Sustainable Asset Valuation (SAVi) assessment for tree planting in Addis Ababa, Ethiopia. We use a spatial analysis to quantify and value the carbon storage, urban flood risk mitigation, and urban cooling services provided by trees. We combine these results into an integrated cost-benefit analysis and calculate the net present value (NPV) and internal rate of return (IRR), both with and without social and environmental externalities.[1]

We simulate four tree planting scenarios. We use the planned 25 million trees as a high estimate for the number of trees that can be planted. Eleven million trees were planted in 2021, so we also include scenarios that assume no additional trees are planted. Thus far, the city has reported an 84% survival rate after the first year. We, therefore, use this as an optimistic survival rate and include a pessimistic survival rate of 30%. We assume that the survival rate is directly related to the percentage of trees maintained, and so include maintenance percentages of 50% and 25%. These scenarios are presented in Table ES1.

We also consider two projections for heat waves and runoff over the next 20 years, using outputs from two climate change scenarios.

Table ES1. Tree planting scenarios

Tree scenario	Number planted (millions)	Survival rate	Number surviving (millions)	Percentage maintained	Number maintained (millions)
High trees planted, high maintenance/survival	25	84%	21	50%	12.5
High trees planted, low maintenance/survival	25	30%	7.5	25%	6.25
Low trees planted, high maintenance/survival	11	84%	9.24	50%	5.5
Low trees planted, low maintenance/survival	11	30%	3.3	25%	2.75

[1] When we include these externalities, we refer to the calculations as sustainable NPV (S-NPV) and sustainable IRR (S-IRR), The S-NPV is the difference between the present value of benefits and avoided costs net of financing costs and the present value of cash outflows. The S-IRR is the discount rate that makes the NPV of benefits from a particular project equal to zero.

Key findings from the analysis are:

- Tree planting can avoid costs of air pollution, flooding, and heat. Thus, trees increase climate resilience while also sequestering carbon.
- Considering only cash flows, the benefits of tree planting do not outweigh the costs. However, when accounting for direct value created for the local community and the avoided costs from air pollution, flooding, heat, and greenhouse gas emissions, trees have positive net benefits (up to ETB 1.8 billion [USD 40 million], undiscounted, over 20 years) (see Table ES2). This highlights the importance of including intangible impacts as part of a systemic valuation of nature-based infrastructure (NBI).
- Ensuring that planted trees survive by investing in maintenance generates more value than planting more trees with low maintenance/survival. The analysis shows that increasing the survival rate from 30% to 84% raises the undiscounted benefit-to-cost ratio by between 0.17 (from 1.17 to 1.34 for 25 million trees planted) and 0.22 (from 1.2 to 1.42 for 11 million trees planted) (see Table ES2).
- Trees provide more value for money and create more jobs than installing rainwater harvesting tanks and replacing diesel/petrol cars with electric vehicles. Even with a large enough investment, these grey infrastructure alternatives may not be able to provide the same services as trees in Addis Ababa.
- Financially, the NPV is negative when considering only cash flows. On the other hand, when accounting for all outcomes of tree planting, the S-NPV of each tree planting scenario is positive and ranges between ETB 200.0 million and ETB 1,345.45 million (USD 4.4 million and USD 29.6 million, respectively) when including the same costs and benefits as the integrated cost-benefit analysis. Specifically, the S-NPV is about four times larger when we assume 84% of trees survive and account for the continued maintenance of 50% of the planted trees than if we assume a survival rate of 30%, and only 25% of the trees are maintained (see Table ES3).
- The S-NPV and S-IRR of trees are much higher than the S-NPV and S-IRR of the corresponding grey infrastructure alternative. The S-NPV of rainwater harvesting tanks and electric vehicles is negative. The IRR is, on average, at least 32.2% for trees and 8.3% for comparable grey infrastructure (see Table ES3). These calculations for grey infrastructure include impacts on water supply, job creation, air quality, flooding, heat, greenhouse gas emissions, and fuel costs.

Table ES2. Undiscounted integrated cost-benefit analysis using temperature and runoff projections from a low climate change scenario. In all planting and survival scenarios, trees provide positive net benefits if the avoided costs are valued. Increasing maintenance and survival raises net benefits and the benefit-to-cost ratio.

	25 million trees planted		11 million trees planted	
Tree survival rate	84%	30%	84%	30%
Total surviving trees (million)	21	7.5	9.24	3.3
Added Benefits				
Fruit production (million ETB)	607	217	293	105
Planting wages (million ETB)	95	95	42	42
Maintenance wages (million ETB)	3,335	1,668	1,584	792
Total added benefits (million ETB)	**4,037**	**1,979**	**1,919**	**938**
Avoided Costs				
Mortality from air pollution (million ETB)	215	77	100	36
Flood damages to property (million ETB)	80	42	49	22
Mortality from flooding (million ETB)	224	119	136	60
Bus fares due to decreased walkability (million ETB)	55	45	51	25
Carbon sequestration (million ETB)	1,966	893	1,023	433
Total avoided costs (million ETB)	**2,539**	**1,175**	**1,359**	**576**
Added benefits + avoided costs (million ETB)	**6,577**	**3,155**	**3,278**	**1,514**
Direct costs				
Planting costs (million ETB)	500	500	220	220
Maintenance costs (million ETB)	4,400	2,200	2,090	1,045
Total direct costs (million ETB)	**4,900**	**2,700**	**2,310**	**1,265**
NET BENEFITS (MILLION ETB)	**1,677**	**455**	**968**	**249**
BENEFIT-TO-COST RATIO	**1.34**	**1.17**	**1.42**	**1.20**
BENEFIT-TO-COST RATIO EXCLUDING AVOIDED COSTS	**0.82**	**0.73**	**0.83**	**0.74**

We find that if trees are maintained they provide more value for money than grey infrastructure alone that provides the same flood, air quality, and carbon benefits. Specifically, we assess electric vehicles, which reduce air pollution and carbon emissions, and rainwater harvesting tanks to mitigate runoff. In this analysis, we also consider the benefits of lower fuel costs when diesel and petrol cars are replaced with electric ones and the added value of water collected in tanks. Although grey infrastructure provides these additional benefits, the undiscounted benefit-to-cost ratio of trees, when maintained, is approximately 10%–20% higher than that of the electric vehicles and rainwater harvesting combined.

Furthermore, it may not be technologically feasible to install the capacity of grey infrastructure needed to provide those services in the city context. For example, to achieve the same greenhouse gas emissions reductions that trees provide, it would be necessary to rapidly replace a large share of the diesel and petrol vehicles in the city. This would require investments from households, the private sector, and the government to purchase electric vehicles and build the necessary physical infrastructure (e.g., charging stations). Additionally, we have not identified a possible alternative investment that could mitigate outdoor air temperatures.

Upon extending the integrated cost-benefit analysis to account for inflation as well as the time value of money, we estimated the sustainable net present value (S-NPV) and sustainable internal rate of return (S-IRR) under the different climate scenarios and tree planting/survival scenarios. For these calculations, the avoided costs and added benefits of tree planting and grey infrastructure alternatives are accounted as revenue streams of the project. These results are presented in Table ES3. When excluding avoided costs and added benefits that do not generate cash flows, the NPV is negative, and the investment would be considered not financially viable.

Table ES3. S-NPV and S-IRR for the four tree planting scenarios using the low climate change projection. All monetary values in 2021 million ETB.

NBI alternative	25 million trees planted		11 million trees planted	
Tree survival scenario	**84%**	**30%**	**84%**	**30%**
S-NPV	1,345.5	336.4	822.7	200.0
S-IRR[2]	87.4%	32.2%	106.2%	37.0%
Grey alternative (electric vehicles and rainwater harvesting)				
S-NPV	-563.6	-259.1	-295.5	-127.3
S-IRR	8.3%	8.3%	8.3%	8.3%

These financial indicators support the conclusions from the integrated cost-benefit analysis. That is, when externalities are considered, trees provide considerable societal value, and financially, trees perform better than grey infrastructure. They are a cost-effective way to address urban heat, improve air quality, reduce flooding, and mitigate carbon emissions, particularly when the survival rate is high.

[2] Note that IRR calculations for tree survival scenarios were adjusted so that initial investments were made in year prior to realization of benefits.

Table ES4. How stakeholders and decision-makers can use the results

Stakeholder	Role in the project	How can the stakeholder use the results of the assessment?
World Resources Institute (WRI)	Convene stakeholder meetings to inform project implementation	WRI will disseminate results to the Cities4Forests and Urban Water Resilience communities of practice, the WRI Nature-based Solutions and Ethiopia programs, the Addis Ababa River Basin and Green Area Development Management Agency, and the Addis Ababa Environment, Forest, and Climate Change Commission.
Addis Ababa city government	Plant and maintain trees	This report can inform improved implementation of the Addis Ababa Green Legacy program. For example, the Addis Ababa River Basin and Green Area Development Management Agency and the Addis Ababa Environment, Forest, and Climate Change Commission can use the results to estimate the impacts of large-scale tree planting in the city.
Civil society organizations	Support tree planting and maintenance	For civil society organizations, the results can support NBI advocacy that supports climate adaptation and mitigation. For example, the analysis shows that ensuring planted trees survive increases the value of the investment; civil society organizations may be able to promote maintenance activities.
Investors/ donors	Fund tree planting and maintenance	Investors and donors can use the results of this assessment to inform decisions about funding climate adaptation and mitigation. For example, the assessment shows that trees are a more feasible way to reduce carbon dioxide (CO_2) and air pollutant emissions than electric vehicles and provide more co-benefits than rainwater harvesting for flood mitigation.

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Glossary

Causal loop diagram: A schematic representation of key indicators and variables of the system under evaluation that shows the causal connections between them and contributes to the identification of feedback loops and policy entry points.

Discounting: A finance process to determine the present value of a future cash value.

Indicator: Parameters of interest to one or several stakeholders that provide information about the development of key variables in the system over time and trends that unfold under specific conditions (United Nations Environment Program [UNEP], 2014).

Internal rate of return (IRR): An indicator of the profitability prospects of a potential investment. The IRR is the discount rate that makes the net present value of all cash flows from a particular project equal to zero. Cash flows net of financing give us the equity IRR.

Integrated Valuation of Ecosystem Services and Tradeoffs (InVEST): "A suite of models used to map and value the goods and services from nature that sustain and fulfill human life. It helps explore how changes in ecosystems can lead to changes in the flows of many different benefits to people" (Natural Capital Project, 2019).

Methodology: The theoretical approach(es) used for the development of different types of analysis tools and simulation models. This body of knowledge describes both the underlying assumptions used as well as qualitative and quantitative instruments for data collection and parameter estimation (UNEP, 2014).

Model transparency: The degree to which model structure and equations are accessible and make it possible to directly relate model behaviour (i.e., numerical results) to specific structural components of the model (UNEP, 2014).

Model validation: The process of assessing the degree to which model behaviour (i.e., numerical results) is consistent with behaviour observed in reality (i.e., national statistics, established databases) and the evaluation of whether the developed model structure (i.e., equations) is acceptable for capturing the mechanisms underlying the system under study (UNEP, 2014).

Net benefits: The cumulative monetary benefits accrued across all sectors and actors over the lifetime of investments compared to the baseline, reported by the intervention scenario.

Net present value (NPV): The difference between the present value of cash inflows net of financing costs and the present value of cash outflows. It is used to analyze the profitability of a projected investment or project.

Optimization: A stream of modelling that aims to identify the policy or set of policies that deliver the best possible outcome from a set of alternatives, given a set of criteria (i.e., parameters to optimize) and/or constraints (i.e., available budget) (UNEP, 2014).

Scenarios: Expectations about possible future events used to analyze potential responses to these new and upcoming developments. Consequently, scenario analysis is a speculative exercise in which several future development alternatives are identified, explained, and analyzed for discussion on what may cause them and the consequences these future paths may have on our system (e.g., a country or a business).

Simulation model: Models can be regarded as systemic maps in that they are simplifications of reality that help to reduce complexity and describe, at their core, how the system works. Simulation models are quantitative by nature and can be built using one or several methodologies (UNEP, 2014).

Sustainable internal rate of return (S-IRR): An indicator of the net benefit prospects of a potential investment. The S-IRR is the discount rate that makes the net present value of benefits from a particular project equal to zero.

Sustainable net present value (S-NPV): The difference between the present value of benefits and avoided costs net of financing costs and the present value of cash outflows. It is used to analyze the net value of a projected investment or project.

1.0 Introduction

Since the 1980s, Addis Ababa, Ethiopia, has lost large amounts of vegetation as impervious surfaces have been expanded (Arsiso et al., 2018; Balew & Semaw, 2021; Dissanayake et al., 2019; Teferi & Abraha, 2017). This has created urban heat islands, made the city more susceptible to flooding, and removed a means of improving air quality. Climate change is expected to exacerbate heat and flooding in the city (Niang et al., 2014), while air pollution has gotten worse over the past 50 years and is projected to continue declining (Addis Ababa Environmental Protection and Green Development Commission, 2021; Singh et al., 2020).

In response to these environmental and climate stresses, the city plans to plant 25 million trees over 5 years starting in 2021. This effort is part of the national Green Legacy Campaign, launched by Prime Minister Abiy Ahmed with the goal of planting 20 billion seedlings in urban and rural locations over 4 years (Getahun, 2020). Trees will be located across all sub-cities within Addis Ababa. This area covers 56,868 hectares and, as of 2021, has a population of 5.006 million (assumed to be 2.383 million men and 2.623 million women, based on city gender distribution from the 2007 census) (Population Census Commission, 2008; United Nations, Department of Economic and Social Affairs, Population Division, 2018).

This report presents the results of a Sustainable Asset Valuation (SAVi) for tree planting in Addis Ababa. The report will inform city tree planting undertaken by the Addis Ababa River Basin and Green Area Development Management Agency and the Addis Ababa Environment, Forest, and Climate Change Commission. It will complement the recommendations and outputs of the Cities4Forest and nature-based solutions initiatives of the World Resources Institute (WRI). Throughout the assessment, we have coordinated with WRI staff, who will share the results with the Cities4Forest community of practice.

SAVi incorporates social and environmental externalities to holistically assess infrastructure investments. In this assessment, we use a spatial analysis to quantify and value the carbon storage, urban flood risk mitigation, and urban cooling services provided by trees. We combine these results into an integrated cost-benefit analysis and calculate the net present value (NPV) and internal rate of return (IRR), both with and without social and environmental externalities. Below, we briefly introduce the co-benefits included in the assessment. Our methods are explained in Section 2, and we present and discuss results in Section 3.

1.1 Addis Ababa Air Quality

In Addis Ababa, the concentration of particulate matter (PM) is consistently above World Health Organization (WHO) guidelines (Box 1). For example, one study found that the 24-hour average background concentration of $PM_{2.5}$ in July–August 2019 was 47.4 µg/m^3, almost double the recommended level (Singh et al., 2021). Similarly, in 2017, annual average $PM_{2.5}$ concentration in Addis Ababa was between 25 and 50 µg/m^3, several times greater than the WHO guidelines of 10 µg/m^3 (Addis Ababa Environmental Protection and Green Development Commission, 2021).

Looking to the future, annual average $PM_{2.5}$ is projected to increase to between 51 and 85 µg/m³ by 2025 if no action is taken. Over this same timeframe, premature deaths due to air pollution among adults aged 25–99 are projected to increase from 2,700 to 6,200 per year (Addis Ababa Environmental Protection and Green Development Commission, 2021).

Box 1. Particulate matter air pollution

PM has been shown to have many negative respiratory and cardiovascular health impacts (United States Environmental Protection Agency, 2021; WHO, 2006). $PM_{2.5}$ is defined as airborne particles less than 2.5 µm in diameter and typically comes from combustion (WHO, 2006). The WHO guidelines state that 24-hour average $PM_{2.5}$ concentration greater than 25 µg/m³ or an annual average above 10 µg/m³ lead to increased mortality (WHO, 2006).

Trees remove airborne PM by absorbing and intercepting air pollutants (Nowak et al., 2006). After particles are deposited on leaves, they are washed off by rain or fall to the ground (Nowak & Heisler, 2010).

1.2 Stormwater Runoff and Flooding in Addis Ababa

Urbanization and an increase in impervious surfaces lead to higher flood risk (Belete, 2011; Birhanu et al., 2016). On top of that, extreme precipitation in east Africa has become more frequent in recent decades, a trend that is likely to continue (Niang et al., 2014).

In Addis Ababa, stormwater infrastructure is poorly designed and maintained, with solid waste often blocking drains (Belete, 2011; United Nations Human Settlements Programme, 2007). The city is vulnerable to both flash flooding and high-volume riverine floods. For example, by one count, in 2017, 76 flood events caused damages estimated at ETB 20 million (USD 440,000) (Jemberie & Melesse, 2021).

Furthermore, up to 80% of the city's population lives in informal settlements, which tend to have very little permeable land cover and are often located in low-lying floodplains (Birhanu et al., 2016; United Nations Human Settlements Programme, 2007). The result is high vulnerability and exposure to floods, and from 2012 to 2021, 83 people in Addis Ababa were killed in flood events (W. Tesso, personal communication, September 13, 2021).

Urban trees reduce runoff and mitigate flood risk. They intercept rain and store water in leaves, where it is released through evapotranspiration. The increase in permeable surfaces also allows water to infiltrate the soil (Trees and Stormwater Runoff, 2017). It has been estimated that street trees can reduce stormwater runoff by 3.2–11.3 m³ per tree (Mullaney, 2015).

1.3 Heat Stress in Addis Ababa

Box 2. Urban heat islands

Urban areas are often warmer than nearby rural locations. Urban land cover, such as roads and buildings, absorbs more heat than plants. Evapotranspiration is lower when there is less vegetation. Vehicles, transport systems, and industrial processes further raise temperatures. The result is urban heat islands, highly built-up places, often close to city centres, that are significantly warmer than surrounding areas (Arsiso et al., 2018; Balew & Semaw, 2021; Rosenzweig et al., 2006; Simwanda et al., 2019).

Trees can mitigate the urban heat island effect by providing shade and increasing evapotranspiration. For example, in New York City, it was estimated that converting impervious surfaces to trees could cool ambient air temperatures by an average of 1.94 °C (Rosenzweig et al., 2006). Additionally, a modelling study in Hong Kong found that tree planting could cool surface temperatures by 1–1.5 °C (Tan et al., 2016).

Addis Ababa experiences an urban heat island effect (Box 2). Simwanda et al. (2019) found that in Addis Ababa, land surface temperatures in the urban centre were up to 3°C warmer than at the edge of the urban–rural delineation. Furthermore, there is a positive correlation between temperature and impervious surfaces, bare land, and grassland/cropland. There is a negative correlation between temperature and the density of green spaces in Addis Ababa (Dissanayake et al., 2019; Simwanda et al., 2019).

The frequency and duration of heatwaves in Addis Ababa are predicted to increase. For example, between 1950 and 1970, there were, on average, two heat waves lasting 5 days every year. By 2050, it is projected that there will be 32–40 such events (Climate change and Urban Vulnerability in Africa, n.d.). Additionally, Arsiso et al. (2018) predict that the nocturnal urban heat island effect during the dry season could increase from a historical average of 1–1.5°C to 2.5–3.2°C by the end of the century.

A preliminary analysis from WRI estimates that 47% of the Addis Ababa population is exposed to land surface temperatures above the city average (W. Tesso, personal communication, July 14, 2021). Although the impact of heat on health and mortality in Addis Ababa is negligible, high temperatures can negatively affect comfort. As a result, when it gets hot (roughly 30°C or warmer), many people choose to take buses or taxis instead of walking, particularly during the afternoon commute (W. Tesso, personal communication, October 13, 2021).

2.0 Methods

Based on conversations with our counterparts at WRI, we identified variables and relations relevant for urban tree planting and chose indicators to include in an integrated cost-benefit analysis. We used the Integrated Valuation of Ecosystem Services and Tradeoffs (InVEST) suite of models to quantify carbon storage, urban flood risk, and urban cooling for several tree planting and survival scenarios. For each scenario, we quantify net benefits over 20 years, accounting for climate change. To further assess the financial outcomes of planting trees in Addis Ababa, we calculate the IRR and NPV, both with and without social and environmental externalities.

2.1 Urban Forestry Causal Loop Diagram

In Addis Ababa, population growth has created a need for more settlement area and more mobility. With the development of new housing, the city can support a larger population. At the same time, the increase in impermeable surfaces has raised ambient air temperatures and worsened flooding, which causes property damage and mortality. Warmer temperatures can cause heat-related illness and may also increase mortality, but such impacts have not been observed in Addis Ababa given its subtropical highland climate.

Nevertheless, warm temperatures do make the city less walkable. Most people in Addis Ababa walk as their primary mode of transport, but when it is very hot, many choose buses or taxis instead (W. Tesso, personal communication, October 13, 2021). This raises the cost of transportation for individuals. Furthermore, less time spent walking could have health impacts that increase mortality.

While some of the need for increased mobility is met through walking and public transit, there is also demand for cars and therefore paved roads. Thus, improved transportation infrastructure supports population growth but creates impervious surfaces, further worsening runoff and floods. A larger fleet of vehicles increases air pollution and carbon dioxide emissions. Air pollutants directly increase mortality and may also make the city less walkable. It is possible that decreased walkability could further increase the need for fossil fuel-based transport.

Box 3. Interpreting a causal loop diagram

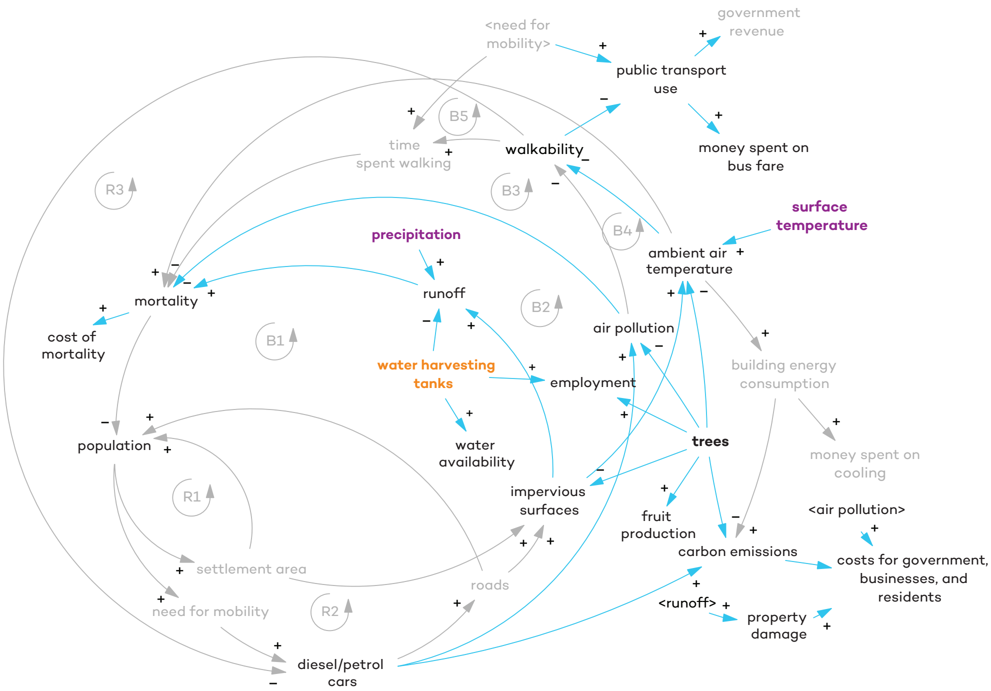
A causal loop diagram displays relations between components of a complex system and exposes feedbacks that can help explain behaviour. Arrows show causal relations. A plus sign (+) indicates that an increase (decrease) in one variable causes an increase (decrease) in the other, that is, they change in the same direction. A negative sign (-) indicates that the variables change in opposition directions.

Feedback loops are labelled balancing (B) or reinforcing (R). In a balancing loop, an increase (decrease) in a variable ultimately causes a decrease (increase) in the same variable. Conversely, a reinforcing loop leads to a further increase (decrease) in a variable after an initial change. Considering the relations and feedbacks displayed in a causal loop diagram helps identify potential impacts of intervening in coupled socio-economic and environmental systems.

In Figure 1, eight feedback loops highlight these dynamics:

- R1: Population growth requires more land for settlements. This enables further population growth.
- R2: An increase in population requires additional mobility. This results in more cars and paved roads, which allows for more population growth.
- B1: Population growth requires settlement area and roads, which increase impervious surfaces. This makes runoff worse and increases mortality, limiting population growth.
- B2: A larger population requires more vehicles, which emit air pollutants. This increases mortality, which slows population growth.
- B3: The increase in air pollutants from cars needed to support a larger population makes the city less walkable. With less time spent walking, mortality could increase, leading to lower population growth.
- B4: As population growth leads to more impervious surfaces, air temperatures get warmer. This decreases walkability, which could increase mortality, thus decreasing population growth.
- B5: Transportation and housing needed to support a larger population increase impervious surfaces, which causes warmer ambient air temperatures. In extreme cases, heat may increase mortality and limit population growth.
- R3: With more diesel and petrol cars, air pollution increases. This makes the city less walkable, requiring more vehicles.

Figure 1. Causal loop diagram for urban tree planting. Purple variables are climate inputs, and orange corresponds to policy interventions. Grey is used to represent variables that were not quantified and relations that were not considered for the case of Addis Ababa.



Source: Authors' diagram.

In addition to exposing and explaining observed outcomes of urban development in Addis Ababa, Figure 1 shows how trees affect this system. We can, therefore, use the diagram to understand, qualitatively, the potential impacts of intervening in the system and to identify the variables that are important to include in our quantitative analysis.

Specifically, by decreasing impermeable surfaces, trees can reduce runoff. This lowers the cost of mortality and property damage.

Less impermeable area and shade from trees create lower air temperatures. This makes the city more walkable. On the one hand, this means individuals may save money due to decreased reliance on public transport. On the other hand, reduced public transport use could lower government revenue. However, there has been a shortage of public transport in Addis Ababa, requiring the city to deploy additional bus services (W. Tesso, personal communication, October 25, 2021). These services are not necessarily operated by the government, and so, for this assessment, we assume that lower ridership will not affect public revenues.

In theory, more time spent walking could also decrease mortality. However, according to the WHO health economic assessment tool, effects of walking on decreased mortality take full effect only after 5 years of sustained increased physical activity (Kahlmeier et al., 2017). In our assessment, the benefits of increased walking are realized only on hot days, so we assume that the health benefits would be minimal.

There are some situations in which cooler temperatures due to trees could reduce building energy consumption and costs for cooling. However, given the climate in Addis Ababa, this impact is not relevant for our analysis.

Trees can remove air pollutants, which lowers mortality. Although many air pollutants can cause harm, we include only $PM_{2.5}$ because this is the focus of the Addis Ababa Air Quality Management Plan for 2021–2025 (Addis Ababa Environmental Protection and Green Development Commission, 2021). Improved air quality may also have an indirect effect by encouraging more walking, which improves health. Due to a lack of data, we did not quantify the impact of air quality on walkability.

Trees also sequester carbon. Carbon storage, as well as reduced flood damages and improved air quality, are cost savings for the government, businesses, and residents.

Tree planting and maintenance create jobs for local people, which we quantify as a benefit via wages earned.

By producing fruit, trees may increase the availability of healthy, affordable food. Due to the complexities of valuing the impact of fruit on food security, we do not include this benefit in our analysis. However, we recognize that fruits are a market commodity and include the producer price of fruit as a benefit in our assessment. Although the fruits grown on city trees may not be sold, this approach captures the monetary value of fruit.

The benefits generated by tree planting can also be obtained from other investments. The examples of water harvesting tanks and electric vehicles, also included in Figure 1, are described next.

Instead of planting trees, water harvesting tanks can also reduce runoff. Rainwater harvesting provides the additional service of increased freshwater availability for households. Like trees, tank construction and maintenance create jobs.

Replacing diesel and petrol cars with electric vehicles is a grey infrastructure alternative to trees that lowers carbon emissions and improves air quality. Using electric vehicles instead of petrol or diesel cars has the additional benefit of lower fuel costs.

Thus, from Figure 1, we can understand how trees, rainwater harvesting, and electric vehicles mitigate the undesirable outcomes of urban development. Although we do not simulate the feedback loops shown in the diagram, we can see how the direct impacts of trees, which we do quantify, can contribute to sustainable development within this dynamic system.

2.2 Tree Planting Scenarios

We simulate four tree scenarios (Table 1). We selected the number of trees planted, tree survival rate, and percentage of trees maintained based on conversations with WRI's Cities4Forests team working in Addis Ababa. For all scenarios, we assume a mix of ficus, jacaranda, pinus, and avocado trees and that 55% of trees that survive are shade trees, 37% are bushes, and 8% are fruit trees.

The city plans to plant 25 million trees over 5 years. We take this number as the maximum number of trees that could be planted. Eleven million trees were planted in 2021, so we also include scenarios that assume no additional trees are planted.

Thus far, the city has reported an 84% survival rate after the first year. We, therefore, use this as an optimistic survival rate and include a pessimistic survival rate of 30%. The survival rate may likely be an intermediate value between 30% and 84%. However, we use these extreme values to assess the range of possible outcomes. We assume that the survival rate is directly related to the percentage of trees maintained, and so include maintenance percentages of 50% and 25%.

In all cases, we compare the results to a business-as-usual (BAU) scenario, in which no trees are planted in Addis Ababa during 2021–2025.

Table 1. Tree planting, survival, and maintenance scenarios

Tree scenario	Number planted (millions)	Survival rate	Number surviving (millions)	Percentage maintained	Number maintained (millions)
High trees planted, high maintenance/survival	25	84%	21	50%	12.5
High trees planted, low maintenance/survival	25	30%	7.5	25%	6.25
Low trees planted, high maintenance/survival	11	84%	9.24	50%	5.5
Low trees planted, low maintenance/survival	11	30%	3.3	25%	2.75

2.3 Climate Scenarios

We assess each tree scenario under two projections for runoff and number of hot days over 20 years. We assume that these climate scenarios are independent of the tree planting/survival scenarios; that is, climate has no impact on the survival rate.

These climate scenarios are based on two representative concentration pathways (RCPs): RCP 4.5, which we use as a low climate change scenario, and RCP 8.5, which we use as a high climate change scenario (Box 4).

Box 4. Representative Concentration Pathway climate scenarios

The RCP scenarios are defined by atmospheric greenhouse gas concentrations. They specify the radiative forcing, that is, changes in the earth's energy budget that cause changes in climate. For example, RCP 4.5 assumes that the radiative forcing at the end of the 21st century is 4.5 watts per m^2 (W/m^2), whereas RCP 8.5 assumes a radiative forcing of 8.5 W/m^2 in 2100. These radiative forcings are affected by greenhouse emissions, and each RCP scenario corresponds to a hypothetical emissions pathway (Intergovernmental Panel on Climate Change [IPCC], 2013). For this assessment, we use projections from the following scenarios:

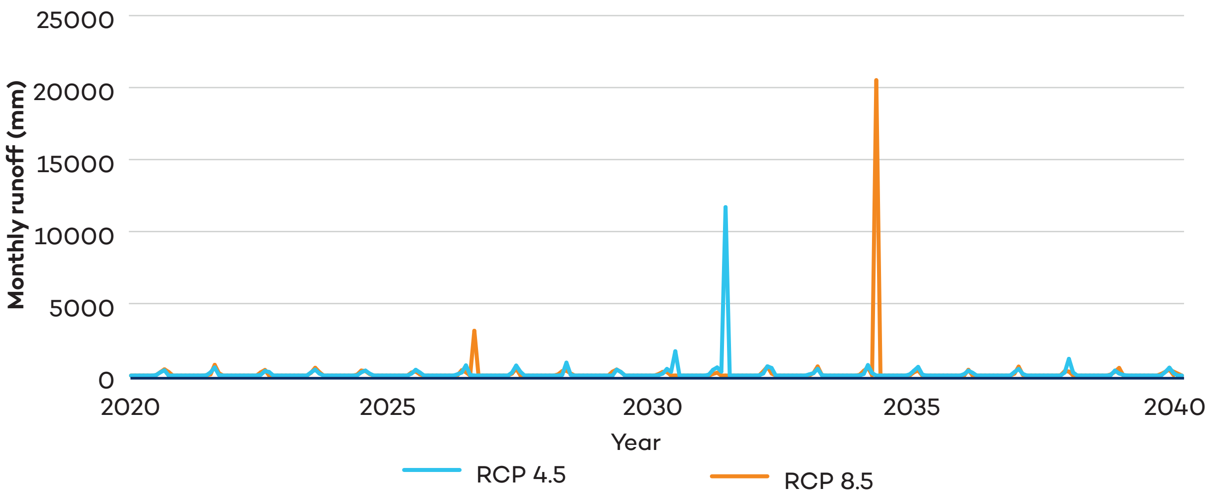
- **RCP 4.5:** A low climate change scenario, which assumes emissions peak in 2040 and then begin to decline.
- **RCP 8.5:** A high climate change scenario, which assumes continued high reliance on fossil fuel-based energy for the remainder of the century.

We use only one model run for each of these climate scenarios. Thus, the projections we use are neither central estimates nor most likely predictions for temperature and runoff under each RCP. Nevertheless, we can use these projections to assess performance under two possible runoff and heat scenarios with different underlying assumptions about greenhouse gas emissions.

2.3.1 Monthly Runoff

Runoff projections for Addis Ababa under the low (RCP 4.5) and high (RCP 8.5) climate scenarios are taken from Copernicus Climate Change Service (2018). As shown in Figure 2, there is more extreme runoff using the RCP 8.5 scenario.

Figure 2. Monthly runoff projections for Addis Ababa under two climate scenarios. There are more extreme runoff events under the RCP 8.5 projection.



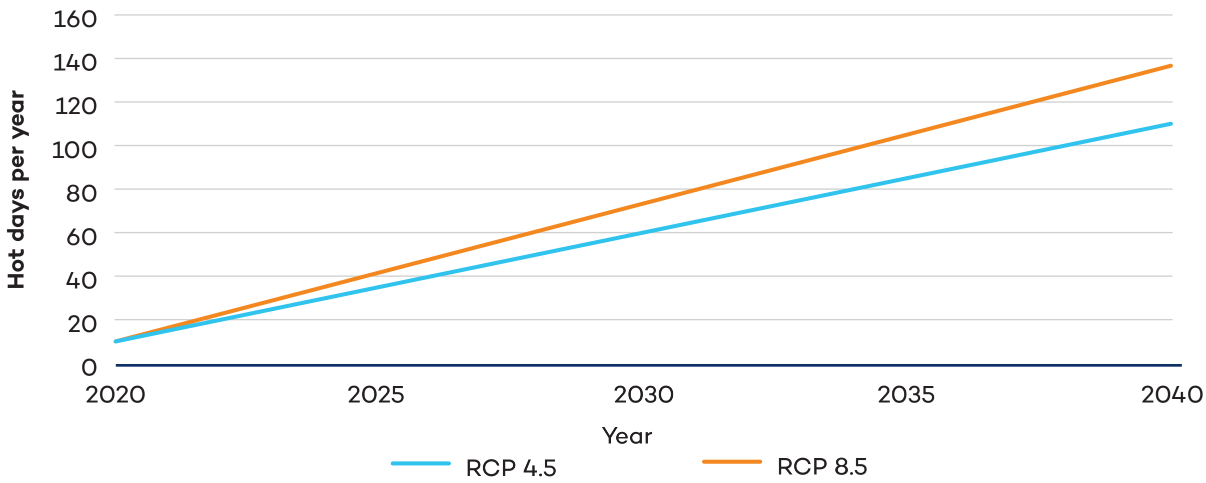
Source: Authors' diagram based on data from Copernicus Climate Change Service, 2018.

2.3.2 Annual Number of Hot Days

Historically, there has been an annual average of two heatwaves lasting 5 days in Addis Ababa. By 2050, the number of heatwaves lasting up to 5 days is projected to increase to 32 under RCP 4.5 and to 40 under RCP 8.5. The average length of heat waves will also increase (Climate change and Urban Vulnerability in Africa, n.d.).

We assume that the number of hot days per year will increase linearly and estimate that there are 10 hot days in 2020. For RCP 4.5, we assume that the number of hot days per year increases by 5 annually. For RCP 8.5, the annual increase is 6.33 hot days per year (Figure 3).

Figure 3. Number of hot days. We assume that the number of hot days increases linearly under both climate scenarios and that there are more hot days under the RCP 8.5 climate scenario.



Source: Authors' diagram using mid-century projections for duration and length of heat waves taken from Climate change and Urban Vulnerability in Africa, n.d.

2.4 Spatial Models Used to Value Ecosystem Services

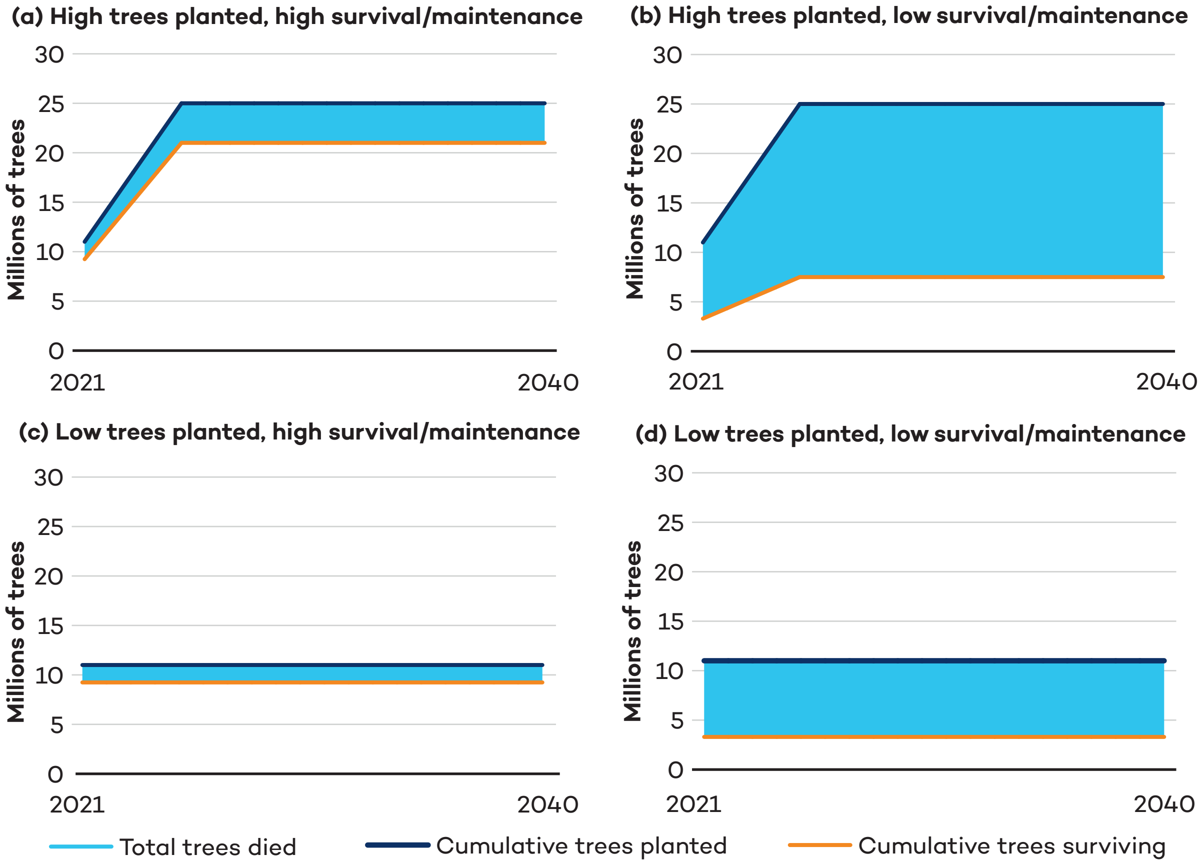
The InVEST models use geospatial data to produce maps that quantify biophysical indicators (Natural Capital Project, 2019). We use InVEST to calculate carbon storage, water retention, and relative cooling. The model creates maps that quantify each indicator for the total number of trees that survive under each scenario. Detailed descriptions of the models and their inputs are in Appendix B.

The analysis assumes a mix of ficus, jacaranda, pinus, and avocado trees are planted. This is a subset of the species that the city planted in 2021 (see Appendix A). We selected this subset based on data availability and use the results to demonstrate the big picture impacts of tree planting in Addis Ababa.

2.5 Assumptions About Tree Planting, Growth, and Survival

For all scenarios, we assume that 11 million trees are planted in 2021. Under the low tree planting scenarios, no additional trees are planted. For the high tree planting scenarios, an additional 3.5 million trees are planted each year from 2022 through 2025. Trees that do not survive die immediately, and any tree that survives lives for at least 20 years. Figure 4 displays the cumulative number of trees planted and surviving for each scenario.

Figure 4. Number of trees planted and surviving for each tree planting scenario. The dark blue shows the cumulative number of trees planted, while the orange line shows the cumulative number that survive. The difference between the two lines (light blue shading) is the total number of trees that die.



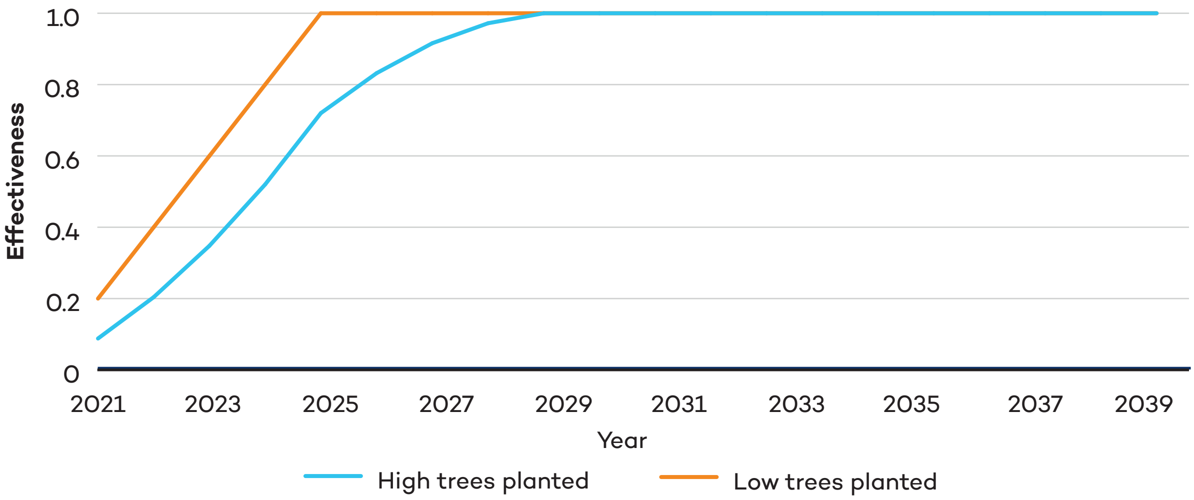
Source: Authors' diagram.

The spatial assessment quantifies the cooling, water retention, and carbon storage benefits of trees that survive. There is no time dimension included in the spatial analysis; it considers only the effect of surviving, mature trees.

However, trees do not mature immediately. Furthermore, when 25 million trees are planted, there are several annual cohorts of trees, with the final cohort planted in Year 5 of the simulation. To account for these time dependencies, we define an "effectiveness" scalar, which increases from zero to one and corresponds to the growth of the urban forest (Figure 5). Water retention, cooling, and air quality services of total surviving trees are multiplied by the effectiveness in each year to calculate the benefits of the urban forest. Annual carbon sequestration is proportional to the annual increase in effectiveness.

We assume that the effectiveness of each cohort increases linearly over 5 years. That is, the effectiveness of each cohort increases from 0.2 in the year it is planted to 1, 5 years later. The total effectiveness of the urban forest is the sum of the effectiveness of each cohort, scaled by the size of the cohort (Figure 5). Five years after planting is complete, we assume that the urban forest is mature, and the full ecosystem services calculated with the InVEST models are realized every year.

Figure 5. Relative forest effectiveness. Water retention, cooling, and air quality services of final number of surviving trees are scaled by the effectiveness in each year. The forest matures more quickly when fewer trees are planted because all trees are planted in 2021. The increase in effectiveness in the high trees planted scenarios is nonlinear because planting is spread over the first 5 years.



Source: Authors' diagram

2.6 Equations Used to Quantify Externalities

Based on the spatial outputs, we value the direct and indirect costs and benefits of planting trees to create an integrated cost-benefit analysis. The valuation includes the following costs and benefits of tree planting:

- Fruit production (using the producer price)
- Job creation (based on wages earned)
- Carbon sequestration (based on the social cost of carbon)
- Reduced air pollution (considering impacts on mortality)
- Avoided flood damages (including property damage and changes in mortality)
- Reduced heat (measured in avoided bus fares)
- Planting and maintenance costs

We selected these benefits based on conversations with local stakeholders. However, trees may provide other benefits, not included in this assessment, such as recreational opportunities and impacts on mental health.

The producer price of fruits and wages from planting and maintenance jobs are direct benefits for the local community. Avoided bus fares also accrue to individuals. Conversely, the avoided costs of carbon, air pollution, and flooding benefit the federal or city government (while also improving life for residents). Public agencies are responsible for the costs of planting and maintenance. Taken as a whole, this analysis provides a comprehensive view of societal costs and benefits that highlights impacts for multiple actors.

We value the indicators for each tree and climate scenario using the following equations. Detailed calculations, including numerical inputs, are in Appendix C.

- Added benefits
  - **Fruit production:** number of trees (delayed by the time until trees produce fruit) × hectares per tree × percentage fruit trees × fruit yield per hectare × fruit producer price
  - **Planting wages:** total number of trees planted × planting jobs per tree × planting wages per job
  - **Maintenance wages:** number of trees maintained × maintenance jobs per tree × maintenance wages per job
- Avoided costs
  - **Avoided bus fares due to improved walkability from cooling:** decrease in the percentage of people who walk on hot days × population × decrease in hot days per °C of cooling × cooling due to trees × average bus fare per ride × forest effectiveness
  - **Avoided flood damages to property:** annual flood damages regression slope × projected runoff without trees × percentage reduction in runoff when trees are planted × forest effectiveness
  - **Avoided mortality from floods:** historical flood mortality × population × annual runoff ÷ historical average annual runoff × percentage reduction in runoff when trees are planted × forest effectiveness × the value of a statistical life
  - **Avoided mortality from air pollution:** population × increase in mortality due to increase in $PM_{2.5}$ concentration × decrease in $PM_{2.5}$ concentration per hectare of tree cover × number of surviving trees × hectares per tree × forest effectiveness × value of a statistical life
  - **Carbon storage:** additional carbon stored relative to BAU × value of carbon storage × annual change in forest effectiveness
- Direct costs
  - **Planting costs:** planting cost per tree × number of trees planted
  - **Maintenance costs:** maintenance cost per tree × number of trees maintained

We include carbon storage as an avoided cost, not an added benefit, because we assume that there are no carbon payments. Thus, reducing greenhouse gas emissions does not directly create a cash flow. It is, therefore, more appropriate to interpret the carbon storage benefit as the avoided social cost of carbon.

2.7 Grey Infrastructure Comparison

We assessed the costs and benefits of rainwater harvesting and electric vehicles able to provide the same water retention, air quality, and greenhouse gas mitigation services as trees. We focus on these impacts of grey infrastructure to compare performance to that of trees. Because both rainwater harvesting tanks and electric vehicles provide many other benefits,

we also include the value of additional water available due to rainwater harvesting, wages from tank construction and maintenance, and the avoided fuel costs from driving electric vehicles instead of diesel/petrol cars. While rainwater harvesting may also lower costs to build and maintain water infrastructure, this impact would likely be small because rainwater harvesting can provide only some of the services provided by other water infrastructure, and the service is provided only intermittently. We also do not include health impacts and benefits for businesses and agriculture, because we are primarily concerned with the comparison to tree planting.

Considering the question of who gains from these infrastructure investments, tank construction and maintenance wages and increased water availability are benefits for the local community. Avoided flooding reduces public costs. Building and maintaining rainwater harvesting tanks may be borne by public or private actors.

The cost to buy an electric vehicle and avoided fuel costs are impacts on individuals. Governments may also be impacted by the cost of procuring electric vehicles, fuel costs, and effects on other transportation infrastructure. Avoided air pollution and carbon emissions may lower government spending.

We assume that rainwater harvesting capacity will be installed to retain the same amount of runoff as the surviving trees when effectiveness equals one. That is, the installed rainwater tank capacity is equal to the runoff reduction due to mature trees divided by the runoff reduction per cubic metre of rainwater harvesting capacity.

We assume that individuals buy electric vehicles instead of purchasing diesel or petrol cars and that enough diesel/petrol cars will be replaced with electric vehicles to reduce air pollution and greenhouse gas emissions at least as much as the surviving trees. The number of electric vehicles needed to have the same effect on carbon emissions as trees is equal to the carbon stored in trees divided by the project lifetime after planting starts (19 years) divided by the annual CO_2 emissions of one diesel/petrol car. The number of electric vehicles needed to provide the same $PM_{2.5}$ benefit as trees is equal to the mass of $PM_{2.5}$ removed per hectare of trees multiplied by the area of trees divided by the annual average $PM_{2.5}$ emissions per diesel/petrol car.

To calculate emissions per vehicle, we assume that 50% of the passenger cars in Addis Ababa use diesel and are in the medium/large size category. The remaining 50% run on petrol and are categorized as mini, although we note that roughly 20% to 25% of the petrol cars in Addis Ababa are larger (Jida et al., 2020). From this, we estimate that the air quality impacts of a single car in Addis Ababa are equal to the average air pollutant emissions of diesel and petrol cars. Similarly, the carbon dioxide emissions are equal to the average carbon emissions of diesel and petrol cars.

We further assume that operating an electric vehicle does not emit any air pollutants or carbon dioxide. We justify this based on the fact that 98% of electricity in Ethiopia comes from renewable sources (International Renewable Energy Agency, 2020).

We acknowledge that the share of electric vehicles and share of renewable of renewable energy generation in Addis Ababa, and Ethiopia more generally, will change in the future. However, considering projections for these variables was outside the scope of this assessment. For the analysis, we assume that they are constant, and we interpret our results in light of this simplification.

Finally, we assume that the annual maintenance costs and lifetime are the same for diesel/petrol cars as for electric vehicles. Consequently, we do not consider maintenance costs in our analysis. Thus, the only differences between the vehicles for the purposes of this assessment are emissions, upfront price, and fuel cost.

The equations to value the costs and benefits of rainwater harvesting and electric vehicles are listed below. Detailed calculations, including numerical inputs, are in Appendix C.

- Benefits and avoided costs
  - **Rainwater harvesting tank construction wages:** rainwater harvesting construction costs × labour cost percentage for rainwater harvesting
  - **Rainwater harvesting tank maintenance wages:** rainwater harvesting maintenance costs × labour cost percentage for rainwater harvesting
  - **Avoided flood damages to property:** annual flood damages regression slope × projected runoff × percentage reduction in runoff due to rainwater harvesting
  - **Avoided mortality from floods:** historical flood mortality × population × percentage reduction in runoff due to rainwater harvesting × annual runoff ÷ historical average annual runoff × the value of a statistical life
  - **Value of additional water supply:** installed water harvesting capacity × domestic water price per m^3
  - **Avoided air pollution:** number of diesel/petrol cars replaced with electric vehicles ÷ number of diesel/petrol cars needed to provide same $PM_{2.5}$ benefit as trees × avoided mortality from air pollution due to trees (assuming effectiveness equals one)
  - **Avoided carbon dioxide emissions:** number of diesel/petrol cars replaced with electric vehicles × the annual average carbon dioxide emissions per diesel/petrol car
  - **Avoided cost of fuel:** difference in the average cost to drive a diesel/petrol car 1 kilometre and the average cost to drive an electric vehicle 1 kilometre[3] × kilometres driven per car per year × number of diesel/petrol cars replaced with electric vehicles
- Direct costs
  - **Rainwater harvesting construction costs:** rainwater harvesting capacity installed × rainwater harvesting installation cost per cubic metre
  - **Rainwater harvesting maintenance costs:** rainwater harvesting capacity installed × annual rainwater harvesting maintenance cost per cubic metre
  - **Cost to purchase electric vehicles:** difference in the price of a new electric vehicle and the price of a new diesel/petrol car × the number of diesel/petrol cars replaced with electric vehicles

[3] This difference is due to the fuel efficiency of internal combustion engine vs. electric vehicles and the cost of petrol and diesel compared to the cost of electricity in Ethiopia.

2.8 Financial Analysis

While the integrated cost-benefit analysis estimates the direct and indirect benefits and direct costs of the project, it does not consider how prices change over time, the time value of money, and the opportunity cost of the investment. To account for these issues, we also conduct a financial analysis. We assume an inflation rate of 2% for all modelled benefits and costs[4] and use a discount rate of 8.5% per annum to determine the present value of costs and benefits at time of intervention. Our calculations are based on a 20-year lifetime of the intervention. These calculations allow us to assess the viability of the project and calculate the expected return on investment when the environmental, social, and economic benefits are considered. Traditionally, nature-based infrastructure (NBI) projects, such as tree planting initiatives, do not generate revenue. However, as we can see from the causal loop diagram, they provide a range of direct benefits for different stakeholders as well as externalities in the form of avoided costs and added benefits.

We demonstrate investment worthiness of the tree planting initiative through the calculation of the NPV and IRR and by integrating the abovementioned externalities and calculating the S-NPV and S-IRR. This extension of traditional NPV and IRR calculations makes sense for decision-makers who want to take a more holistic approach when assessing whether the project would deliver value for money to society over its lifecycle.

In wanting to present a more nuanced picture of the value of the project, we have also included a scenario in which we consider the investment opportunity cost. With any investment there is a cost associated with choosing one investment over all other investments. For example, while we consider the investment in tree planting in relation to a grey alternative that may deliver similar environmental benefits, an analysis that includes the investment opportunity cost goes beyond this comparison. By including the investment opportunity cost, we compare the investment in tree planting against the increase in GDP that accrues to the economy when an average investment of the same size is made. This average investment is not sector specific and may have environmental benefits and costs that are quite different than the tree planting initiative. To do so, we scale the investment amount by a fiscal multiplier of 1.6, the estimated multiplier that Ilzetzki et al. (2013) found for fiscal spending by governments in developing countries. This opportunity cost is spread over the 5 years following each capital investment. Despite the limitations of the method used, and the limited comparability of investments for social and environmental outcomes with those that prioritize economic performance, it is important to compare the different investment allocation options available to the municipality. Practically, with this estimation we assess whether NBI generates more financial value compared to other public spending, in addition to resulting in higher social and environmental benefits.

[4] Annual inflation in Ethiopia is volatile and differs significantly among sectors of the economy. For this reason, we used 2% which is a conservative estimate of global inflation given global inflation of 2.5% over the past 10 years (The World Bank, n.d.). We used a higher inflation rate of 3% per annum to calculate the value of the carbon storage benefit as we expect the value of carbon storage to increase more rapidly. This estimation is more conservative than the estimation made by Gollier (2021) that has carbon prices growing at 4% plus inflation.

3.0 Results and Discussion

Results from the spatial models, integrated cost-benefit analysis, and financial analysis show that:

- Tree planting can avoid costs of air pollution, flooding, and heat. Thus, trees increase climate resilience while also sequestering carbon.
- Considering only cash flows, the benefits of tree planting do not outweigh the costs. However, when accounting for direct value created for the local community and the avoided costs from air pollution, flooding, heat, and greenhouse gas emissions, trees have positive net benefits (up to ETB 1.8 billion [USD 40 million], undiscounted, over 20 years) (see Table 3). This highlights the importance of including intangible impacts as part of a systemic valuation of NBI.
- Ensuring that planted trees survive by investing in maintenance generates more value than planting more trees with low maintenance/survival. The analysis shows that increasing the survival rate from 30% to 84% raises the undiscounted benefit-to-cost ratio by between 0.17 (from 1.17 to 1.34 for 25 million trees planted) and 0.22 (from 1.2 to 1.42 for 11 million trees planted) (see Table 3).
- Trees provide more value for money and create more jobs than installing rainwater harvesting tanks and replacing diesel/petrol cars with electric vehicles. Even with a large enough investment, these grey infrastructure alternatives may not be able to provide the same services as trees in Addis Ababa.
- Financially, the S-NPV of each tree planting scenario is positive and ranges between ETB 200.0 million (USD 4.4 million) and ETB 1,345.5 million (USD 29.6 million) when including the same costs and benefits as the integrated cost-benefit analysis. Specifically, the S-NPV is about four times larger when we assume 84% of trees survive and account for the continued maintenance of 50% of the planted trees than if we assume a survival rate of 30% and only 25% of the trees are maintained (see Table 6).
- The S-NPV and S-IRR of trees are much higher than the S-NPV and S-IRR of the corresponding grey infrastructure alternative. The S-NPV of rainwater harvesting tanks and electric vehicles is negative. The IRR is on average at least 32.2% for trees and 8.3% for comparable grey infrastructure (see Table 6).

3.1 Spatial Analysis: Trees store carbon, retain water, and cool temperatures

Depending on the tree planting scenario, trees retain 431–1,647 thousand m^3 more water than the BAU scenario with no trees planted. This corresponds to a 2.4%–9.3% increase in water retention (Table 2).

Planting trees increases carbon storage by 0.264–1.2 million tons (8.1%–36.8%). Using a conversion factor of 3.667 tons of CO_2 per ton of carbon, this means that trees could store 0.969–4.401 million tons of CO_2 (Table 2). This would contribute to Ethiopia's pledge to reduce annual land use/land change and forestry emissions by 33.2 million tons CO_2 per year

by 2030 in its updated unconditional nationally determined contribution under the Paris Agreement (Federal Democratic Republic of Ethiopia, 2021)

For heat mitigation, the InVEST model calculates an average temperature across the entire city and the heat mitigation index, which measures the effect of large green spaces on urban temperatures. We find that, compared to BAU, planting trees could reduce the average city temperature by 0.61–1.41 °C (Table 2). Figure 6 shows the heat mitigation index for BAU and for all tree planting scenarios. This figure shows that in the tree planting scenarios, a larger area of the city experiences the cooling impact of trees. This effect is bigger when more trees survive.

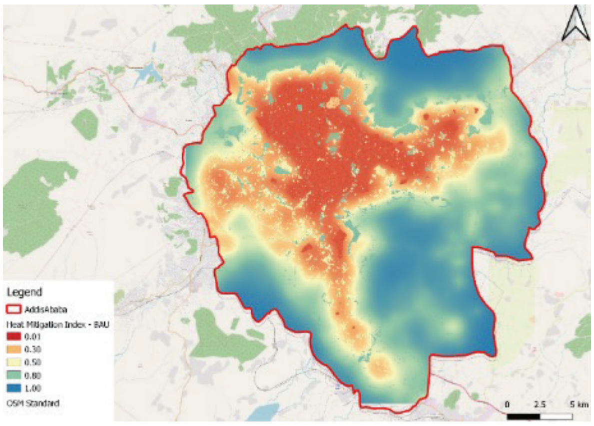
Complete results of the spatial analysis are in Appendix B.

Table 2. Runoff retention, carbon storage, and average cooling from trees. Values calculated using the InVEST models.

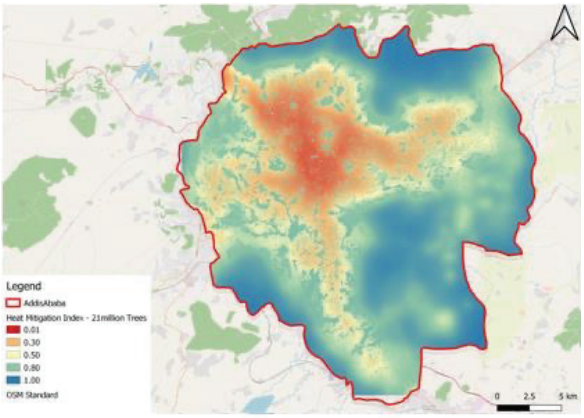
Spatial Analysis Results Summary

	Runoff retention compared to BAU (1,000 m³)	Runoff retention compared to BAU (%)	Carbon storage compared to BAU (1,000 tons)	Carbon storage compared to BAU (%)	Average cooling compared to BAU (°C)
High trees planted, high maintenance/ survival	1,647	9.3	1,200	36.8	1.41
High trees planted, low maintenance/ survival	873	4.9	545	16.7	1.14
Low trees planted, high maintenance/ survival	973	5.5	625	19.2	1.22
Low trees planted, low maintenance/ survival	431	2.4	264	8.1	0.61

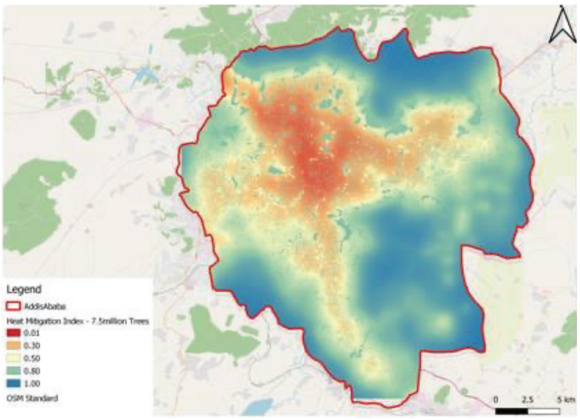
Figure 6. Heat mitigation index as calculated using the InVEST model. The heat mitigation index is, on average, higher when more trees survive, demonstrating the cooling potential of trees. In general, the heat mitigation index is lower in the areas with more built-up land cover.



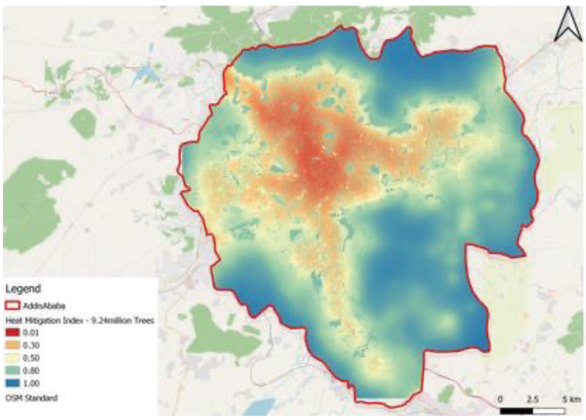
(a) BAU



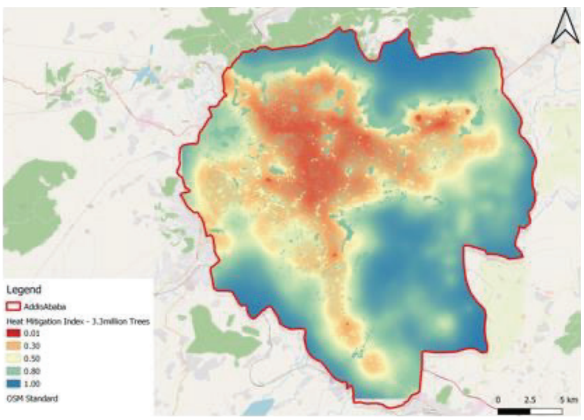
(b) High trees planted, high survival (21 million surviving)



(c) High trees planted, low survival (7.5 million surviving)



(d) Low trees planted, high survival (9.24 million surviving)



(e) Low trees planted, low survival (3.3 million surviving)

Source: Authors' diagram based on outputs from InVEST model. Background map data from OpenStreetMap (© OpenStreetMap contributors, https://www.openstreetmap.org/copyright).

3.2 Integrated Cost-Benefit Analysis: Trees have positive net benefits

The integrated cost-benefit analysis results for all tree planting and survival scenarios using the RCP 4.5 climate scenario are in Table 3.

Table 3. Undiscounted integrated cost-benefit analysis using temperature and runoff projections from RCP 4.5. In all tree planting and survival scenarios, trees provide positive net benefits if the avoided costs are valued. Increasing maintenance and survival raises net benefits and the benefit-to-cost ratio.

	25 million trees planted		11 million trees planted	
Tree survival rate	84%	30%	84%	30%
Total surviving trees (million)	21	7.5	9.24	3.3
Added Benefits				
Fruit production (million ETB)	607	217	293	105
Planting wages (million ETB)	95	95	42	42
Maintenance wages (million ETB)	3,335	1,668	1,584	792
Total added benefits (million ETB)	**4,037**	**1,979**	**1,919**	**938**
Avoided Costs				
Mortality from air pollution (million ETB)	215	77	100	36
Flood damages to property (million ETB)	80	42	49	22
Mortality from flooding (million ETB)	224	119	136	60
Bus fares due to decreased walkability (million ETB)	55	45	51	25
Carbon sequestration (million ETB)	1,966	893	1,023	433
Total avoided costs (million ETB)	**2,539**	**1,175**	**1,359**	**576**
Added benefits + avoided costs (million ETB)	**6,577**	**3,155**	**3,278**	**1,514**
Direct costs				
Planting costs (million ETB)	500	500	220	220
Maintenance costs (million ETB)	4,400	2,200	2,090	1,045
Total direct costs (million ETB)	**4,900**	**2,700**	**2,310**	**1,265**
NET BENEFITS (MILLION ETB)	**1,677**	**455**	**968**	**249**
BENEFIT-TO-COST RATIO	**1.34**	**1.17**	**1.42**	**1.20**
BENEFIT-TO-COST RATIO EXCLUDING AVOIDED COSTS	**0.82**	**0.73**	**0.83**	**0.74**

As shown in Table 3, all tree planting scenarios have positive net benefits with a benefit-to-cost ratio greater than one. The single largest benefit is wages earned for tree maintenance, highlighting the fact that trees in Addis Ababa can create jobs. Nevertheless, considering only the added benefits, tree planting would not be a profitable investment.

Most of the value from tree planting comes from the avoided costs. Notably, the avoided social cost of carbon is more than 75% of the total avoided costs and about 30% of the combined avoided costs and added benefits.

It is important to recognize that the avoided costs of air pollution, flooding, heat, and carbon emissions are not cash flows. Therefore, some investors will consider these impacts immaterial. Others may internalize them as potential risks, but they do not have a financial impact for the project at this time. Furthermore, the added benefits (planting and maintenance wages and fruit production) will accrue to the local community. Thus, private sector investors may not directly generate any money through tree planting.

However, as our analysis shows, trees create considerable value in avoided costs. The avoided costs of air pollution, carbon, and flooding may manifest as cost savings for the city or national government. Still, considering only these avoided costs, trees would not have positive net benefits for public sector actors. This highlights that it is important to consider both direct benefits to the local community and intangible societal impacts when valuing NBI.

To account for uncertainty in some parameter values, we conducted a sensitivity analysis on the maintenance costs and impact of heat on bus fares. Although these variables change the net benefits and benefit-to-cost ratio, we still conclude that trees create value for money when externalities are included. Results of this sensitivity analysis are in Appendix D.

3.3 Trees Can Mitigate Climate Change Impacts

We compared the results using two different projections for temperature and runoff, one assuming a low-emissions scenario (RCP 4.5) and the other assuming a high-emissions scenario (RCP 8.5). These inputs affect the avoided mortality and damages of flooding and bus fares required on hot days. Results for the RCP 4.5 scenario are in Table 3, and those for RCP 8.5 are in Table D1.

Depending on the tree scenario, avoided costs are 5.5%–6.5% higher under RCP 8.5 compared to RCP 4.5. Net benefits are 8.3%–16.2% higher. Thus, without tree planting, heat and flooding impacts may be worse under a higher climate change scenario, but trees can mitigate these impacts and increase climate resilience.

However, the benefit-to-cost ratio increases by only 0.03–0.04 when comparing RCP 4.5 and RCP 8.5. Furthermore, as shown in Figure 7, added benefits and direct costs do not depend on climate change, and the differences in avoided costs and net benefits are small. These similarities imply that trees will provide comparable value for money regardless of future climate (assuming that climate has no impact on survival rate).

Figure 7. Comparison of calculated added benefits, avoided costs, direct costs, and net benefits for all tree planting and survival scenarios under two climate scenarios (RCP 4.5 and RCP 8.5). In all cases, avoided costs are higher under RCP 8.5, while added benefits and direct costs do not depend on climate. This leads to slightly higher net benefits when runoff and heatwaves increase, but net results are similar across climate scenarios.

Source: Authors' diagram.

3.4 Long-Term Survival Is Critical for Generating Value

Looking at the benefit-to-cost ratios in Table 3, we see that the low tree planting scenario with high survival/maintenance provides the most value per dollar invested, while the high tree planting scenario with low survival/maintenance generates the least value for money. This highlights the importance of ensuring that planted trees survive.

Increasing the survival rate from 30% to 84% more than doubles total added benefits and avoided costs, while increasing costs by only 65%–82%. These results suggest that, with a limited budget, maintenance may be more important than planting more trees. For example, investing ETB 2,310 million to plant 11 million trees with an 84% survival rate has higher net benefits and a larger benefit-to-cost ratio than investing ETB 2,748 million to plant 25 million trees with a 30% survival rate.

3.5 Trees Are a More Feasible Investment Than Grey Infrastructure Alternatives

The number of electric vehicles and capacity of rainwater harvesting tanks necessary to achieve the same carbon, air quality, and runoff retention benefits as trees are shown in Table 4. More cars are needed to meet CO_2 reductions than are needed to improve air quality to the same extent as trees. We assume that enough diesel/petrol cars will be replaced with electric vehicles to provide at least as much value as trees, and so use the number of cars needed for equal CO_2 benefit to estimate the costs and benefits of grey infrastructure

Table 4. Number of diesel/petrol cars that must be replaced with electric vehicles and required rainwater harvesting capacity to provide the same air quality, carbon, and runoff retention benefits as trees for all tree scenarios

	Electric vehicles needed for equal CO_2 benefit	Electric vehicles needed for equal air quality benefit	Rainwater harvesting capacity needed for equal runoff reduction (m^3)
High trees planted, high maintenance/survival	58,564	34,332	53,161
High trees planted, low maintenance/survival	26,603	12,261	28,199
Low trees planted, high maintenance/survival	30,492	15,106	31,403
Low trees planted, low maintenance/survival	12,894	5,395	13,923

The integrated cost-benefit analysis for grey infrastructure comparable to the high trees planted and high maintenance/survival scenario (i.e., 53,161 m^3 of rainwater harvesting capacity and 58,564 electric vehicles) under RCP 4.5 is in Table 5. Grey infrastructure comparisons for the other tree planting and climate scenarios are in Appendix D.

In all scenarios, the undiscounted, 20-year fuel savings from electric vehicles more than outweigh the purchase costs, while also providing societal benefits in the form of reduced air pollution and carbon emissions. However, we note that this is an optimistic scenario for the benefits of electric vehicles. We assume that the cost to drive an electric vehicle is ETB 4.54 (USD 0.1) per 100 km ("Electric Car Maker Sees Transportation 'Revolution' in Ethiopia," 2010). This is in line with an electricity price of 0.007 USD per kWh (GlobalPetrolPrices. Com, 2021a). With widespread electric vehicle use, it would likely become necessary for Ethiopia to increase reliance on fossil fuels for electricity generation, which would raise prices. This would reduce the cost difference between driving an electric vehicle and driving a diesel or petrol car (assumed to be ETB 130 [USD 3] per 100 km for this assessment). Electricity generation from fossil fuels also implies air pollution and carbon emissions from powering

electric vehicles, so societal benefits would be lower. Thus, in reality, the net benefits of electric vehicles are likely lower than what we estimate.

As explained in Section 3.5.1, the benefits of rainwater harvesting depend on climate scenario, but in all cases, undiscounted net benefits are positive (Figure 8).

Figure 8 shows that when trees are maintained (i.e., high survival rate), tree planting is more cost effective than the combination of electric vehicles and rainwater harvesting tanks. Additionally, under all scenarios, trees create more jobs than grey infrastructure. However, when considering total net benefits, grey infrastructure outperforms trees if the survival rate is low. This further emphasizes the need to ensure long-term tree survival through maintenance.

Although not included in our assessment, we do note that trees likely have a longer lifetime than grey infrastructure, and the maintenance costs for trees are expected to decline over time, while maintenance costs of grey infrastructure typically increase over time. For these reasons, we may have overestimated the value of grey infrastructure relative to tree planting.

It is interesting to note that although trees, when maintained, have a higher benefit-to-cost ratio than grey infrastructure, the grey alternatives, combined, provide more valuable services. There are several reasons for this.

First, for both rainwater harvesting tanks and electric vehicles, we assume that the amount installed/purchased will provide the same (or greater) benefits as the mature urban forest (i.e., effectiveness equals one). Thus, in the analysis, these grey infrastructure alternatives provide full benefits starting in year 2022. This is different from trees, which are planted over the course of 5 years and take even longer to mature.

Second, the fleet of electric vehicles has a larger impact on air pollutants than the mature urban forest because we have assumed that more vehicles will be purchased than necessary to avoid $PM_{2.5}$ emissions.

Third, electric vehicles lower fuel costs, and rainwater harvesting also provides additional water supply.

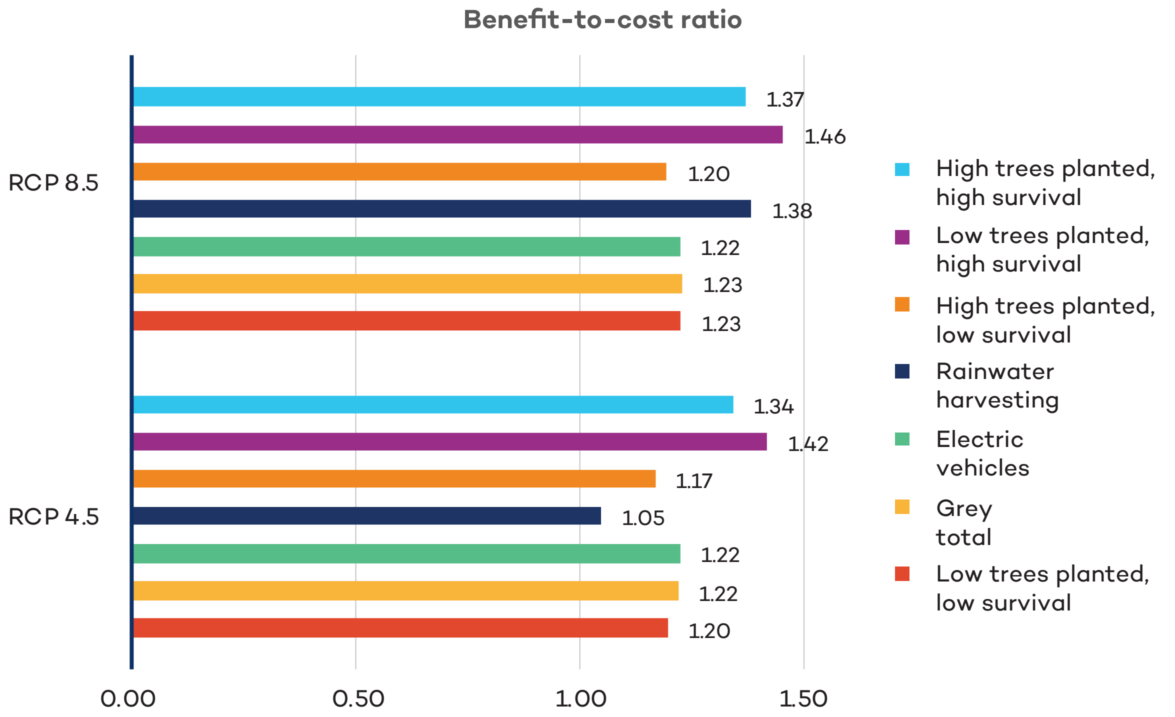
For these reasons (benefits effective immediately, greater $PM_{2.5}$ impact, and additional services provided), we estimate that grey infrastructure provides more benefits than do the trees. This is true even though the grey infrastructure assessed does not mitigate heat or provide value in terms of food production. However, grey infrastructure, particularly electric vehicles, is also more expensive than tree planting. Thus, trees generate more value per dollar invested.

Table 5. Comparison of undiscounted costs and benefits of planting 25 million trees with 84% survival and grey infrastructure alternatives (53,161 m^3 of rainwater harvesting capacity and 58,564 electric vehicles) under RCP 4.5. Grey infrastructure generates more benefits than trees but is also more expensive. Ultimately, trees have a higher benefit-to-cost ratio.

Grey infrastructure comparison: High trees planted, high survival, RCP 4.5

		Grey Alternatives			
	Trees	**Rainwater harvesting**	**Electric vehicles**	**Grey total (harvesting + vehicles)**	**Difference (trees – grey)**
Added benefits (million ETB)					
Fruit production	607	-	-	-	607
Additional water supply	-	13	-	13	-13
Wages	3,430	117	-	117	3,313
Total added benefits	**4,037**	**130**	**-**	**130**	**3,907**
Avoided Costs (million ETB)					
Mortality from air pollution	215	-	403	403	-188
Flood damages to property	80	84	-	84	-5
Mortality from flooding	224	234	-	234	-10
Bus fares due to decreased walkability	55	-	-	-	55
Carbon sequestration	1,966	-	1,966	1,966	-
Fuel cost	-	-	33,486	33,486	-33,486
Total avoided costs	**2,539**	**318**	**35,854**	**36,173**	**-33,633**
Added benefits + avoided costs	**6,577**	**448**	**35,854**	**36,302**	**-29,726**
Direct costs (million ETB)					
Tree planting costs	500	-	-	-	500
Tree maintenance costs	4,400	-	-	-	4,400
Rainwater harvesting construction costs	-	147	-	147	-147
Rainwater harvesting maintenance costs	-	280	-	280	-280
Electric vehicle purchase cost	-	-	29,282	29,282	-29,282
Total direct costs	**4,900**	**427**	**29,282**	**29,710**	**-24,810**
NET BENEFITS (MILLION ETB)	**1,677**	**21**	**6,572**	**6,593**	**-4,916**
BENEFIT-TO-COST RATIO	**1.34**	**1.05**	**1.22**	**1.22**	**0.12**

Figure 8. Calculated benefit-to-cost ratios for all tree planting and climate scenarios for trees and grey infrastructure alternatives. With a high survival rate, trees have a larger benefit-to-cost ratio, but grey infrastructure provides more value for money if there is a low tree survival rate.



Source: Authors' diagram

3.5.1 Grey Infrastructure and Climate Change

Figure 8 shows that the benefit-to-cost ratio for electric vehicles and rainwater harvesting combined is not strongly affected by climate change, with a value of 1.22 under RCP 4.5 and 1.23 under RCP 8.5. This is because most of the costs and benefits of these grey infrastructure alternatives come from electric vehicles, which affect carbon storage and air quality. We assume that neither of these indicators changes based on climate scenario, so the benefit-to-cost ratio for electric vehicles will be the same under both RCPs.

However, with more potential flooding under RCP 8.5, the value of avoided flood mortality and damage is greater, as expected. Looking at RCP 4.5, the benefit-to-cost ratio of rainwater harvesting is 1.05. In this climate scenario, both individual direct benefits and societal avoided costs must be included to justify investing in tanks. Under RCP 8.5, the benefit-to-cost ratio is 1.38, and the avoided costs alone are greater than the construction and maintenance costs. This suggests that, under the high climate change scenario, rainwater harvesting provides more value for money than most tree planting scenarios. However, because trees provide other valuable services, rainwater harvesting has lower net benefits (Table 5, Table D2–Table D8). Furthermore, unlike trees, tanks provide value only when there is high rainfall.

3.5.2 Technological Limitations of Grey Infrastructure

Our analysis assumes that 13,923–53,161 m^2 of area is available for rainwater harvesting. Mulu et al. (2020) found that there is 132,910 m^2 of roof catchment area in Akaki Kality sub-city of Addis Ababa and assume that this could be used for rainwater harvesting. Thus, our assumption of using of up to 53,161 m^2 to achieve the same water retention benefits as trees is plausible.

We also assume that 12,894–58,564 electric vehicles will be purchased. There are approximately 510,555 vehicles in Addis Ababa, of which about 34% (173,589) are passenger cars (Jida et al., 2020). Thus, it may be unrealistic to assume that 58,564 new cars will be bought in one year. To better assess the feasibility of this assumption, it would also be important to consider the projected share of electric vehicles in Addis Ababa over the next 20 years.

The large number of electric vehicles needed also indicates that it may be impossible for grey infrastructure to provide the same benefits as trees in Addis Ababa. That is, money may not be the only limiting factor. While subsidies could encourage people to buy electric vehicles, other factors may also influence the decision to buy a new car. Additionally, Meszaros et al. (2021) conclude that electricity supply in Ethiopia may be a challenge for widespread electric vehicle use. These other barriers highlight the advantages of NBI.

Furthermore, we have not identified a grey infrastructure alternative for cooling. Fifty four percent of people in Addis Ababa rely on walking as their primary mode of transport (W. Tesso, personal communication, October 25, 2021). As the city warms due to climate change, outdoor cooling will become increasingly important for the many people who walk every day. Not only are trees a cost-effective way to mitigate heat, but urban green spaces may also be one of the only ways to provide this benefit.

3.6 Financial Analysis

Like the undiscounted results in Section 3.2, the S-NPV of trees increases substantially (and the S-IRR is orders of magnitude larger) when the maintenance and survival of trees are higher.

Compared to grey infrastructure, the considered tree planting interventions have much higher S-NPVs and S-IRRs. This is because grey infrastructure alternatives have high upfront costs, while the costs of trees are spread more evenly across the 20 years. Thus, when future costs and benefits are discounted, trees perform better. In fact, when using a discount rate of 8.5%, the investment necessary for electric vehicles and rainwater harvesting tanks is not paid off after 20 years. This contrasts with trees, which have a positive NPV for all scenarios when not including the government opportunity cost and for all high survival scenarios when including the government opportunity cost.

3.6.1 Base Financial Analysis

The results of the financial analysis, when accounting for inflation and applying a discount rate of 8.5%, underline the positive returns associated with the project that are presented above. Table 6 shows that when the adjustments are made, the project has a positive S-NPV under all scenarios. Under the scenario in which 25 million trees are planted, the S-NPV is ETB 336.4 million–1,345.5 million (USD 7.4 million–29.6 million) over a 20-year period depending on the assumed survival rate of the planted trees. In the case of only 11 million trees being planted, the estimated S-NPV ranges from ETB 200.0 million to ETB 822.7 million (USD 4.4 million to USD 18.1 million) depending on whether 30% of the trees survive or if 84% of trees survive.

To calculate the compounded average annual benefit (S-IRR) we adjusted the calculation so that initial investments were made in the year prior to realization of benefits; otherwise, the S-IRR is incalculable.[5] Upon making this adjustment, and when it is assumed that 84% of trees survive, the S-IRR is calculated to be 87.4%–106.2% higher than estimated costs. When it is assumed that only 30% of trees survive, the S-IRR is calculated to be 32.2%–37.0% higher than the estimated costs, depending on the number of trees planted.[6]

Table 6. S-NPV and S-IRR under RCP 4.5 climate scenario and accounting for all added benefits, added avoided costs, and investment and maintenance costs. All values are in 2021 million ETB.

NBI alternative	**25 million trees planted**		**11 million trees planted**	
Tree survival scenario	**84%**	**30%**	**84%**	**30%**
S-NPV	1,345.5	336.4	822.7	200.0
S-IRR[7]	87.4%	32.2%	106.2%	37.0%
Grey alternative	**53,161 m³ of rainwater harvesting and 58,564 electric vehicles**	**28,199 m³ of rainwater harvesting and 26,603 electric vehicles**	**31,403 m³ of rainwater harvesting and 30,492 electric vehicles**	**13,923 m³ of rainwater harvesting and 12,894 electric vehicles**
S-NPV	-563.6	-259.1	-295.5	-127.3
S-IRR	8.3%	8.3%	8.3%	8.3%

[5] An IRR is incalculable when the net investment (positive flows minus investment costs) in the first time period is positive. Essentially, the rate of return of the investment is infinity as there is no net upfront cost.

[6] For more details on variations of the financial analyses, including under the RCP 8.5 climate scenario, see Appendix D, Section 3.

[7] Note that IRR calculations for tree survival scenarios were adjusted so that initial investments were made in year prior to realization of benefits.

As outlined in Section 3.5, we also modelled a grey alternative that would deliver similar climate and environmental benefits as the tree planting program. From Table 6, we can see that in all cases the S-NPV of the grey alternative is less than zero, which indicates that the benefits of installing the rainwater harvesting tanks and converting to electric vehicles do not outweigh the costs. Comparing 25 million trees with an 84% survival rate and the equivalent grey investment, the tree planting program has an S-NPV that is ETB 1.9 billion (USD 42.1 million higher).[8] This gap shrinks as fewer trees are planted and fewer survive, but even when only 11 million trees are planted and only 30% survive, the S-NPV of trees is still ETB 327.3 million (USD 7.2 million) higher than the grey alternative.

3.6.2 Financial Analysis Considering Only Added Benefits and Investment and Maintenance Costs

As NPV and IRR are traditionally associated with cash flows, we thought it important to calculate the value of the project when only added benefits and investment and maintenance costs are considered. As can be seen in Table 8, under the assumption of a 20-year project lifetime, the tree planting project has a negative NPV under all scenarios. These negative NPV values reflect that the wages of persons planting and maintaining the trees are less than the total cost of planting and maintenance, an understandable outcome. The only other added benefit to offset these higher costs are linked to the fruit production of the trees; however, this production is not lucrative enough to offset the higher planting costs.

Table 7. NPV under RCP 4.5 climate scenario and accounting for all added benefits and investment and maintenance costs. All values are in 2021 million ETB.

NBI alternative	25 million trees planted		11 million trees planted	
Tree survival scenario	**84%**	**30%**	**84%**	**30%**
NPV	-736.4	-622.7	-350.0	-300.0
Grey alternative	**53,161 m³ of rainwater harvesting and 58,564 electric vehicles**	**28,199 m³ of rainwater harvesting and 26,603 electric vehicles**	**31,403 m³ of rainwater harvesting and 30,492 electric vehicles**	**13,923 m³ of rainwater harvesting and 12,894 electric vehicles**
NPV	-29,550.0	-13,445.5	-15,404.5	-6,518.2

[8] This difference is based on the positive S-NPV of ETB 1,345.5 million of the tree planting alternative and the negative S-NPV (ETB -563.6 million) of the equivalent grey infrastructure.

The tree planting interventions have much lower negative NPVs than the grey alternatives (that is, the NPV of trees is greater than the NPV of grey alternatives). As highlighted in the previous sections, this is linked to the significant upfront costs of purchasing electric vehicles instead of petrol- and diesel-powered cars. When these significant costs are added to the installation and maintenance costs of the rainwater harvesting infrastructure, it is logical that wages from installation and maintenance do not come close to offsetting these significant costs.

These significant upfront costs and continued annual maintenance costs also mean that we cannot calculate IRRs under this scenario. Without accounting for the avoided costs in the IRR calculation, one large net negative cash flow (the initial investment net of immediate wage and fruit production benefits) is followed by continued annual negative net cash flows because annual maintenance costs are higher than annual added benefits. Without net positive cash flows to offset the initial investment, there is no return on the investment. Thus, we cannot calculate the IRR, and the investment is unattractive and not viable for most investors.

3.6.3 Financial Analysis Considering Investment Opportunity Cost

As mentioned in Section 2.8, in wanting to present a more nuanced picture of the value of the project, we have also included a scenario in which we consider the investment opportunity cost. With any investment there is a cost associated with choosing one alternative over another. By using the estimated multiplier that Ilzetzki et al. (2013) found for fiscal spending by governments in developing countries, we estimated the opportunity cost of money being spent toward this project as opposed to other projects. Obviously, the multiplier used in calculating the opportunity cost would change depending on the sectors of the alternative investment considered; however, the government multiplier provides an estimate.

When these costs are taken into consideration, Table 7 shows the tree planting project has a positive S-NPV only when a high percentage of the planted trees survive. When only 30% of the trees survive and the investment opportunity cost is taken into account, the S-NPV is negative. As expected, and by definition, these values are lower when compared to those presented in Table 6 because we are including extra costs to the project valuation than in previous calculations.

Table 8. S-NPV and S-IRR under RCP 4.5 climate scenario and accounting for all added benefits, added avoided costs, and investment and maintenance costs. All monetary values are in 2021 million ETB. Double asterisk denotes multiple S-IRRs.[9]

NBI alternative	25 million trees planted		11 million trees planted	
Tree survival scenario	**84%**	**30%**	**84%**	**30%**
S-NPV	718.2	-290.9	522.7	-100.0
S-IRR[10]	33.8%	**	47.0%	-3.4%
Grey alternative	**53,161 m^3 of rainwater harvesting and 58,564 electric vehicles**	**28,199 m^3 of rainwater harvesting and 26,603 electric vehicles**	**31,403 m^3 of rainwater harvesting and 30,492 electric vehicles**	**13,923 m^3 of rainwater harvesting and 12,894 electric vehicles**
S-NPV	-40,831.8	-18,563.6	-21,277.3	-9,000
S-IRR	0.9%	0.9%	0.9%	0.9%

Similar to the estimates for the grey alternative in Table 6, Table 7 indicates that the grey alternative interventions have negative S-NPVs. However, what is particularly striking from Table 7 is the magnitude of negative S-NPVs. For example, when the investment opportunity cost is considered, the grey alternative of adding 53,161 cubic metres of rainwater harvesting and buying 58,564 electric vehicles instead of petrol- and diesel-powered cars would have a negative S-NPV of almost ETB 41 billion (USD 900 million). This estimation reflects the significant upfront cost of the grey intervention. To this point, the cost of purchasing 58,564 electric vehicles instead of petrol- and diesel-powered cars is ETB 29.3 billion (USD 644 million). When that cost is considered with the opportunity cost of investing in electric vehicles instead of other investments, the upfront cost included in the S-NPV calculation increases to over ETB 68 billion (USD 1.5 billion). Unsurprisingly, the benefits that accrue because of the intervention do not offset these massive costs, hence the negative S-NPV values.

[9] Multiple S-IRRs and IRRs occur when period net flows alternate between positive and negative over the time horizon of the project.

[10] Note that IRR calculations for tree survival scenarios were adjusted so that initial investments were made in year prior to realization of benefits.

4.0 Conclusion

In this report, we have presented the results of a Sustainable Asset Valuation for tree planting under the Green Legacy Campaign in Addis Ababa. Using spatial models to generate inputs for an integrated cost-benefit analysis and financial assessment, we have shown that planting trees generates value for society and can increase climate resilience.

Specifically, we have calculated the benefits of trees in terms of air quality, stormwater retention, ambient air temperatures, carbon storage, job creation, and fruit production under two climate scenarios. We have also shown that trees are a more feasible investment than grey infrastructure alternatives. The results can inform the city's plans to plant 25 million trees over the next 5 years.

We have demonstrated the value of urban green spaces for climate adaptation and the importance of investing not only to build, but also to maintain NBI. Trees provide a range of services for communities and public agencies, alike, but only if they survive. Furthermore, many of these impacts are not direct cash flows. This highlights some challenges in valuing and funding NBI. It is our hope that this integrated assessment can allow for these non-monetary impacts to be included in decision making.

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Appendix A. Tree Species Planted in 2021

The following list includes tree species planted in 2021. This list comes from information received from the Cities4Forests team in WRI Africa, based on government data. This list is not exhaustive but includes species that we know are being planted by the city. Bold items were included in our assessment.

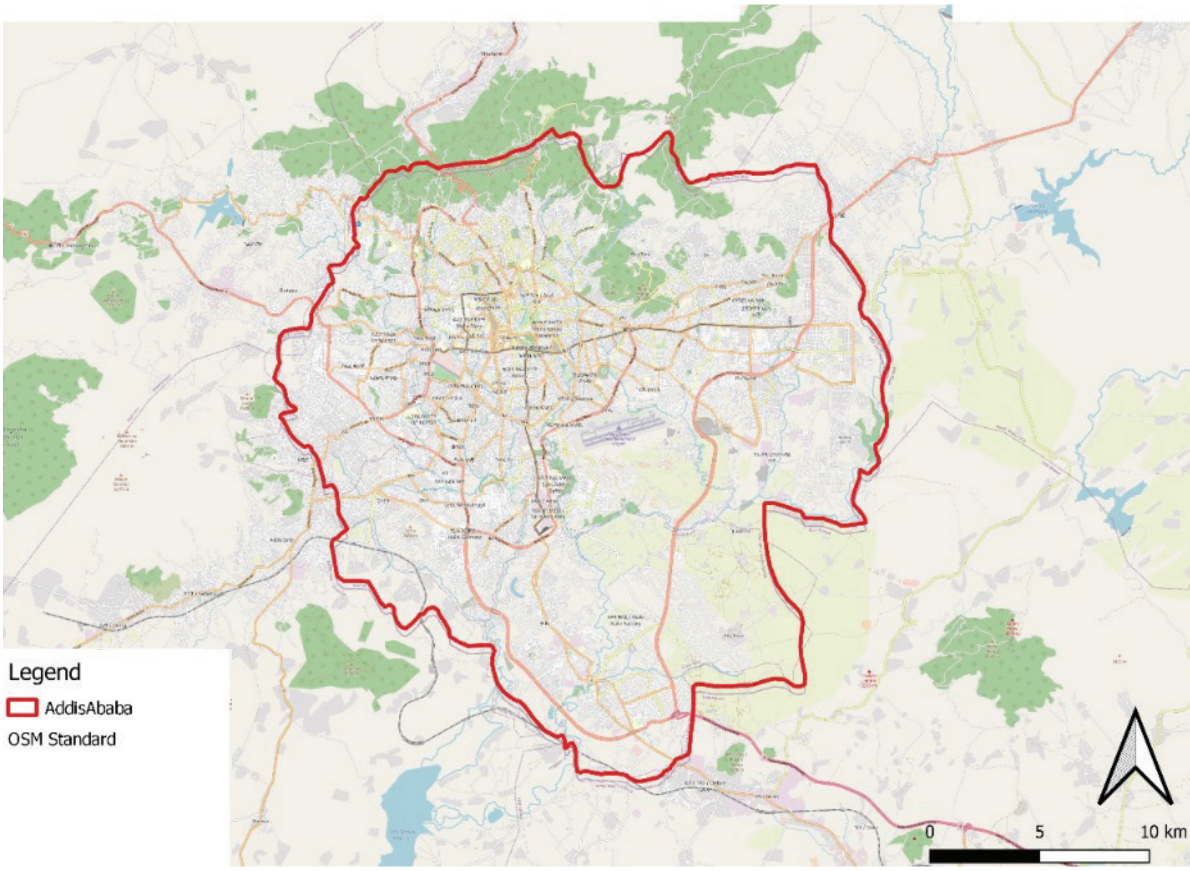
- *Acacia decurrens*
- *Acacia melanoxylon*
- *Acacia saligna*
- *Acacia tortilis*
- *Afrocarpus Gracilior*
- ***Avocado***
- *Bottle brush*
- *Cordia Africana*
- *Duranta*
- ***Ficus***
- *Grevillea robusta*
- ***Jacaranda***
- *Juniperus procera*
- *Mango*
- *Melia azedarach*
- *Olea europaea var. africana*
- ***Pinus patula***

Appendix B. Spatial Analysis

1. Model Setup Study Area

The study area of this analysis is Addis Ababa, the capital city of Ethiopia (Figure B1).

Figure B1. Addis Ababa city limits



Source: Authors' diagram created using data from OpenStreetMap (© OpenStreetMap contributors, https://www.openstreetmap.org/copyright).

Coordination System

The spatial assessment results are based on the world project coordinate system called "V WGS 84 / Pseudo-Mercator—Spherical Mercator—ESPG: 3857." Details on the coordinate system are as follows:

```
PROJCS["WGS 84 / Pseudo-Mercator",
  GEOGCS["WGS 84",
    DATUM["WGS_1984",
      SPHEROID["WGS 84",6378137,298.257223563,
        AUTHORITY["EPSG","7030"]],
      AUTHORITY["EPSG","6326"]],
    PRIMEM["Greenwich",0,
      AUTHORITY["EPSG","8901"]],
    UNIT["degree",0.0174532925199433,
      AUTHORITY["EPSG","9122"]],
    AUTHORITY["EPSG","4326"]],
  PROJECTION["Mercator_1SP"],
  PARAMETER["central_meridian",0],
  PARAMETER["scale_factor",1],
  PARAMETER["false_easting",0],
  PARAMETER["false_northing",0],
  UNIT["metre",1,
    AUTHORITY["EPSG","9001"]],
  AXIS["X",EAST],
  AXIS["Y",NORTH],
  EXTENSION["PROJ4","+proj=merc +a=6378137 +b=6378137 +lat_ts=0.0 +lon_0=0.0
+x_0=0.0 +y_0=0 +k=1.0 +units=m +nadgrids=@null +wktext  +no_defs"],
  AUTHORITY["EPSG","3857"]]
```

Land-Cover Maps

BAU

Three data sources were used to create the land use/land cover (LULC) map of Addis Ababa:

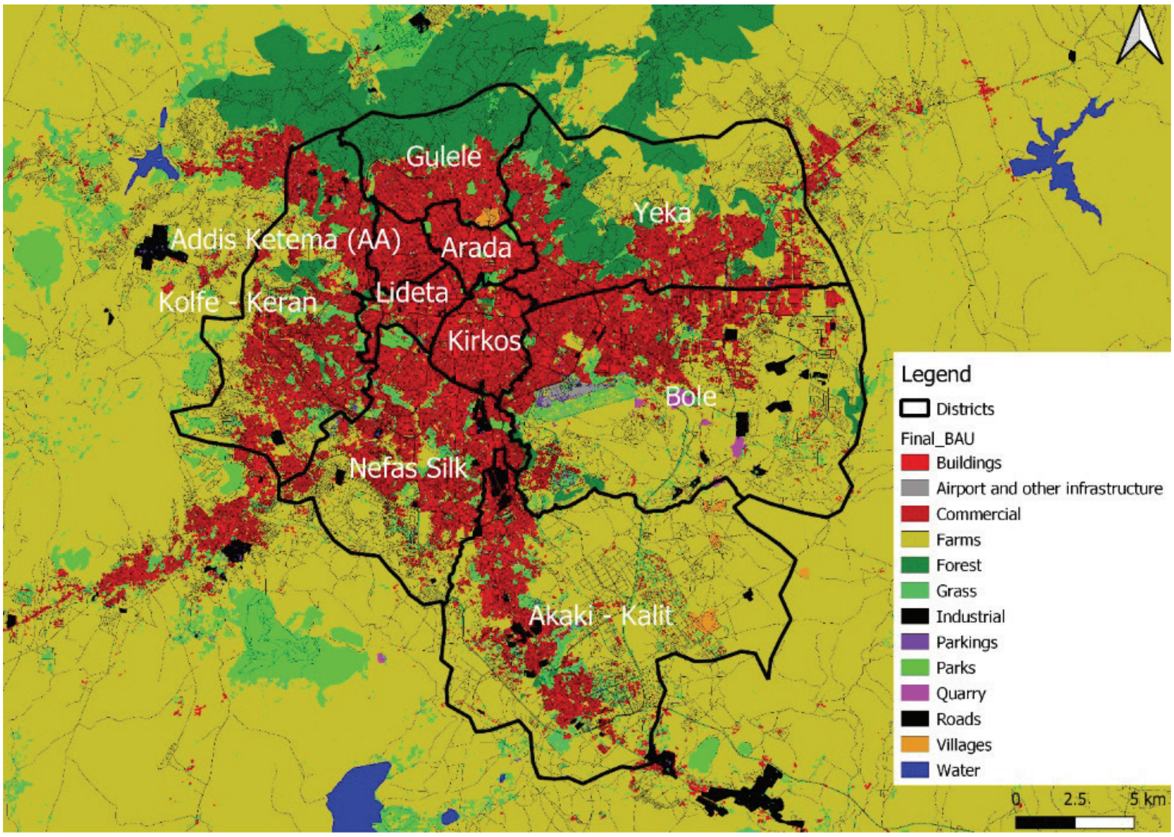
1. OpenStreetMap: This website allows users to download the shapefiles of the following land classes, which were then rasterized in QGIS 3.10 (resolution 10 m) (© OpenStreetMap contributors, https://www.openstreetmap.org/copyright).
    - Airport
    - Buildings
    - Commercial areas
    - Farms
    - Forests
    - Grassland
    - Industrial Areas
    - Parking lots and fuel stations
    - Urban Parks
    - Quarry
    - Waterbodies (lakes and ponds)
    - Villages
2. Geofabrik: From this website, the vector files of the following land classes were downloaded and then rasterized in QGIS 3.10 (resolution 10m) (Central Statistics Agency & Regional Bureau of Finance and Economic Development, 2021).
    - Roads
    - Rivers (merged with lakes and ponds into the single class "water")
3. The LULC map created by the CCI Land Cover (LC) team (CCI Land Cover team, 2021) (© Contains modified Copernicus data (2015/2016), © ESA Climate Change Initiative—Land Cover project 2017). This is a prototype high-resolution LULC map at 20 m over Africa based on 1 year of Sentinel-2A observations from December 2015 to December 2016. The area of interest was extracted from this map and its resolution was increased to 10 m in QGIS 3.10.

    The legend of this map includes 10 generic classes that appropriately describe the land surface at 20 m: "trees cover areas," "shrubs cover areas," "grassland," "cropland," "vegetation aquatic or regularly flooded," "lichen and mosses / sparse vegetation," "bare areas," "built-up areas," "snow and/or ice," and "open water."

    The raster files created from OpenStreetMap and Geofabrik were merged into a single raster file. Since the maps created with this step presented some gaps, we used the LULC map created by the CCI LC team to avoid any areas with missing information. The land classes of the CC LC team were renamed and merged with the respective classes described in points 1) and 2). For example, "built-up areas" were merged with "buildings."

Figure B2 shows the LULC map in the BAU scenario, while Figure B3 shows the colour legend and the codes of each land class.

Figure B2. BAU LULC



Source: Authors' diagram based on data from CCI Land Cover team (2021) (© Contains modified Copernicus data (2015/2016), © ESA Climate Change Initiative—Land Cover project 2017).

Figure B3. Legend and codes (BAU)

Land Classes - BAU

- 2 - Buildings
- 3 - Airport and other infrastructure
- 4 - Commercial
- 5 - Farms
- 6 - Forest
- 7 - Grass
- 8 - Industrial
- 9 - Parkings
- 10 - Parks
- 12 - Quarry
- 13 - Roads
- 14 - Villages
- 15 - Water

Source: Authors' diagram.

TREE PLANTING SCENARIOS

This assessment considers the following LULC scenarios:

- 11 million trees planted, with 84% survival and 30% survival (9.24 million and 3.3 million surviving trees respectively)
- 25 million trees planted, with 84% survival and 30% survival (21 million and 7.5 million surviving trees respectively).

Table B1 summarizes the different LULC scenarios considered in this analysis.

Table B1. Tree planting ambition in Addis Ababa

Million trees	Survival rate		
	100%	**84%**	**30%**
25	25.00	21.00	7.50
11	11.00	9.24	3.30

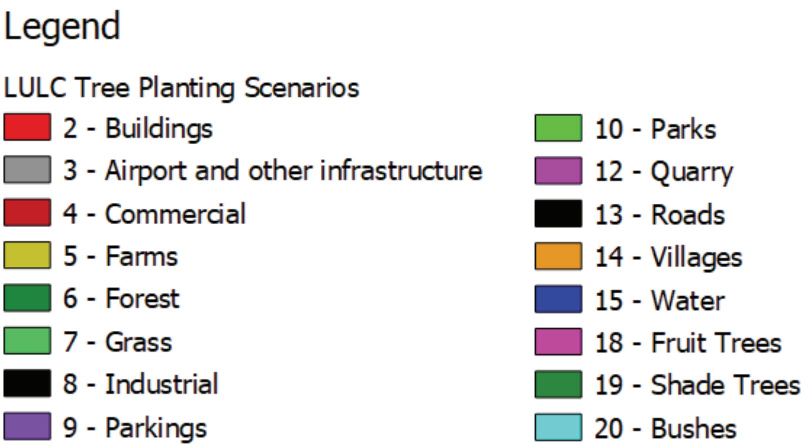
For each scenario, we assumed that 55% are shade trees, 37% are bushes, and 8% are fruit trees.

Note: Since the LULC map has a resolution of 10 m, every pixel covers an area of 100 m². We assumed that in each pixel, 15 trees will be planted. From that information, we derived the number of pixels covered by new trees and the area covered (m²).

Note: To locate new trees in the LULC BAU map we chose to "plant" them along the road network of the city and by replacing farmland and grassland areas with trees. When considering the survival LULC scenarios, we chose to prioritize trees along the street.

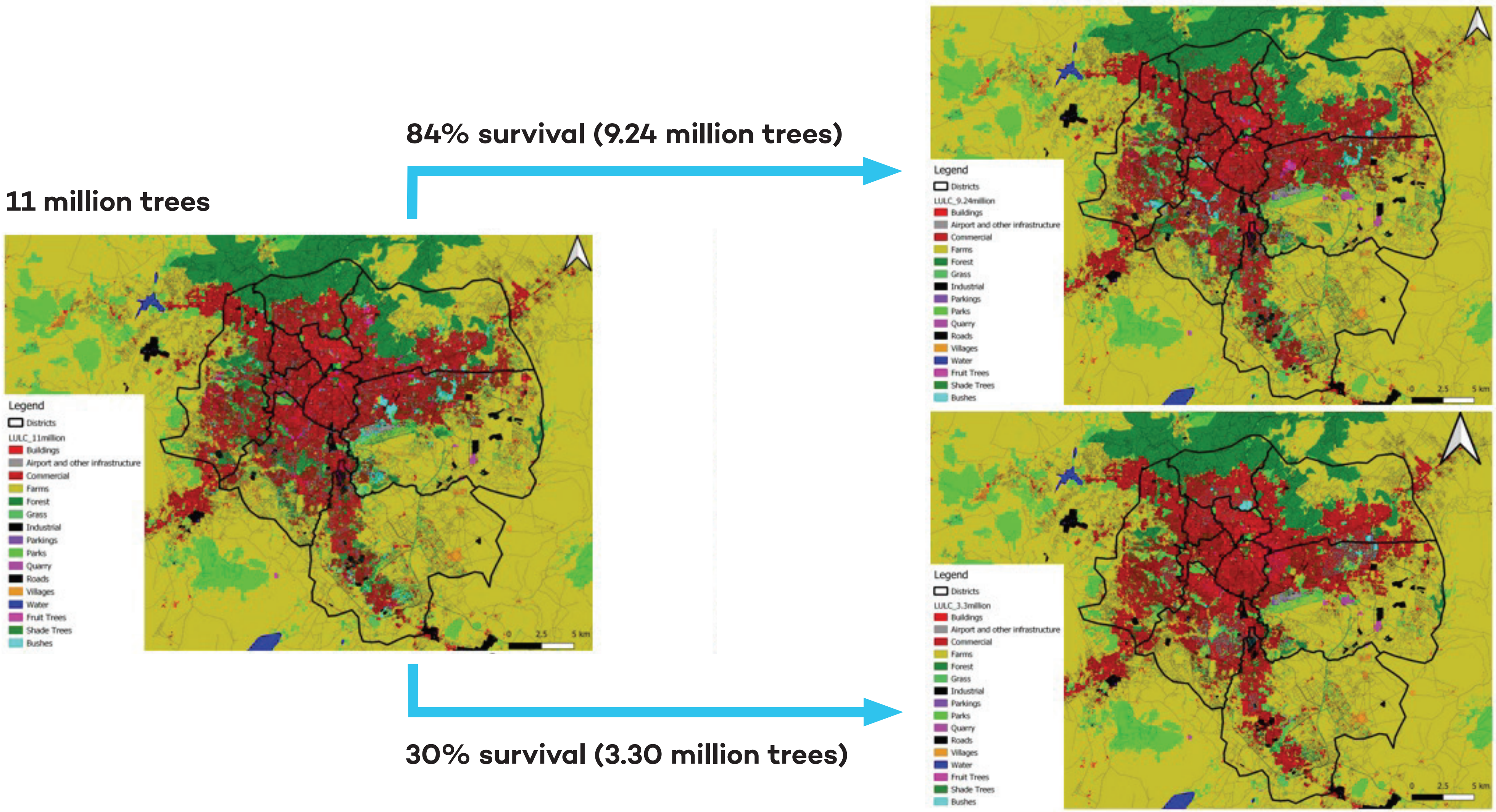
Figure B4 shows the colour legend and the codes of each land class. Figure B5 and Figure B6 show the different LULC scenarios.

Figure B4. Legend and codes (trees)



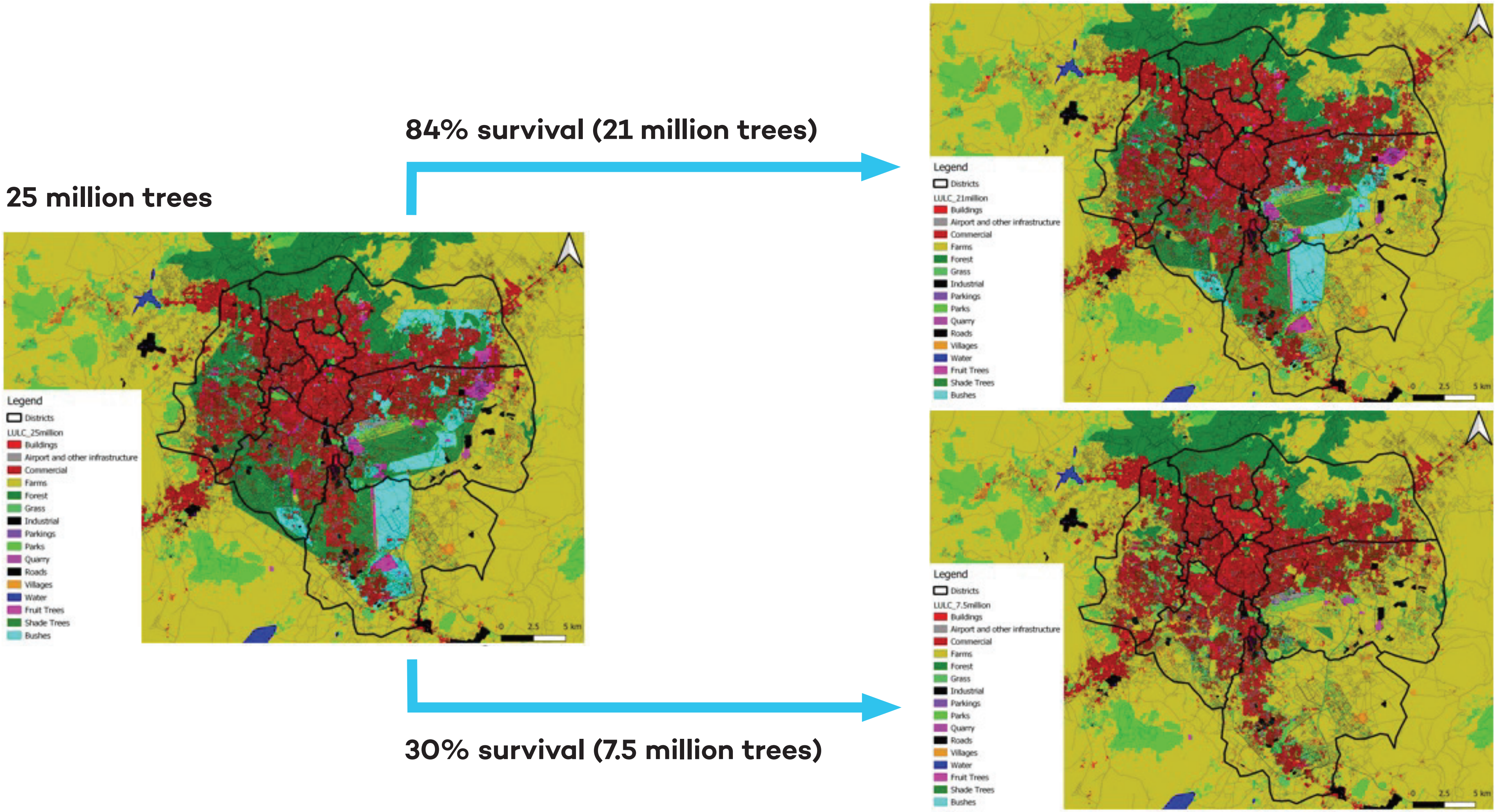
Source: Authors' diagram.

Figure B5. LULC 11 million trees and survival scenarios



Source: Authors' diagram based on data from CCI Land Cover team (2021) (© Contains modified Copernicus data (2015/2016), © ESA Climate Change Initiative – Land Cover project 2017).

Figure B6. LULC for 25 million trees and survival scenarios



Source: Authors; diagram based on data from CCI Land Cover team (2021) (© Contains modified Copernicus data (2015/2016), © ESA Climate Change Initiative – Land Cover project 2017).

Software and Simulation

The ecosystem services map simulation has been performed using InVEST Software V.3.9.0 (Natural Capital Project, 2019). The input spatial data for the InVEST model have been prepared using QGIS version 3.10 available under a CC BY-SA licence (QGIS, 2019). The tabulated data will be managed and prepared in Microsoft Excel V. 2016.

2. Carbon Storage

"Terrestrial ecosystems, which store more carbon than the atmosphere, are vital to influencing carbon dioxide-driven climate change. The InVEST Carbon Storage and Sequestration model uses maps of land use along with stocks in four carbon pools (aboveground biomass, belowground biomass, soil, and dead organic matter) to estimate the amount of carbon currently stored in a landscape" (Sharp et al., 2020).

INPUT DATA PREPARATION AND PROCESSING

1. LULC maps: The maps described in the preceding section were used in this model.
2. Carbon Pools: Table of LULC classes, containing data on carbon stored in each of the four fundamental pools for each LULC class:
   - Carbon above ground: The values of carbon density in aboveground mass, measured in megagrams per hectare (Mg/ha), where 1 Mg/ha is equal to 1 ton/ha, of each land-use type are shown in Table B2
   - Carbon below ground: The values of carbon density in belowground mass (Mg/ha or tons/ha) of each land-use type are shown in Table B2,
   - Carbon stored in organic matter: The values of carbon density in dead mass (Mg/ha or tons/ha) of each land-use type are shown in Table B2.
   - Carbon stored in soil: The values of carbon density in dead mass (Mg/ha or tons/ha) of each land-use type are shown in Table B2.

The unit of measurement for these coefficients is Mg/ha or tons/ha. Average carbon coefficients values have been found in the "2006 IPCC Guidelines for National Greenhouse Gas Inventories" report, Chapter 4 "Agriculture, Forestry and Other Land Use" (IPCC, 2006).

It is worth noting how the carbon pools for the new trees were calculated. To begin with, we retrieved the CO_2 stored (in kg) of four species: ficus, jacaranda, and pinus from the USDA Forest Service (Urban Ecosystems and Processes Team, 2008), and avocado from ZEROCO2 (2020). We then calculated the average value. Next, we divided the average value by 3.67 (from CO_2 to C) and by 1,000 (from kg to tons), and we multiplied it by 15 (number of trees in one pixel). Also considering that grass can be found between trees, we calculated the aboveground biomass and subsequently, following the IPCC guidelines, the other carbon pools (C_Below, C_Soil, and C_dead).

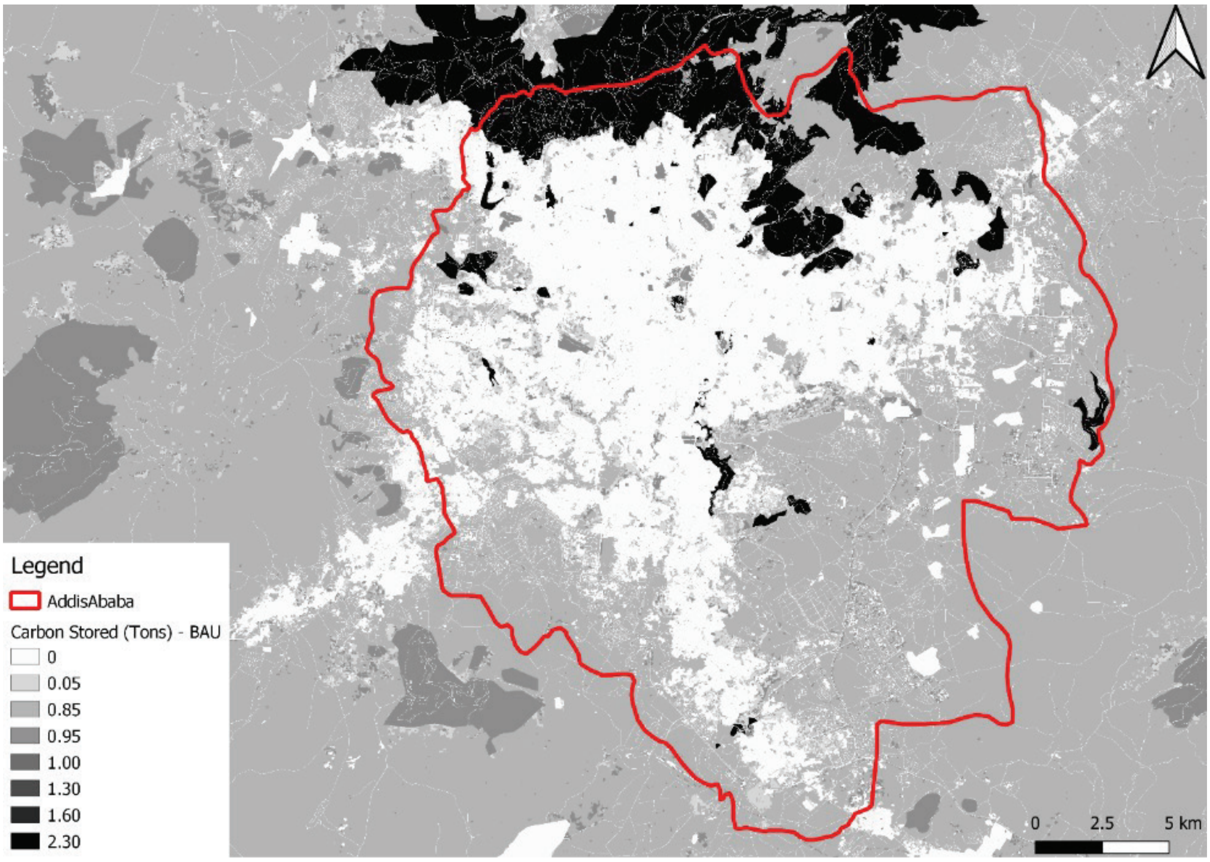
Table B2. Carbon pools

lucode	C_above	C_below	C_soil	C_dead
2	0.00	0.00	0.00	0.00
3	0.00	0.00	0.00	0.00
4	0.00	0.00	0.00	0.00
5	9.87	2.66	72.09	0.00
6	70.50	19.04	138.67	2.00
7	2.91	0.79	1.36	0.00
8	0.00	0.00	0.00	0.00
9	0.00	0.00	0.00	0.00
10	18.80	5.08	66.91	5.00
12	0.00	0.00	0.00	0.00
13	0.00	0.00	0.00	0.00
14	0.00	0.00	0.00	0.00
15	0.00	0.00	0.00	0.00
18	7.31	4.10	117.87	2.25
19	12.19	6.83	138.67	3.75
20	2.44	1.37	97.07	0.75

RESULTS

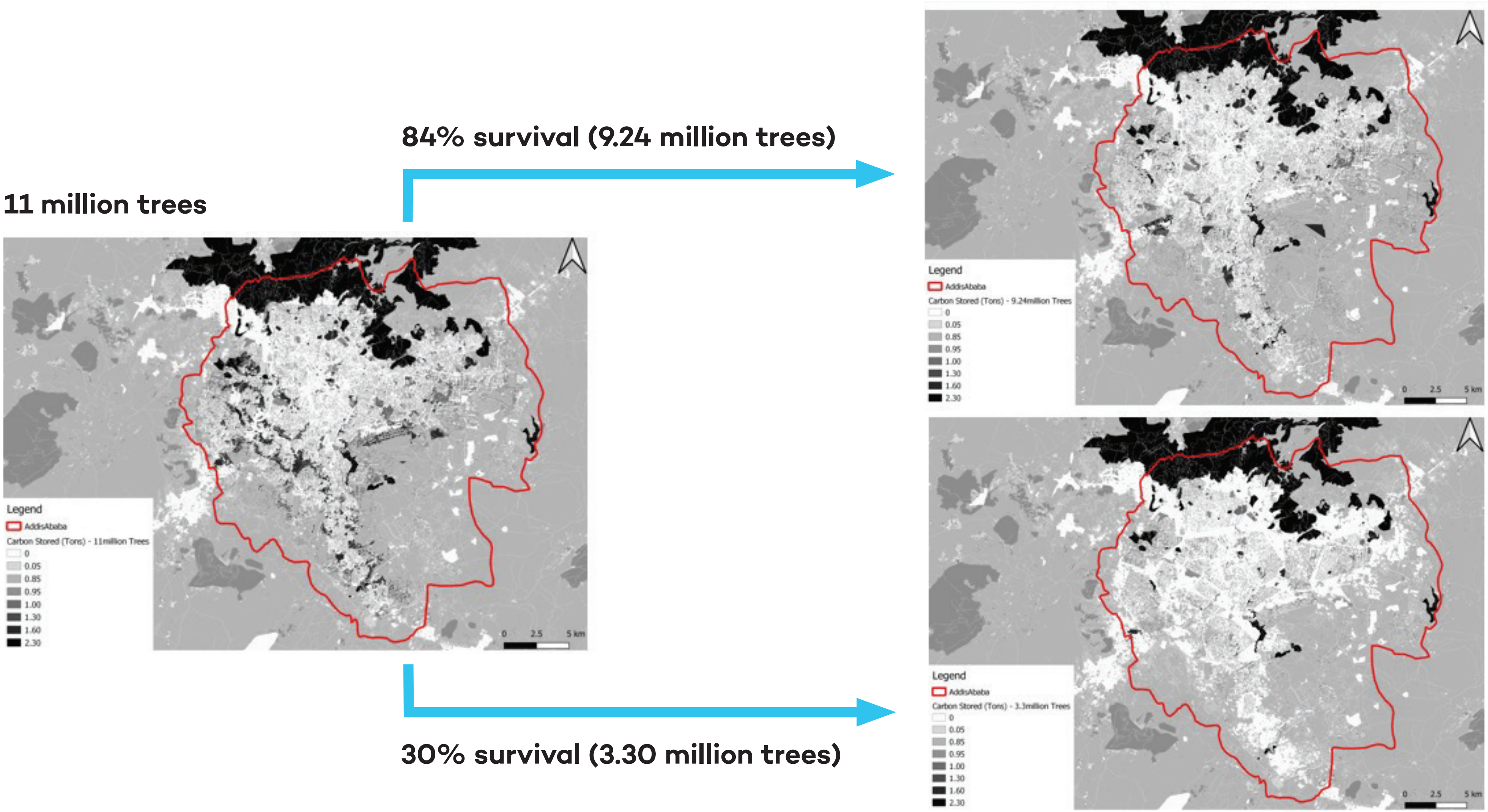
Figure B7 shows the amount of carbon stored in tons in each pixel using the LULC BAU map, while Figure B8 and Figure B9 show the carbon stored with 11 million and 25 million new trees planted, including survival scenarios.

Figure B7. Carbon model outputs (LULC BAU)



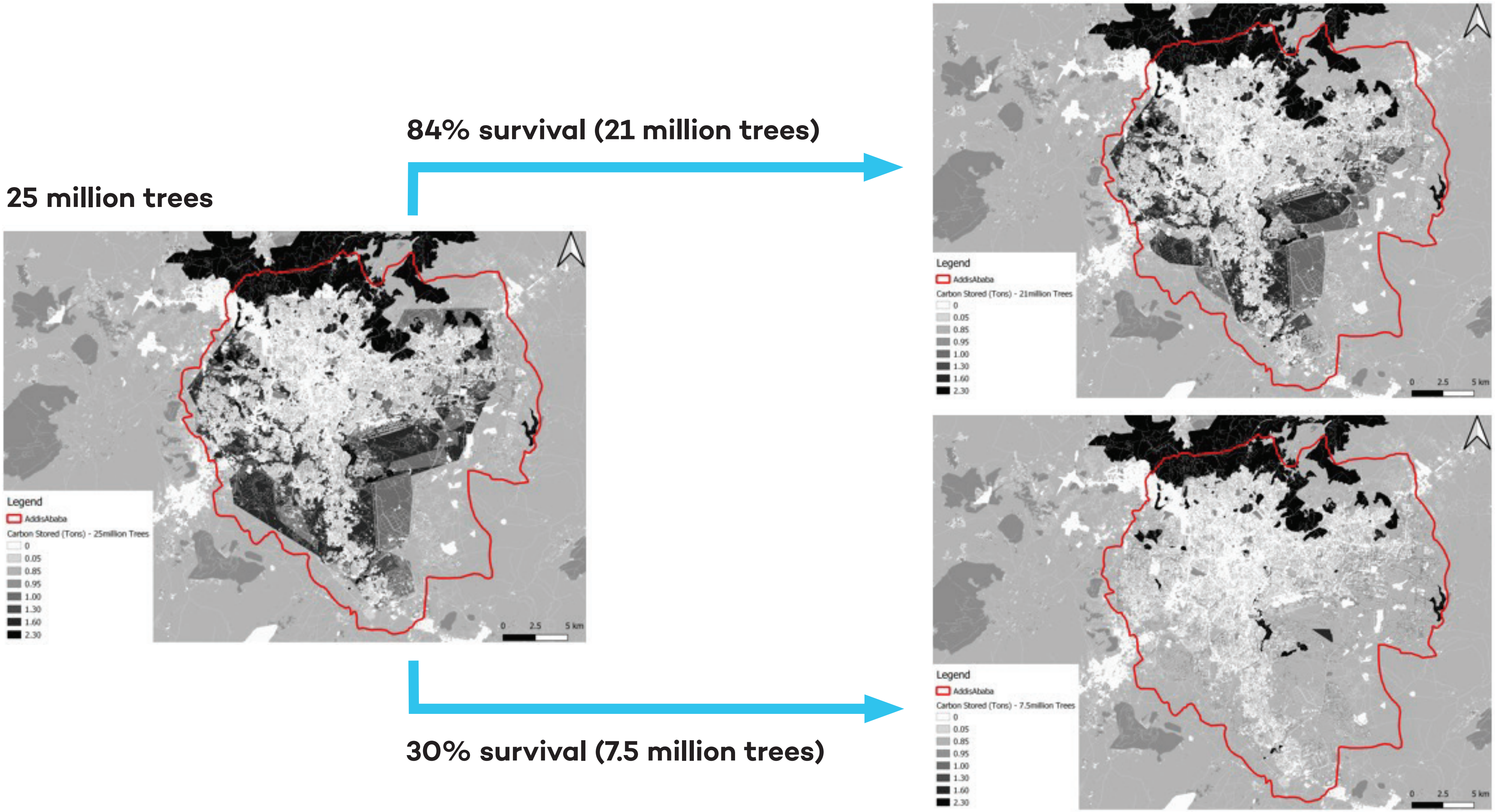
Source: Authors' diagram based on outputs from InVEST model.

Figure B8. Carbon storage—11 million trees and survival scenarios



Source: Authors' diagram based on outputs from InVEST model.

Figure B9. Carbon storage—25 million trees and survival scenarios



Source: Authors' diagram based on outputs from InVEST model.

Table B3. Carbon storage statistics

LULC scenario (number of trees planted)	Total carbon stored (Tons)	(InVEST) Difference between LULC scenarios and LULC BAU (%)
LULC BAU	3,260,764.55	
LULC 3.3 million	3,525,014.70	8.10%
LULC 7.5 million	3,805,951.95	16.72%
LULC 9.24 million	3,885,662.36	19.16%
LULC 11 million	4,110,309.99	26.05%
LULC 21 million	4,460,961.33	36.81%
LULC 25 million	4,599,440.57	41.05%

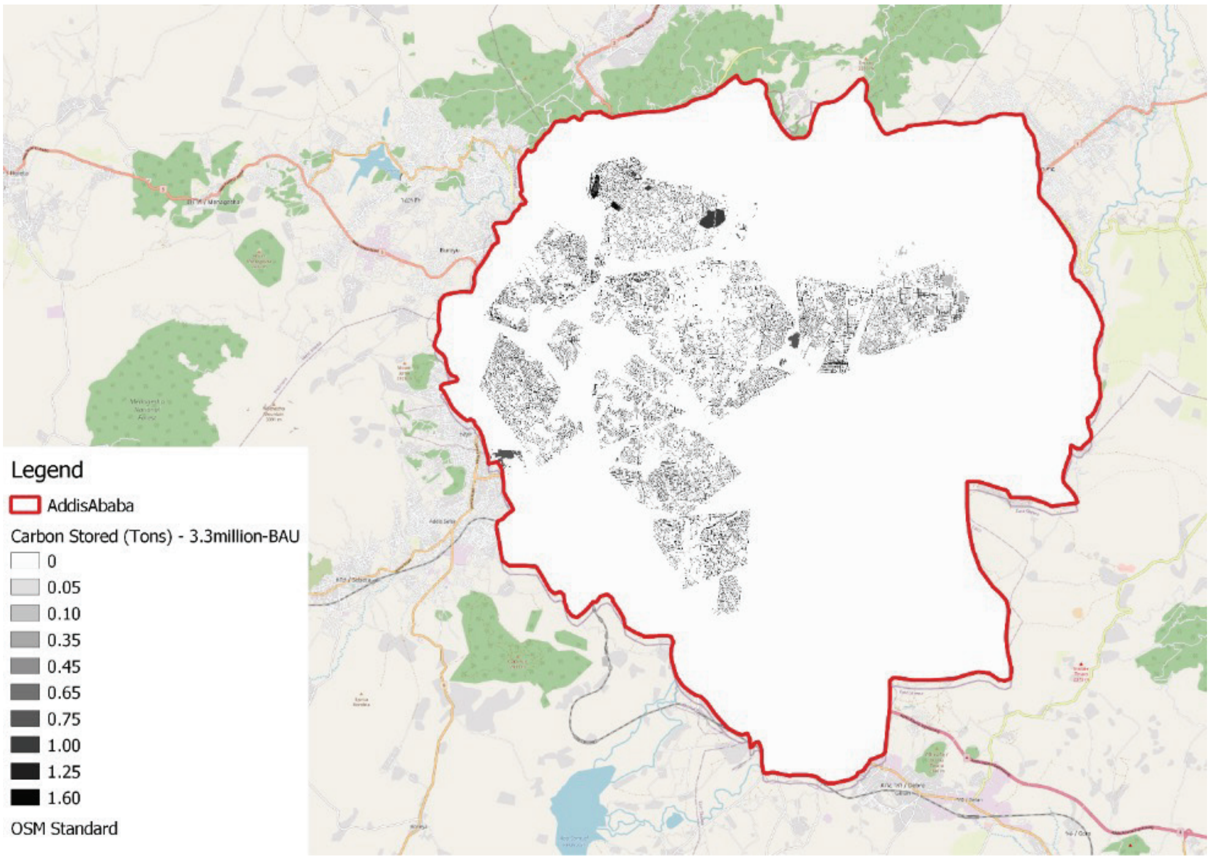
As Table B3 shows, increasing the number of trees in Addis Ababa would also increase the total amount of carbon stored.

If 11 million trees are planted in Addis Ababa, the carbon stored would increase by 26% compared to the BAU scenario. However, under the survival scenarios of 84% and 30%, the total carbon stored would increase by 19% and 8% respectively, compared to the base case scenario.

If 25 million trees are planted in Addis Ababa, the carbon stored would increase by 41% compared to the BAU scenario. However, under the survival scenarios of 84% and 30%, the total carbon stored would increase by 36% and 17% respectively, compared to the base case scenario.

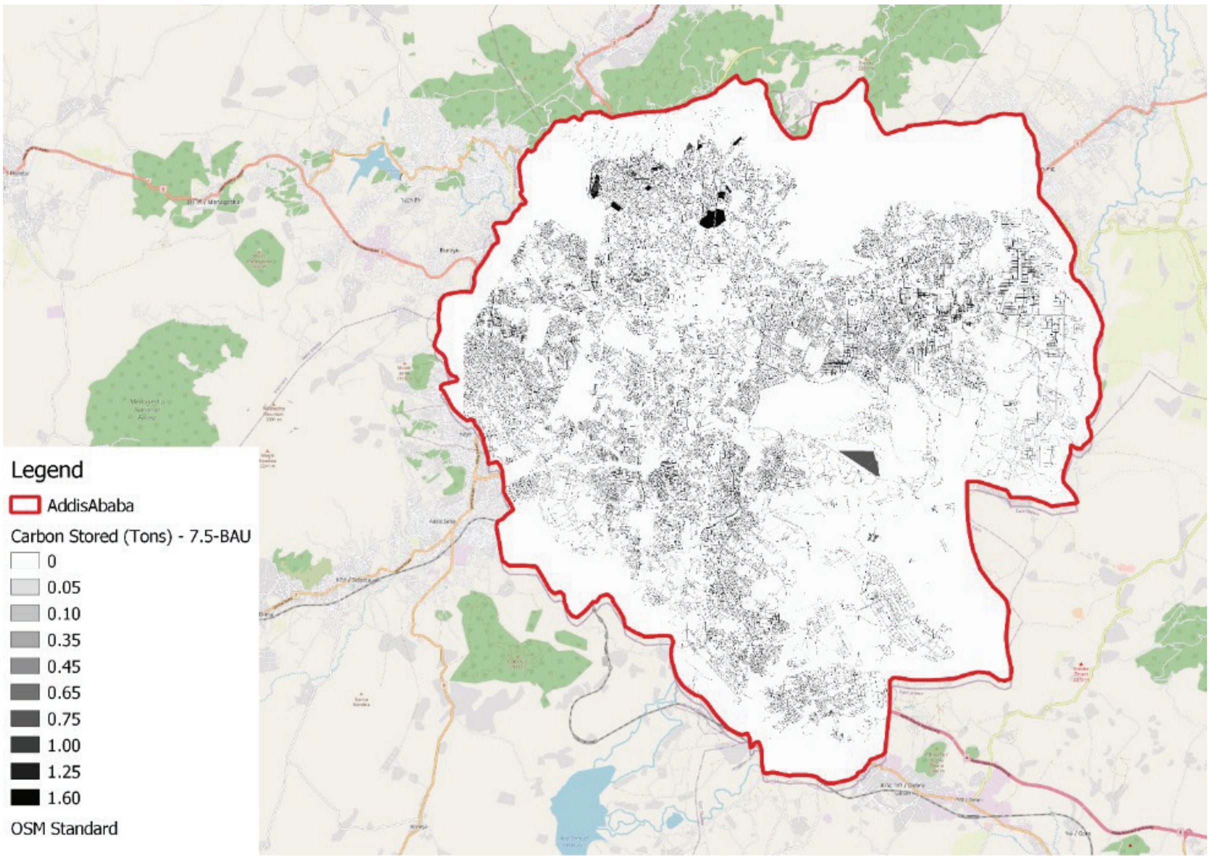
Finally, we calculated in QGIS3.10 the difference between each alternative scenario and the LULC BAU scenario to better visualize the increase in carbon storage. Figure B10, Figure B11, Figure B12, Figure B13, Figure B14, and Figure B15 show the location of carbon storage increase of each scenario compared to the base case scenario.

Figure B10. Carbon storage—3.3 million trees scenario—BAU



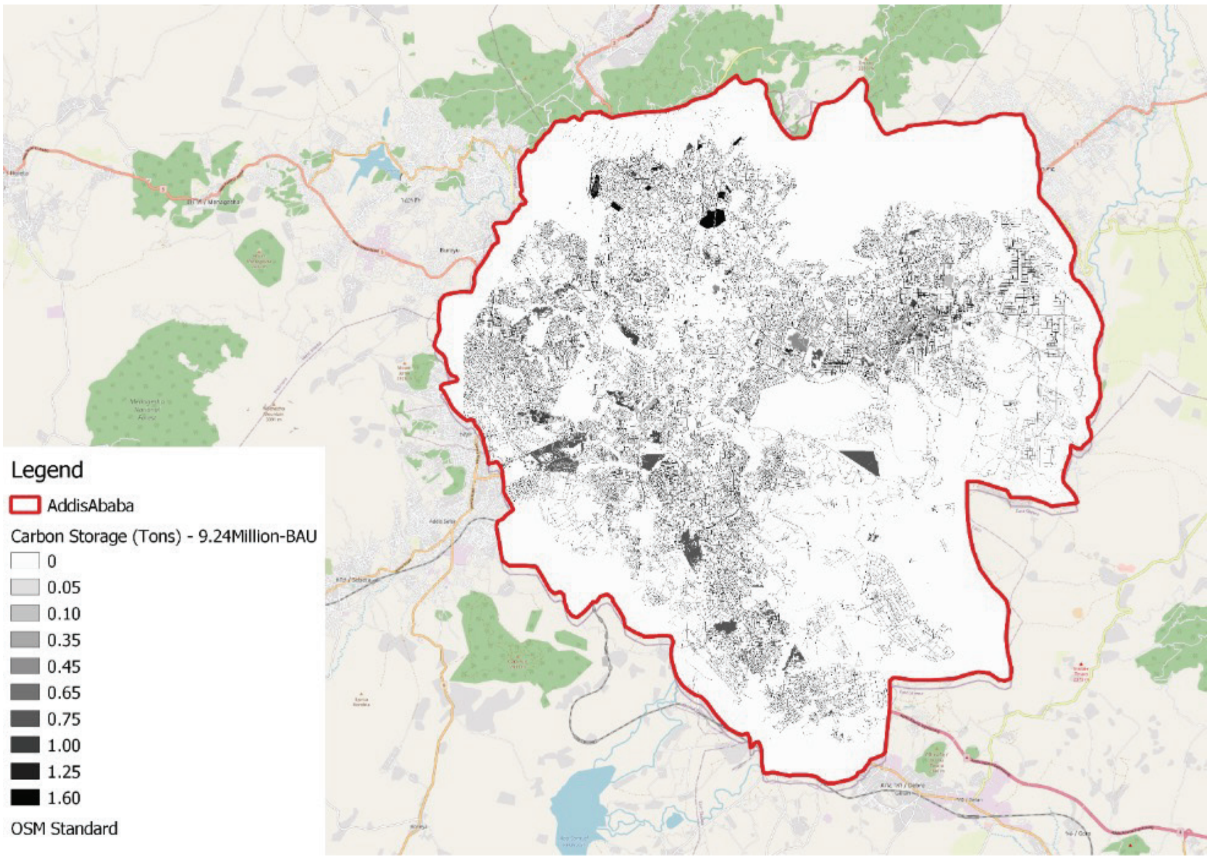
Source: Authors' diagram based on outputs from InVEST model. Background map data from OpenStreetMap (© OpenStreetMap contributors, https://www.openstreetmap.org/copyright).

Figure B11. Carbon storage—7.5 million trees scenario—BAU



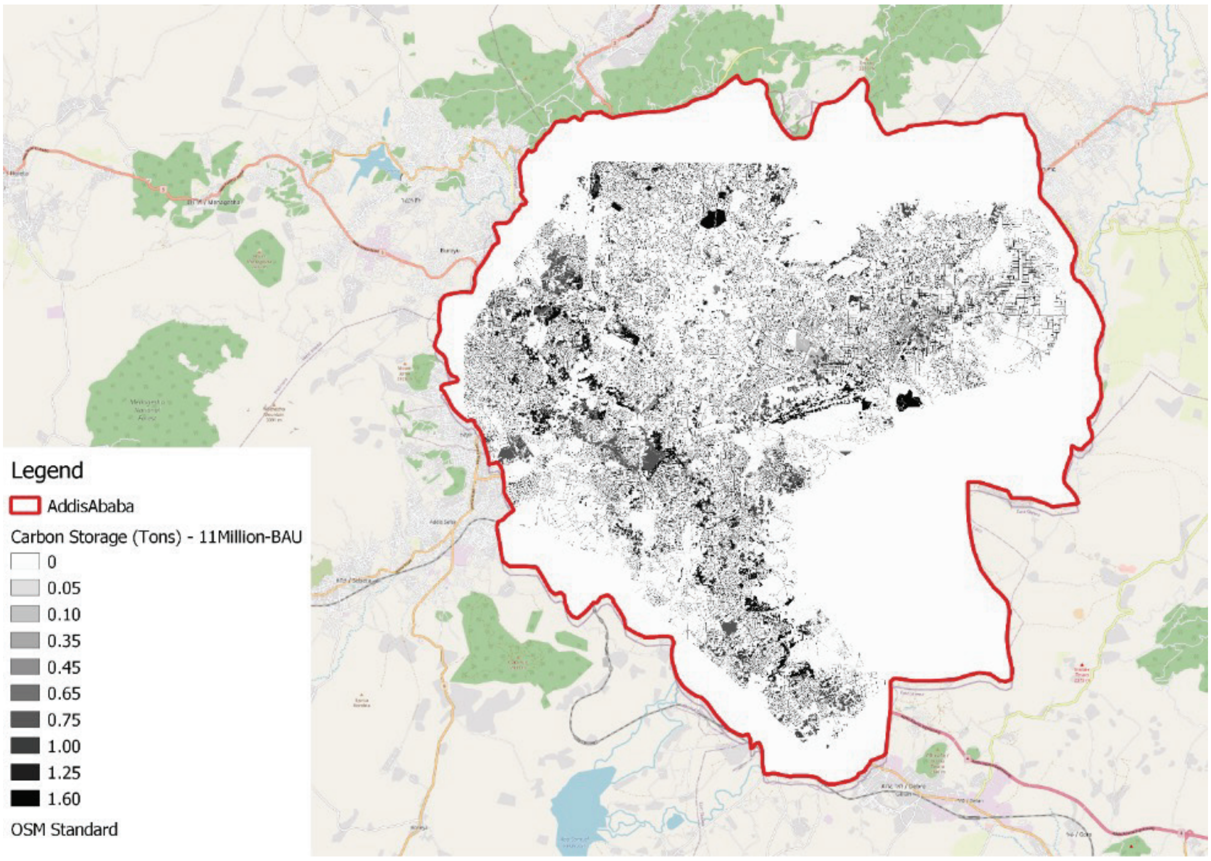
Source: Authors' diagram based on outputs from InVEST model. Background map data from OpenStreetMap (© OpenStreetMap contributors, https://www.openstreetmap.org/copyright).

Figure B12. Carbon storage—9.24 million trees scenario—BAU



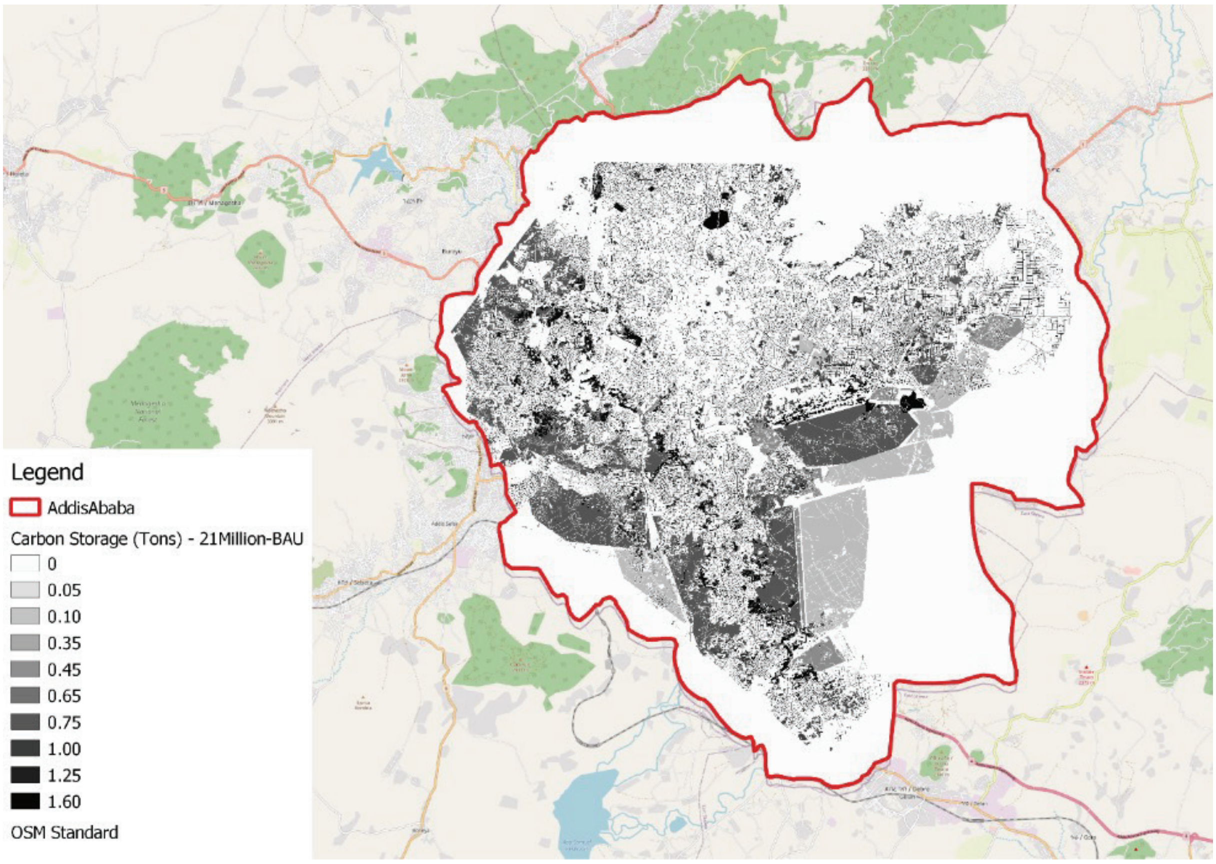
Source: Authors' diagram based on outputs from InVEST model. Background map data from OpenStreetMap (© OpenStreetMap contributors, https://www.openstreetmap.org/copyright).

Figure B13. Carbon storage—11 million trees scenario—BAU



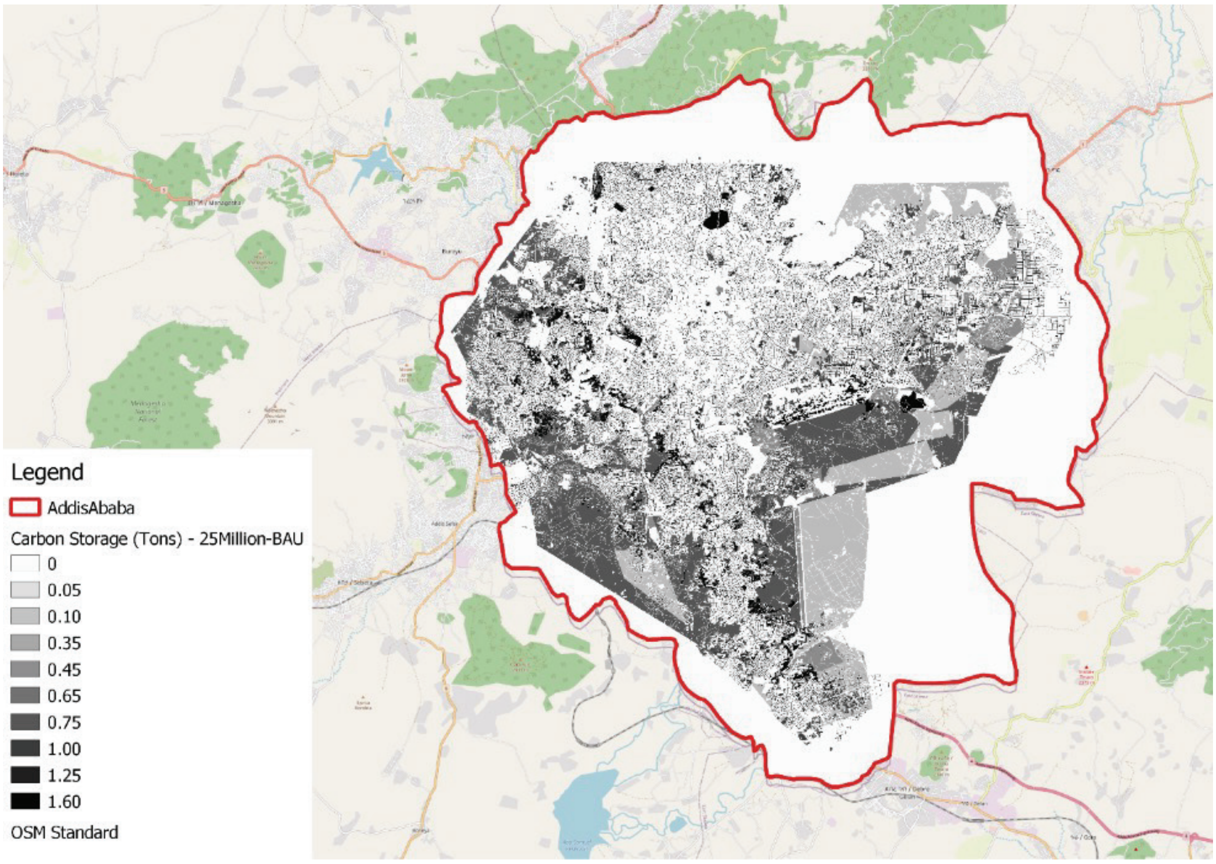
Source: Authors' diagram based on outputs from InVEST model. Background map data from OpenStreetMap (© OpenStreetMap contributors, https://www.openstreetmap.org/copyright).

Figure B14. Carbon storage—21 million trees scenario—BAU.



Source: Authors' diagram based on outputs from InVEST model. Background map data from OpenStreetMap (© OpenStreetMap contributors, https://www.openstreetmap.org/copyright).

Figure B15. Carbon storage—25 million trees scenario—BAU



Source: Authors' diagram based on outputs from InVEST model. Background map data from OpenStreetMap (© OpenStreetMap contributors, https://www.openstreetmap.org/copyright).

3. Urban Flood Risk

"Flood hazard comes from different sources, including: riverine (or fluvial) flooding, coastal flooding, and stormwater (or urban) flooding—the focus of this InVEST model. Natural infrastructure can play a role for each of these flood hazards. Related to stormwater flooding, natural infrastructure operates mainly by reducing runoff production, slowing surface flows, and creating space for water (in floodplains or basins).

"The InVEST model calculates the runoff reduction, i.e. the amount of runoff retained per pixel compared to the storm volume" (Sharp et al., 2020).

Input Data Preparation and Processing

1. **LULC maps:** The maps described in Section 1.1.1 and 1.1.2 were used in this model.
2. **Depth of rainfall in mm:** For this analysis, we used 63.14 mm as a reference since this value is indicated by Zemuy (2008) as an event of 0.5 hours that can occur every 5 years in Addis Ababa.

3. **Soils Hydrological Group Raster:** Raster of categorical hydrological groups. Pixel values must be limited to 1, 2, 3, or 4, which correspond to soil hydrologic group A, B, C, or D, respectively (used to derive the curve number [CN]). The dataset can be requested from Gijs Simons at futurewater.eu/about-us/our-team/gijs-simons/.
4. **Biophysical Table:** A table containing model information corresponding to each of the land-use classes in the Land Cover Map (Table B4). All LULC classes in the Land Cover raster must have corresponding values in this table. These values have been derived from sample data provided by InVEST. Each row is a land-use/land-cover class, and columns must be named and defined as follows:
    - lucode: Land-use/land-cover class code. LULC codes must match the "value" column in the Land Cover Map raster and must be integer or floating-point values, in consecutive order, and unique.
    - CN values for each LULC type and each hydrologic soil group. Column names should be CN_A, CN_B, CN_C, CN_D, which the letter suffix corresponding to the hydrologic soil group.

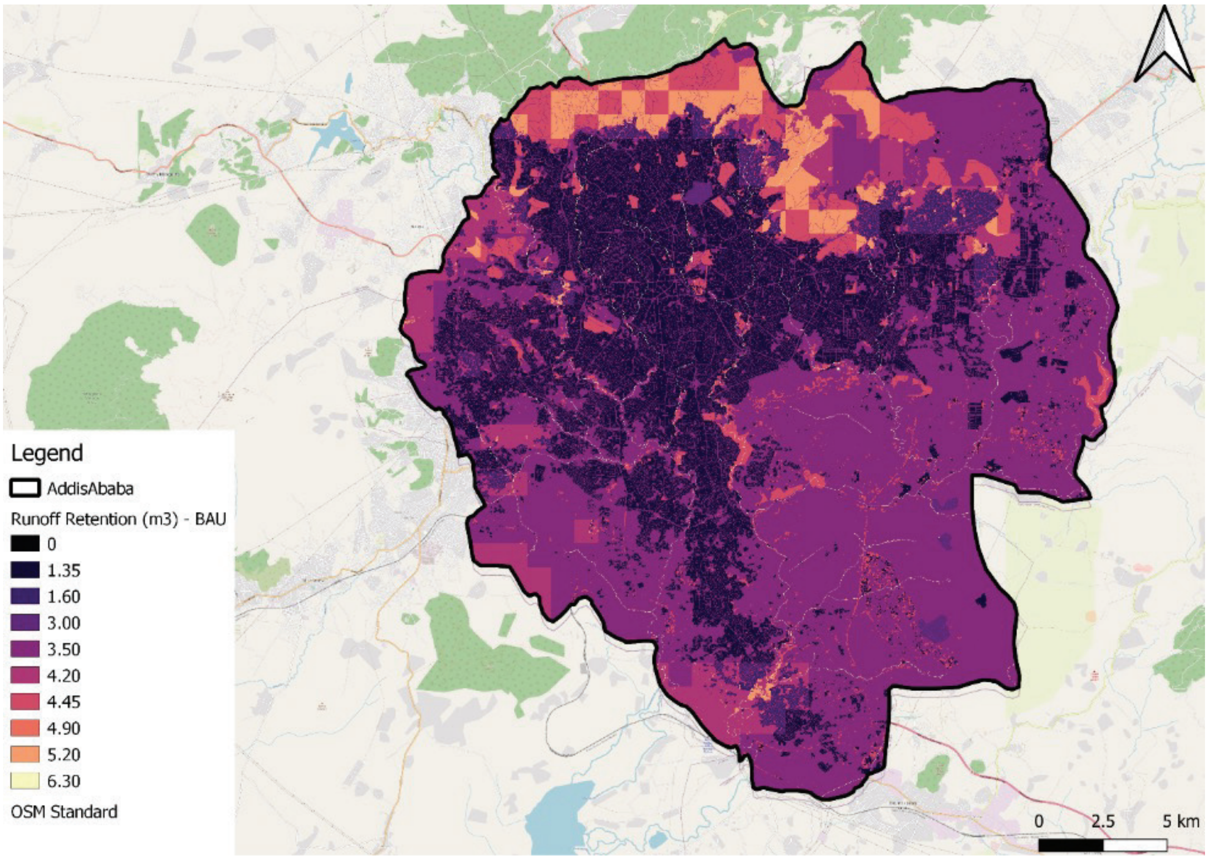
Table B4. Biophysical table

lucode	CN_A	CN_B	CN_C	CN_D
2	89	92	94	95
3	51	68	79	84
4	89	92	94	95
5	49	69	79	84
6	35	56	70	77
7	49	69	79	84
8	89	92	94	95
9	49	69	79	84
10	35	56	70	77
12	49	69	79	84
13	49	69	79	84
14	61	75	83	87
15	1	1	1	1
18	35	56	70	77
19	35	56	70	77
20	36	60	73	79

Results

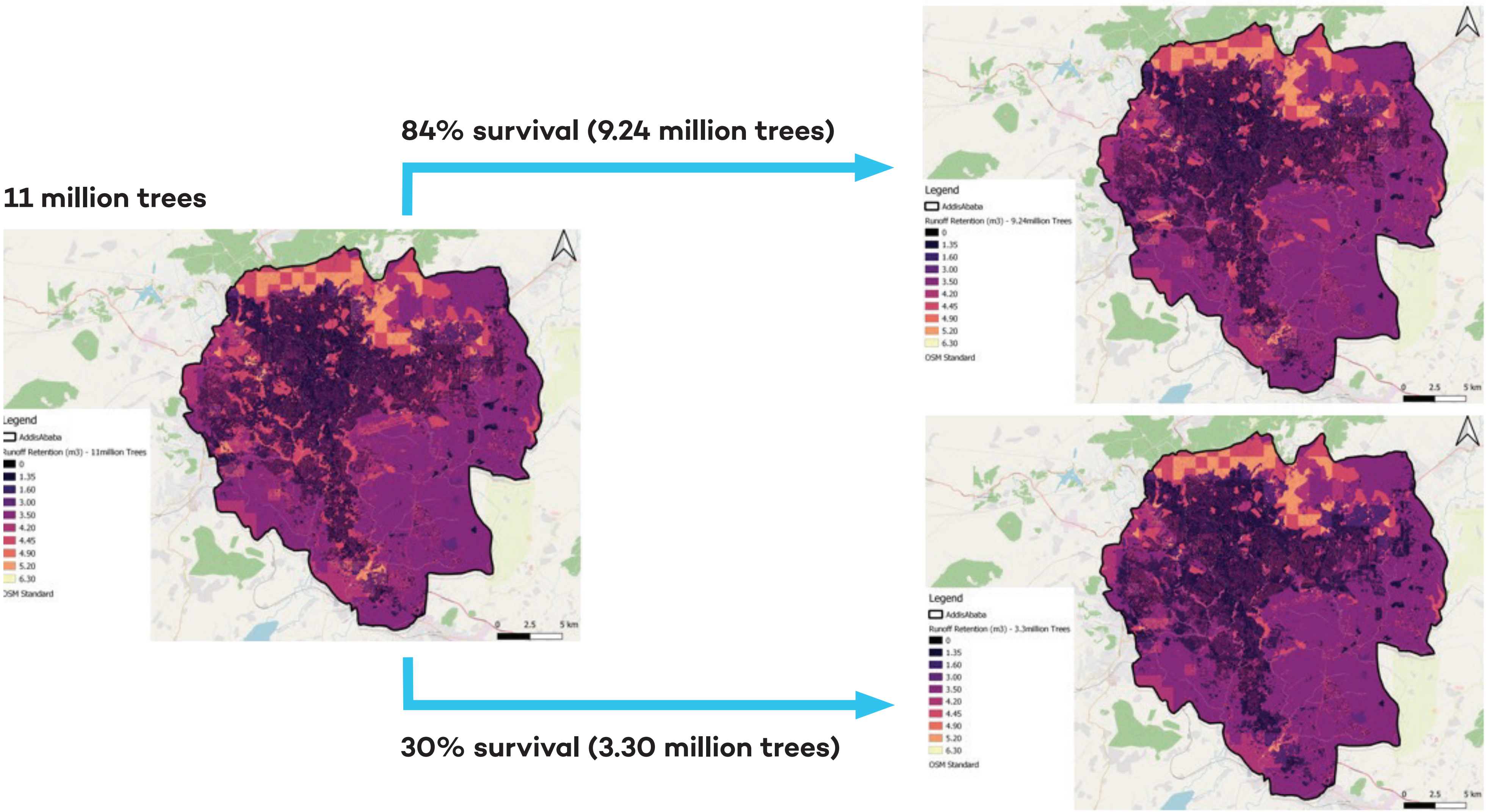
Figure B16 shows the runoff retention volumes (m³) in the study area using the LULC BAU map, while Figure B17 and Figure B18 show the runoff retention volumes with 11 million and 25 million new trees planted, including survival scenarios.

Figure B16. Runoff retention (m³)—LULC BAU



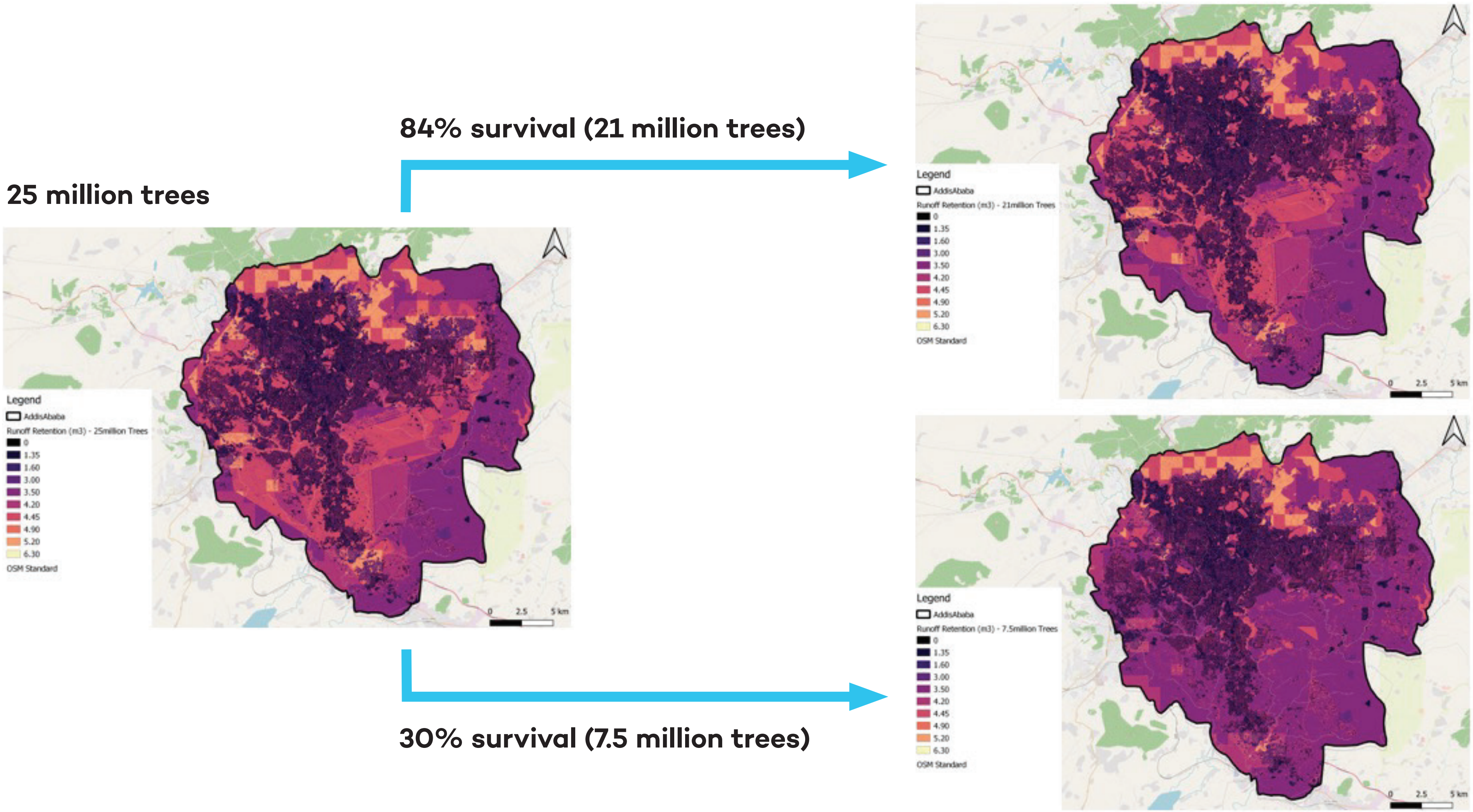
Source: Authors' diagram based on outputs from InVEST model. Background map data from OpenStreetMap (© OpenStreetMap contributors, https://www.openstreetmap.org/copyright).

Figure B17. Runoff retention—11 million trees and survival scenario



Source: Authors' diagram based on outputs from InVEST model. Background map data from OpenStreetMap (© OpenStreetMap contributors, https://www.openstreetmap.org/copyright).

Figure B18. Runoff retention—25 million trees and survival scenarios



Source: Authors' diagram based on outputs from InVEST model. Background map data from OpenStreetMap (© OpenStreetMap contributors, https://www.openstreetmap.org/copyright).

Table B5. Runoff retention statistics

LULC scenario (number of trees planted)	Total runoff retention volume (m³)	(InVEST) Difference between LULC scenarios and LULC BAU (%)
LULC BAU	17,753,675.28	
LULC 3.3 million	18,184,950.60	2.43%
LULC 7.5 million	18,627,161.99	4.92%
LULC 9.24 million	18,726,405.09	5.48%
LULC 11 million	18,829,729.43	6.06%
LULC 21 million	19,400,402.65	9.28%
LULC 25 million	19,631,835.43	10.58%

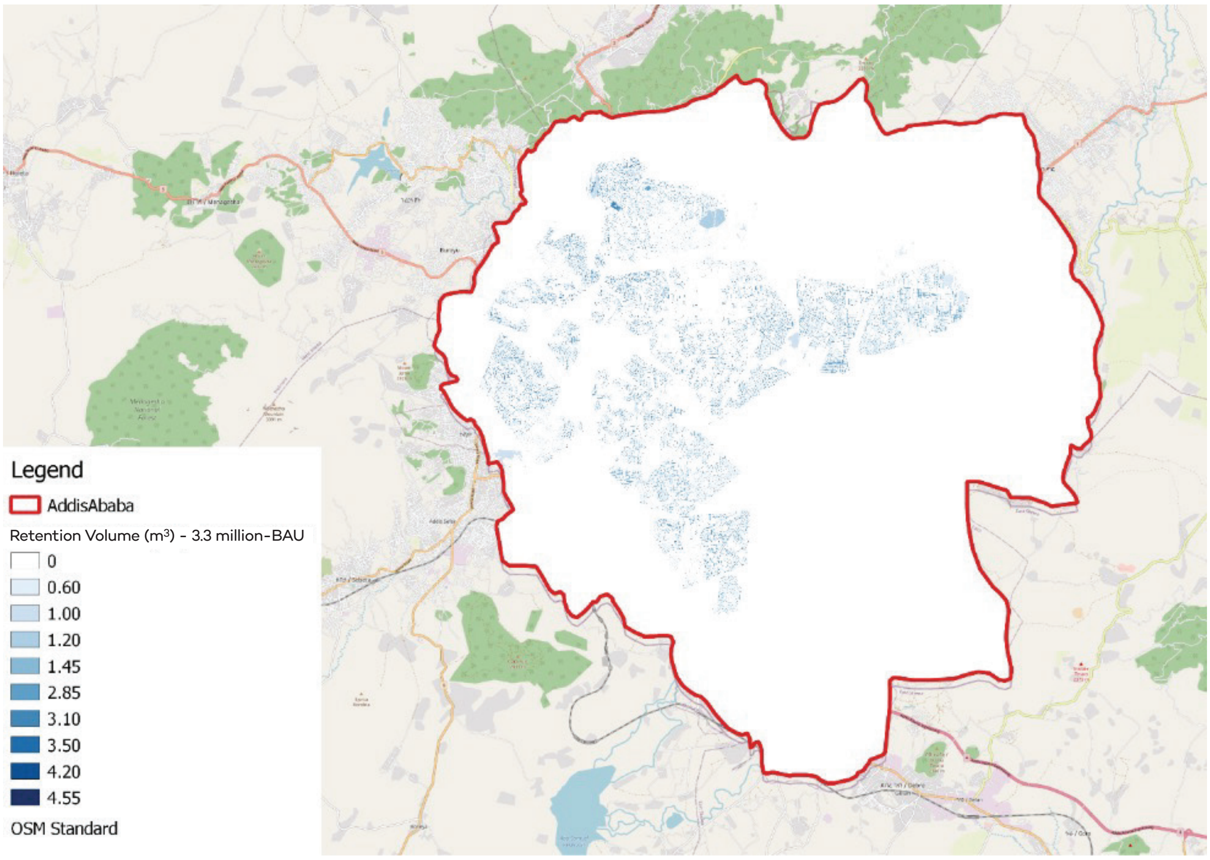
As Table B5 shows, increasing the number of trees in Addis Ababa would also increase the total runoff retention volume during a rainfall event of 63.14 mm.

If 11 million trees are planted in Addis Ababa, the runoff retention volume would increase by 6% compared to the BAU scenario. However, under the survival scenarios of 84% and 30%, the total carbon stored would increase by 5.5% and 2.4% respectively, compared to the base case scenario.

If 25 million trees are planted in Addis Ababa, the runoff retention volume would increase by 11.6% compared to the BAU scenario. However, under the survival scenarios of 84% and 30%, the total carbon stored would increase by 9% and 5% respectively, compared to the base case scenario.

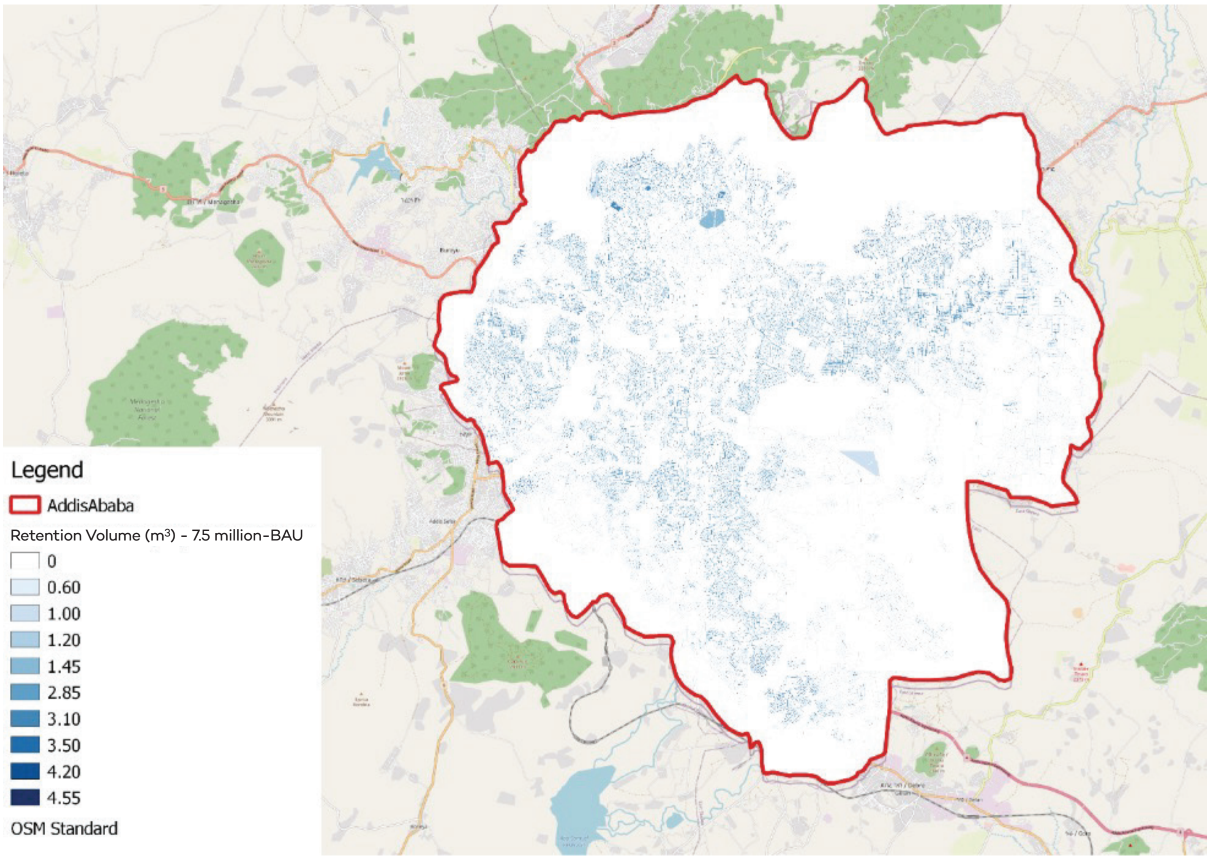
Finally, we used QGIS3.10 to calculate the difference between each alternative scenario and the LULC BAU scenario to better visualize the increase in flood retention. Figure B19, Figure B20, Figure B 21, Figure B22, Figure B23, and Figure B24 show the location of flood retention increase of each scenario compared to the base case scenario.

Figure B19. Flood retention—3.3 million trees scenario—BAU



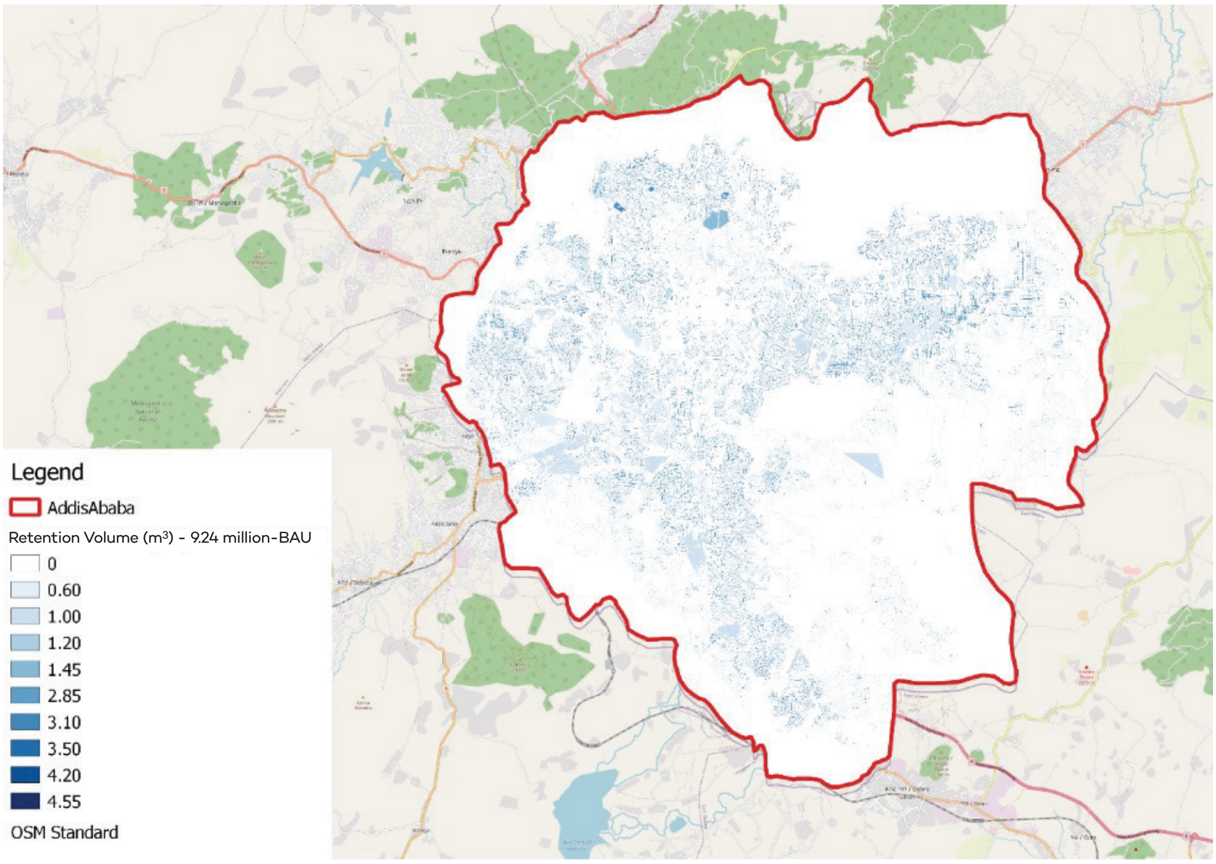
Source: Authors' diagram based on outputs from InVEST model. Background map data from OpenStreetMap (© OpenStreetMap contributors, https://www.openstreetmap.org/copyright).

Figure B20. Flood retention—7.5 million trees scenario—BAU



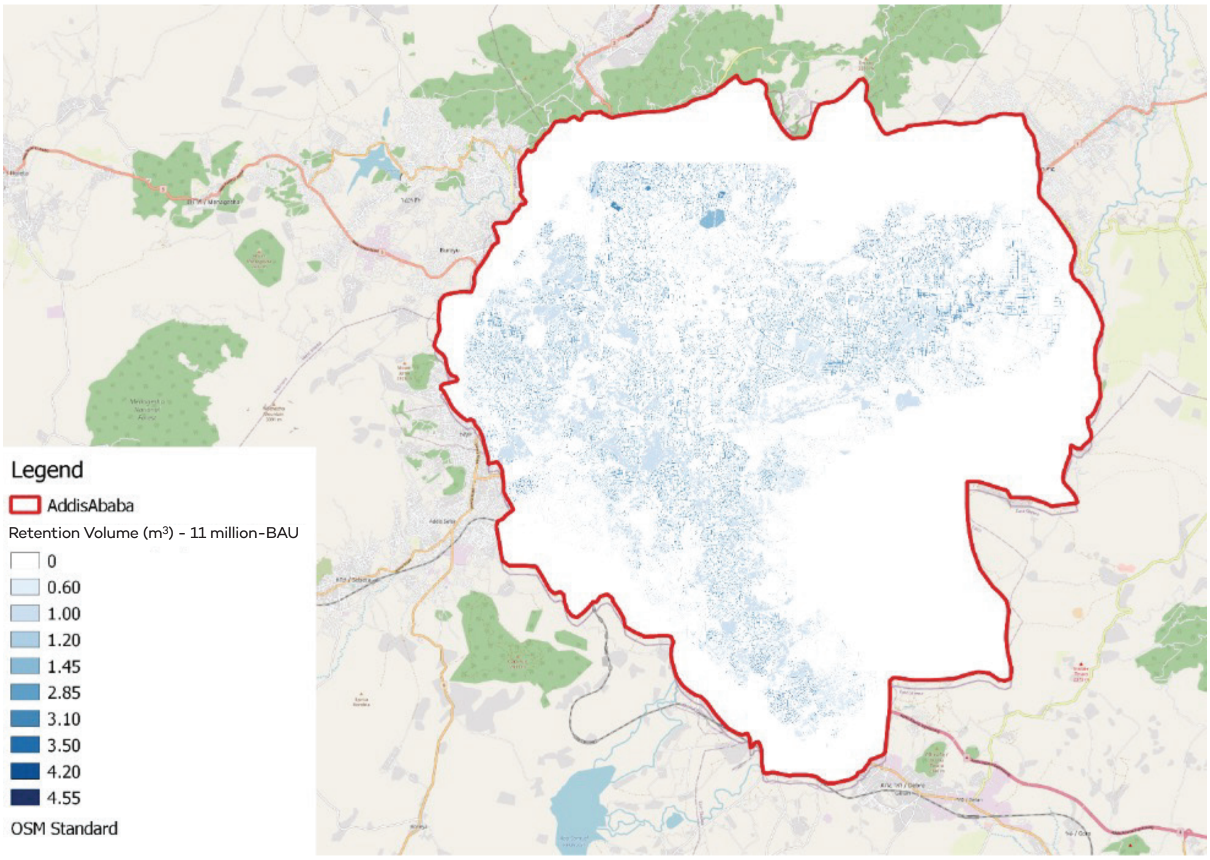
Source: Authors' diagram based on outputs from InVEST model. Background map data from OpenStreetMap (© OpenStreetMap contributors, https://www.openstreetmap.org/copyright).

Figure B21. Flood retention—9.24million trees scenario—BAU



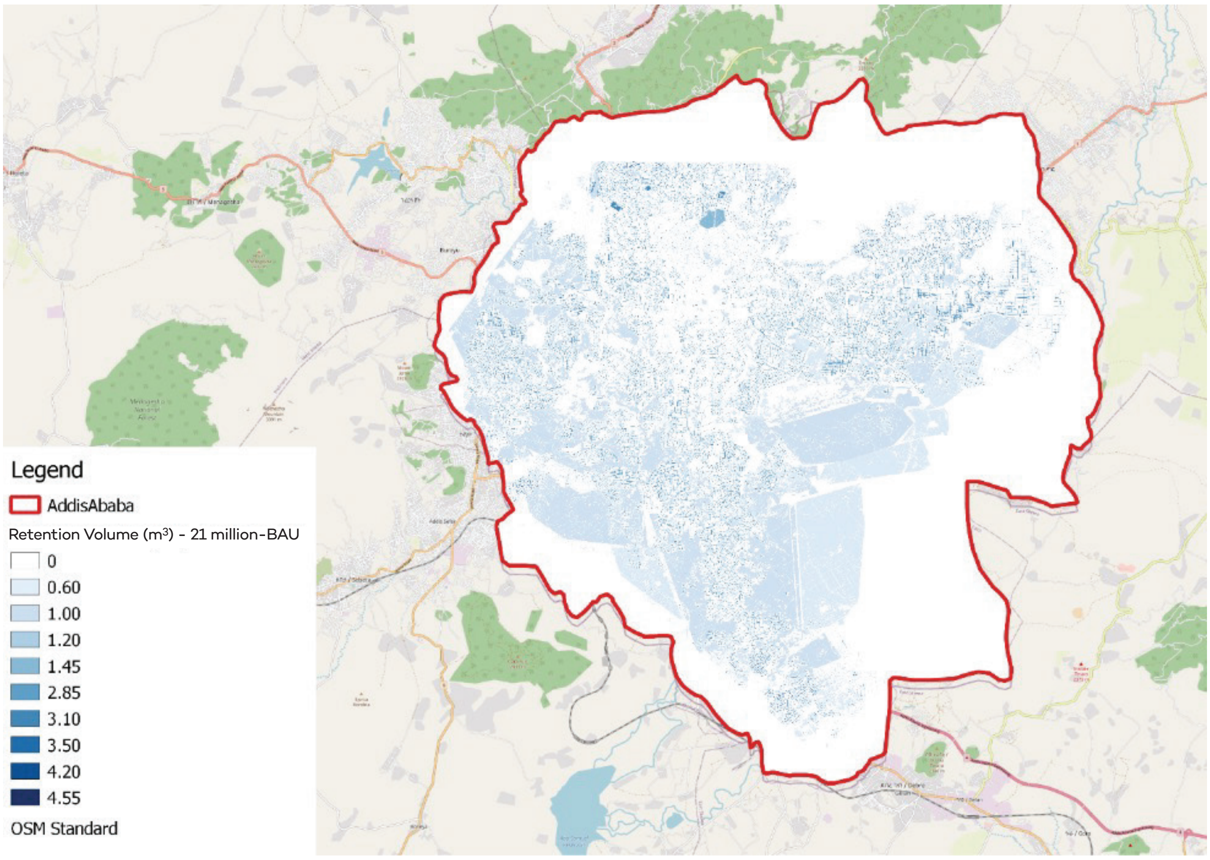
Source: Authors' diagram based on outputs from InVEST model. Background map data from OpenStreetMap (© OpenStreetMap contributors, https://www.openstreetmap.org/copyright).

Figure B22. Flood retention—11 million trees scenario—BAU



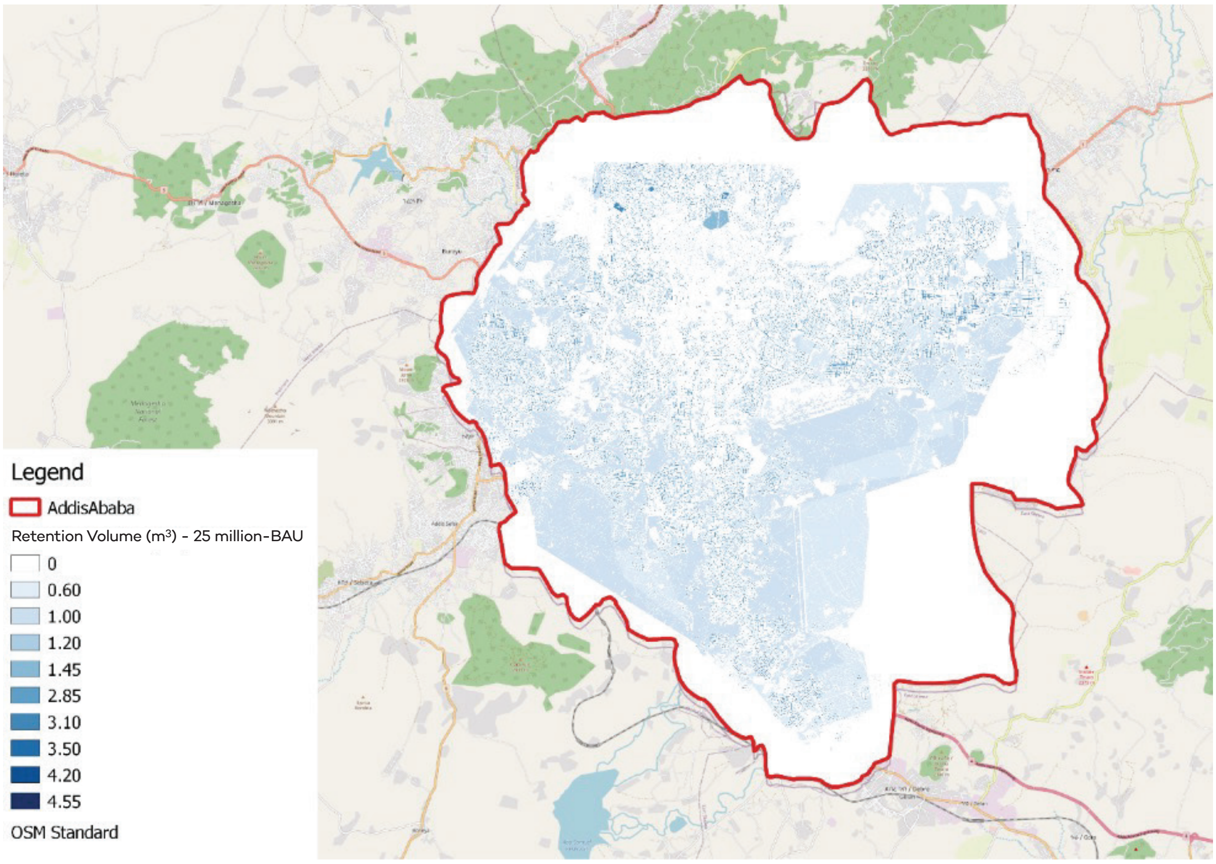
Source: Authors' diagram based on outputs from InVEST model. Background map data from OpenStreetMap (© OpenStreetMap contributors, https://www.openstreetmap.org/copyright).

Figure B23. Flood retention— 21 million trees scenario—BAU



Source: Authors' diagram based on outputs from InVEST model. Background map data from OpenStreetMap (© OpenStreetMap contributors, https://www.openstreetmap.org/copyright).

Figure B24. Flood retention—25 million trees scenario—BAU



Source: Authors' diagram based on outputs from InVEST model. Background map data from OpenStreetMap (© OpenStreetMap contributors, https://www.openstreetmap.org/copyright).

4. Urban Cooling

"Vegetation can help reduce the urban heat island (UHI) effect by providing shade, modifying thermal properties of the urban fabric, and increasing cooling through evapotranspiration. This has consequences for the health and wellbeing of citizens through reduced mortality and morbidity, increased comfort and productivity, and the reduced need for air conditioning (A/C). The InVEST urban cooling model calculates an index of heat mitigation based on shade, evapotranspiration, and albedo, as well as distance from cooling islands (e.g., parks). The index is used to estimate a temperature reduction by vegetation" (Sharp et al., 2020).

Input Data Preparation and Processing

1. **LULC maps:** The maps described in Sections 1.1.1 and 1.1.2 were used in this model.
2. **Biophysical table:** A table containing model information corresponding to each of the land-use classes in the Land Cover Map (Table B6). All LULC classes in the Land Cover raster must have corresponding values in this table. Each row is a land-use/land-cover class and columns must be named and defined as follows:

   2.1 lucode: Required. Land-use/land-cover class code. LULC codes must match the "value" column in the Land Cover Map raster and must be integer or floating-point values, in consecutive order, and unique.

   2.2 Shade: A value between 0 and 1, representing the proportion of tree cover (0 for no tree; 1 for full tree cover; with trees>2 m). Required if using the weighted factor approach to cooling coefficient calculations.

   2.3 Kc: Required. Crop coefficient, a value between 0 and 1 (see Allen et al. 1998).

   2.4 Albedo: A value between 0 and 1, representing the proportion of solar radiation directly reflected by the LULC type. Required if using the weighted factor approach to cooling coefficient calculations.

   2.5 Green_area: Required. A value of either 0 or 1, 1 meaning that the LULC is counted as a green area (green areas >2 ha have an additional cooling effect), and 0 meaning that the LULC is not counted as a green area.

   The values of the biophysical table used in this study have been retrieved from Brocco (2021) and from the input samples of the InVEST package.

Table B6. Biophysical table—cooling model

lucode	Shade	Kc	Albedo	Green_area
2	0.05	0.37	0.18	0
3	0.18	0.55	0.19	0
4	0.05	0.37	0.18	0
5	0.45	0.7	0.2	1
6	1	1	0.15	1
7	0.45	1	0.2	1
8	0.05	0.37	0.18	0
9	0	0.3	0.2	0
10	1	1	0.15	1
12	0	0.3	0.2	0
13	0	0.3	0.2	0
14	0.33	0.76	0.19	0
15	1	1	0.06	1
18	1	1	0.15	1
19	1	1	0.15	1
20	0.8	1	0.18	1

3. **Reference evapotranspiration:** A GIS raster data set with an average evapotranspiration value for each cell in millimetres, for the month of April. Reference evapotranspiration is the potential loss of water from the soil by both evaporation from the soil and transpiration by healthy alfalfa (or grass) if sufficient water is available. Its value is in millimetres. In this study, the global evapotranspiration of reference crops was adopted from "Global Aridity Index and Potential Evapotranspiration (ET0) Climate Database v2." The spatial resolution of the data is 30 arc-seconds (approximately 1km at the equator). The dataset is available from figshare.com under a CC BY 4.0 licence (Trabucco & Zomer, 2019).
4. **Areas of interest:** The whole city of Addis Ababa was considered.
5. **Green area maximum cooling distance:** 500 m, suggested by the developers of InVEST.
6. **Reference air temperature:** 26.82°C, as reported by Teferi and Abraha (2017).
7. **Magnitude of the UHI effect:** 15°C, as reported by Teferi and Abraha (2017).
8. **Air temperature maximum blending distance:** 500 m, suggested by the developers of InVEST.

9. **Cooling capacity calculation method:** "Weighted Factors," suggested by the developers of InVEST.
10. **Shade:** Default value: 0.6.
11. **Evapotranspiration index and albedo:** Default value: 0.2.

Results

The following is a short description of the most important outputs from the urban cooling model.

1. **uhi_results_[Suffix].shp:** A copy of the input vector with areas of interest with the following additional fields:
    - "avg_tmp_v" - Average temperature value (degrees centigrade)
2. **hm_[Suffix].tif:** The calculated heat mitigation index maps (spatial outputs)

The first outputs "uhi_results" are simple vector files and do not show any relevant spatial outputs. However, they indicate the "Average temperature value (degC)" using the LULC BAU and LULC Trees maps. Table B7shows the average temperature using the different LULC scenarios

Table B7. Urban cooling statistics

LULC Scenario (number of trees planted)	Average temperature value (degC)	(InVEST) Difference between LULC scenarios and LULC BAU (%)
LULC BAU	32.74	
LULC 3.3 million	32.13	-1.85%
LULC 7.5 million	31.60	-3.48%
LULC 9.24 million	31.52	-3.72%
LULC 11 million	31.43	-3.99%
LULC 21 million	31.33	-4.30%
LULC 25 million	31.30	-4.40%

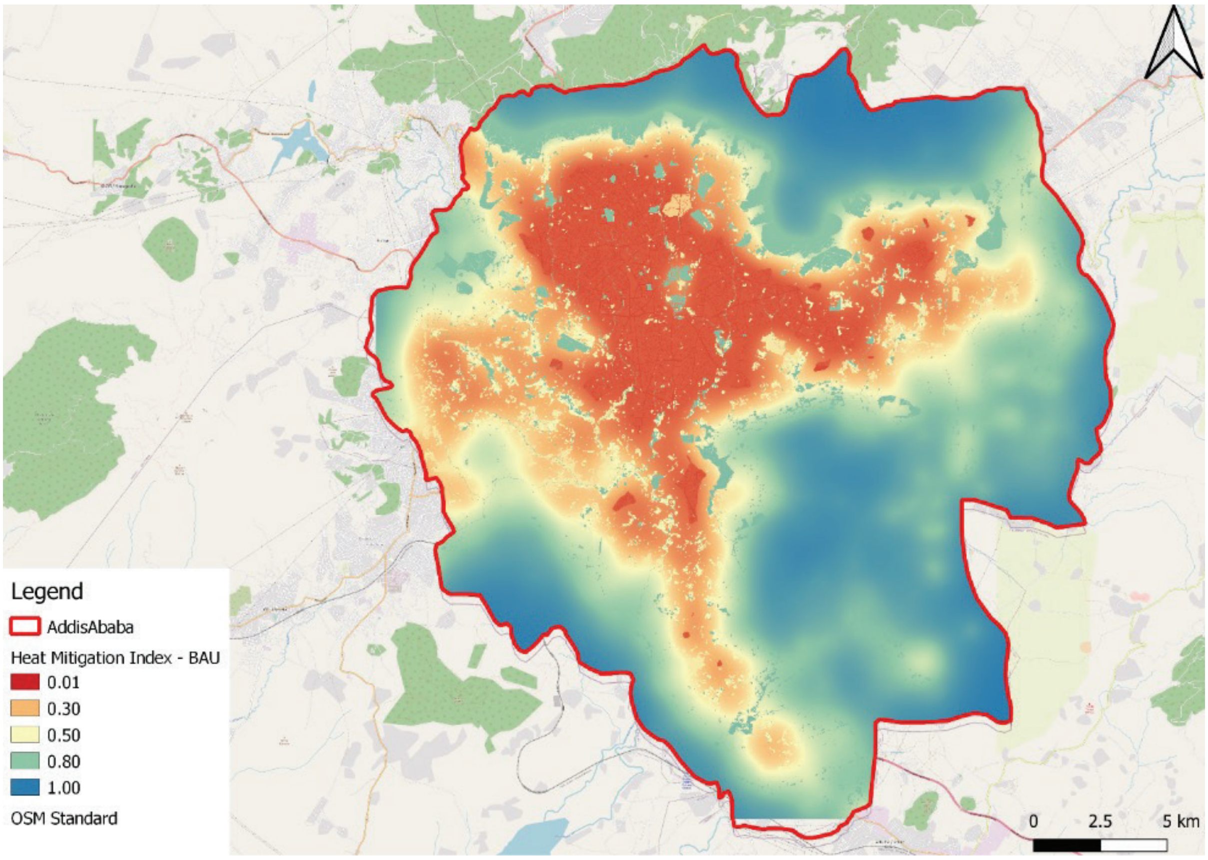
As Table B7 shows, increasing the number of trees in Addis Ababa would also decrease the average temperature in the city, under the conditions illustrated in Section 4.1.

If 11 million trees are planted in Addis Ababa, the average temperature would decrease by 4% compared to the BAU scenario. However, under the survival scenarios of 84% and 30%, the average temperature would decline by 3.7% and 1.8% respectively, compared to the base case scenario.

If 25 million trees are planted in Addis Ababa, the average temperature would decrease by 4.4% compared to the BAU scenario. However, under the survival scenarios of 84% and 30%, the average temperature would decline by 4.3% and 3.5% respectively, compared to the base case scenario.

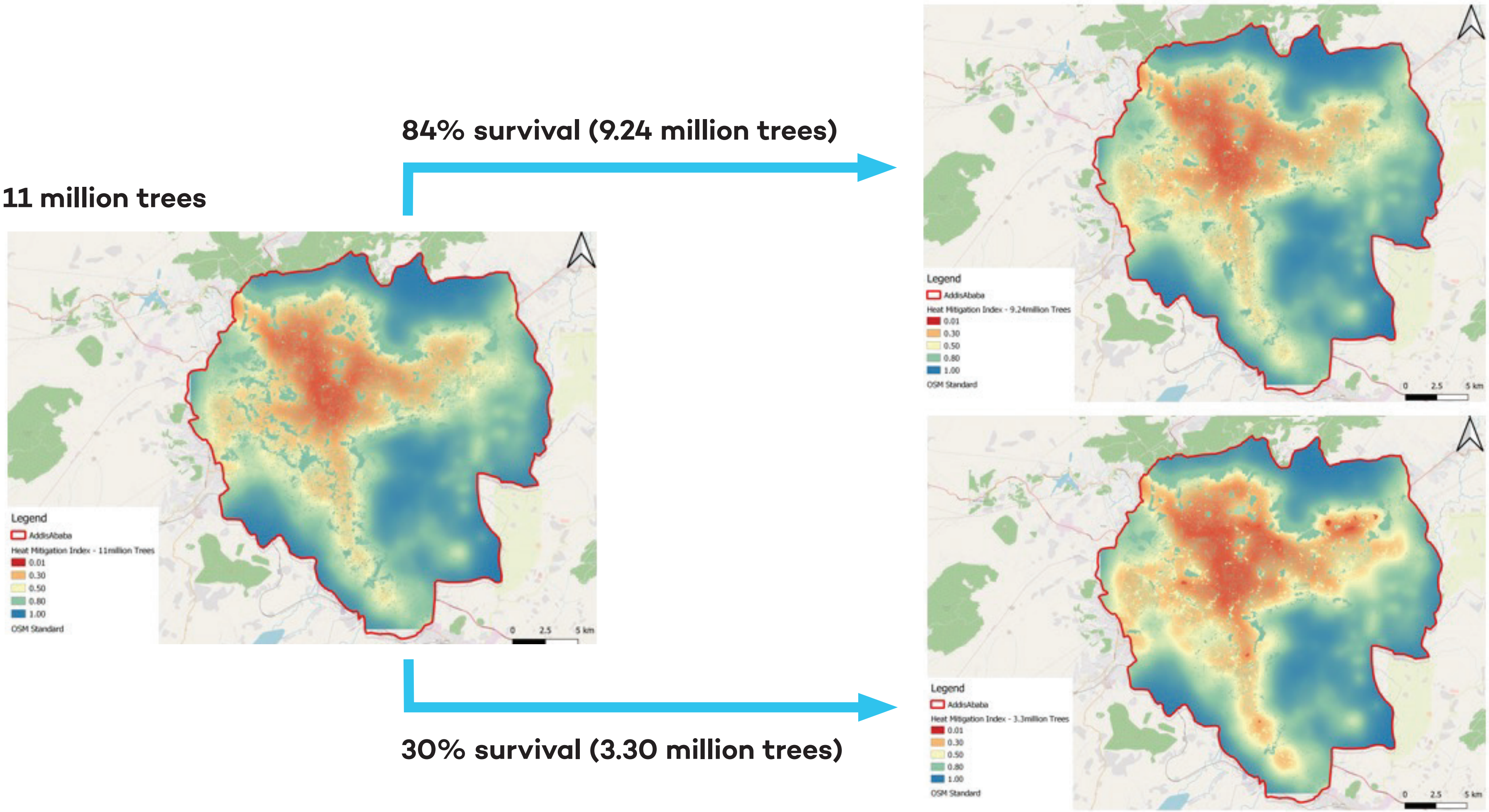
Figure B25 shows calculated heat mitigation index maps using the LULC BAU, while Figure B26 and Figure B27 show the heat mitigation index with 11 million and 25 million new trees planted, including survival scenarios. These maps can be useful to understand the locations where the cooling effects of trees will be more relevant.

Figure B25. Heat Mitigation Index (LULC BAU)



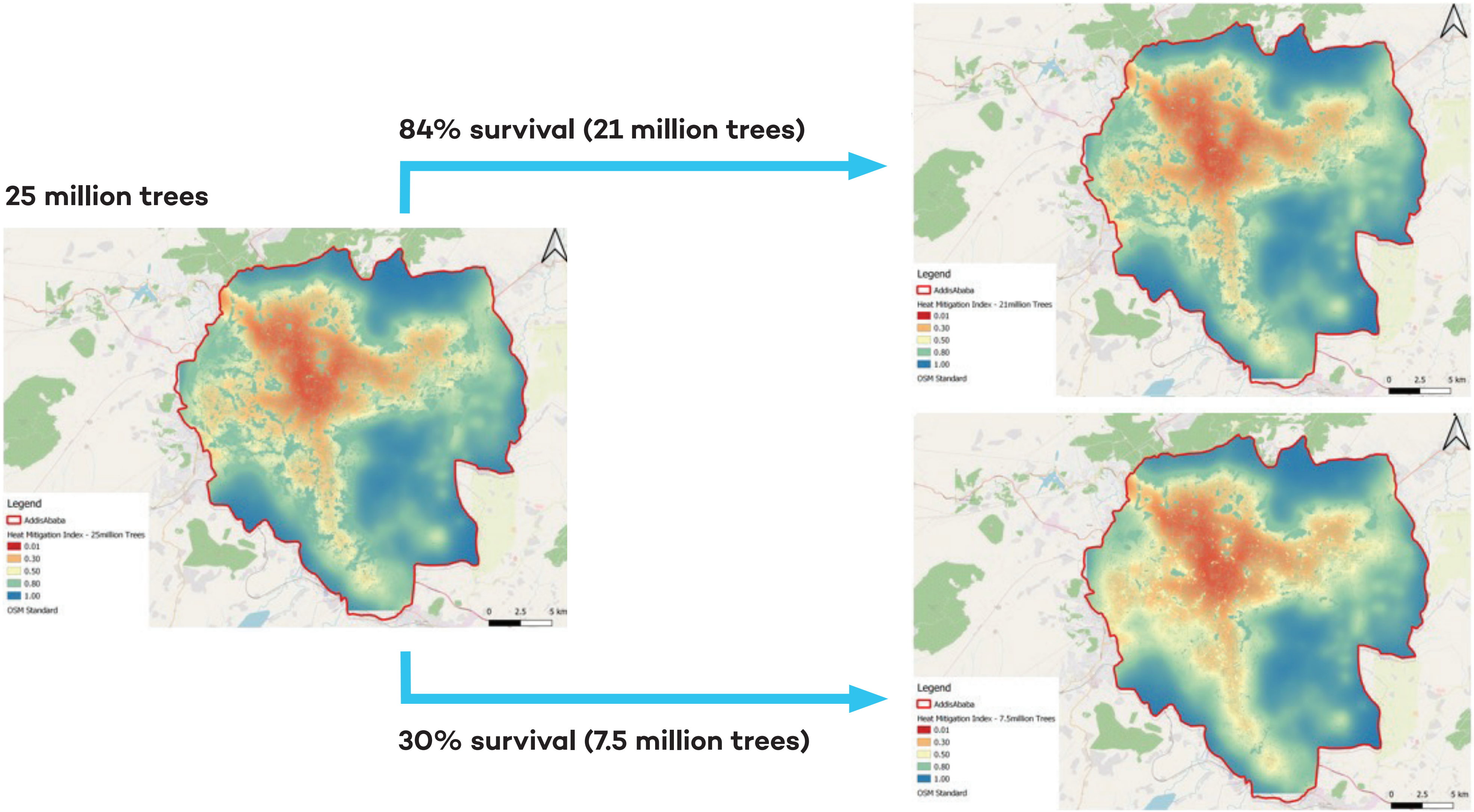
Source: Authors' diagram based on outputs from InVEST model. Background map data from OpenStreetMap (© OpenStreetMap contributors, https://www.openstreetmap.org/copyright).

Figure B26. Heat Mitigation Index—11 million trees and survival scenarios.



Source: Authors' diagram based on outputs from InVEST model. Background map data from OpenStreetMap (© OpenStreetMap contributors, https://www.openstreetmap.org/copyright).

Figure B27. Heat Mitigation Index—25 million trees and survival scenarios



Source: Authors' diagram based on outputs from InVEST model. Background map data from OpenStreetMap (© OpenStreetMap contributors, https://www.openstreetmap.org/copyright).

Appendix C. Detailed Assumptions, Equations, and Parameter Values

Table C1 shows the parameter values and underlying assumptions used to calculate the integrated cost-benefit analysis of tree planting in Addis Ababa. All monetary values are reported in USD and ETB using an exchange rate of 0.022 USD per ETB.

Table C1. Parameters and assumptions used to calculate costs and benefits of tree planting in Addis Ababa

Parameter	Unit	Value	Explanation, assumptions and sources
Parameters used for carbon storage benefit			
Value of carbon storage	USD/t CO_2 (ETB/t CO_2)	9.83 (446.7)	Ethiopian coffee farmers received EUR 212,500 for reducing emissions by 25,300 t CO_2 between 2016 and 2018 (Fairtrade Africa, 2020). We assume a constant carbon price per ton and use a conversion rate of USD 1.17 per EUR.
Parameters used for fruit production benefit			
Hectares per tree	ha/tree	0.000667	Assumed based on the spatial analysis assumption that 15 trees can be planted in 100 m^2
Fruit yield per tree	hg/ha /year	42,914	In Ethiopia, the 2018 avocado yield was 42,914 hectograms (hg) per hectare (Food and Agriculture Organization of the United Nations, 2021). We assume that yield in Addis Ababa will be constant over the simulation and is equal to this national average.
Fruit producer price	USD/ton (ETB/ton)	190.3 (8,650)	In 2018 the producer price for avocados was USD 190.3 per ton (Food and Agriculture Organization of the United Nations, 2021). We assume that the price in Addis Ababa is equal to this national average and is constant throughout the simulation.

Parameter	Unit	Value	Explanation, assumptions and sources
Parameters used for planting and maintenance wages			
Planting jobs per tree	Full-time equivalent (FTE)/tree	0.000167	We assume that planting trees creates one FTE job per hectare of green space (Del Pino et al., 2020), each tree requires 6.67 m^2, and 25% of the labour for planting trees is hired, with the remainder done by volunteers. Thus, the number of paid planting jobs per tree is 6.67÷10,000×0.25
Maintenance jobs per tree	FTE/tree/year	0.000667	We assume that maintaining trees creates one FTE job per hectare of green space (Del Pino et al., 2020) and that each tree requires 6.67 m^2.
Tree planting and maintenance wages	USD/FTE (ETB/FTE)	500.28 (22,740)	The Ethiopian average monthly wage for skilled agricultural, forestry, and fishery workers is USD 41.69 (International Labour Organization, 2021). We multiply by 12 to determine annual wages.
Parameters used for avoided heat, flood, and air pollution impacts			
Decrease in percentage of people who walk on hot days	percentage	5.4%	According to the Addis Ababa Transport office, walking is the primary source of transportation for 54% of the city population (W. Tesso, personal communication, October 25, 2021). Previous studies have demonstrated a decrease in active forms of transport as temperatures exceed a threshold (Böcker et al., 2013; Phung & Rose, 2007). Results vary by location, and most studies have been conducted in North America, Europe, and Australia (Böcker et al., 2013). Rather than transferring results from existing studies, we assume a 10% reduction and conduct a sensitivity analysis on this assumption. Therefore, the decrease in percentage of people who walk on hot days is 0.1 × 54 = 5.4
Decrease in hot days per °C of cooling due to trees	days/°C	2	Assumed. Note: the decrease in hot days per °C of cooling × cooling from trees cannot exceed the projected number of hot days

Parameter	Unit	Value	Explanation, assumptions and sources
Average bus fare per ride	USD/ride (ETB/ride)	0.06 (2.7)	We use ridership and cost data from September 2021 provided by W. Tesso (personal communication, October 25, 2021) to calculate the average bus fare for rides less than 5 kilometres for all types of public transport weighted by the transport share percentage.
Annual flood damages regression	USD/mm (ETB/mm)	644.4 × runoff–440,000 (29,291 × runoff–20,000,000)	Linear regression between annual property damage from flooding (W. Tesso, personal communication, September 27, 2021) and annual runoff (Hersbach et al., 2019) using data from 2012 through 2019.
Historical average flood mortality	Per capita	0.00000176	Annual mortality from 2012 to 2021 was calculated using flood death data from W. Tesso (personal communication, September 13, 2021) and population data from United Nations, Department of Economic and Social Affairs, Population Division (2018). We average across the 10 years to calculate expected annual mortality for historical runoff conditions.
Historical average annual runoff	mm/year	780.41	2012-2019 average annual runoff using data from (Hersbach et al., 2019)
Increase in mortality due to increase in $PM_{2.5}$ concentration	1/μg $PM_{2.5}$ /m^3	0.0000114	The Addis Ababa air quality management plan reports that in 2017, there were 2,700 deaths attributable to $PM_{2.5}$. Assuming a BAU scenario, the plan projects that in 2025, the $PM_{2.5}$ concentration will be approximately 35 μg/m^3 higher than in 2017 and that there will be 6,200 deaths from $PM_{2.5}$ (Addis Ababa Environmental Protection and Green Development Commission, 2021). Assuming a population of 4.216 million in 2017 and 5.957 million in 2025 (United Nations, Department of Economic and Social Affairs, Population Division, 2018), we calculate a 0.0004 increase in per capita mortality due to a 35 μg/m^3 increase in $PM_{2.5}$ concentration. We assume that the relationship between mortality and $PM_{2.5}$ concentration is linear so divide 0.0004 by 35 μg/m^3 to estimate the increase in mortality per unit increase in $PM_{2.5}$ concentration.

Parameter	Unit	Value	Explanation, assumptions and sources
Decrease in $PM_{2.5}$ concentration per hectare of tree cover	µg $PM_{2.5}$/ m^3/ha	0.00000215	Nowak et al. (2013) report the concentration of $PM_{2.5}$ and the mass removed per m^2 of tree cover in 10 U.S. cities. From this, we estimate the concentration reduction per hectare of tree cover for each city and take an average across all cities.
Value of a statistical life	USD/life (ETB/life)	102,000 (4,636,363)	Value of a statistical life in Ethiopia estimated by Viscusi & Masterman (2017).
Parameters used for planting and maintenance costs			
Tree planting cost	USD/tree (ETB/tree)	0.55 (25)	Land preparation and seedling costs are USD 0.44–0.66 (ETB 20–30) per tree (W. Tesso, personal communication, August 4, 2021). We use an average value.
Tree maintenance cost	USD/tree/ year (ETB/ tree/ year)	0.44 (20)	We assume annual maintenance costs are 80% of total planting costs and conduct a sensitivity analysis on this assumption.
Parameters used for grey infrastructure comparison			
Runoff reduction per m^3 of rainwater harvesting capacity	percent/m^3	0.00017%	Mulu et al. (2020) report that, on average, 132,910 m^2 of area dedicated to rainwater harvesting in Addis Ababa, can store 125,172 m^3 of water every year. From this, we calculate that 1.06 m^2 is required to store 1 m^3. Furthermore, Jemberie & Melesse (2021) find that 21.3 ha of rainwater harvesting capacity reduces runoff by 35%. Assuming a linear relationship between runoff reduction and area of rainwater harvesting, this implies that 1 m^2 of rainwater harvesting reduces runoff by 0.00016%. Dividing this by 1.06 m^2 per m^3 gives 0.00017% per m^3 of rainwater harvested.
Domestic water price	USD/m^3 (ETB/m^3)	0.29 (13)	The Open University (2017) reports that the domestic cost of water for a household in Ethiopia that uses 11–20 m^3 per month is ETB 13.

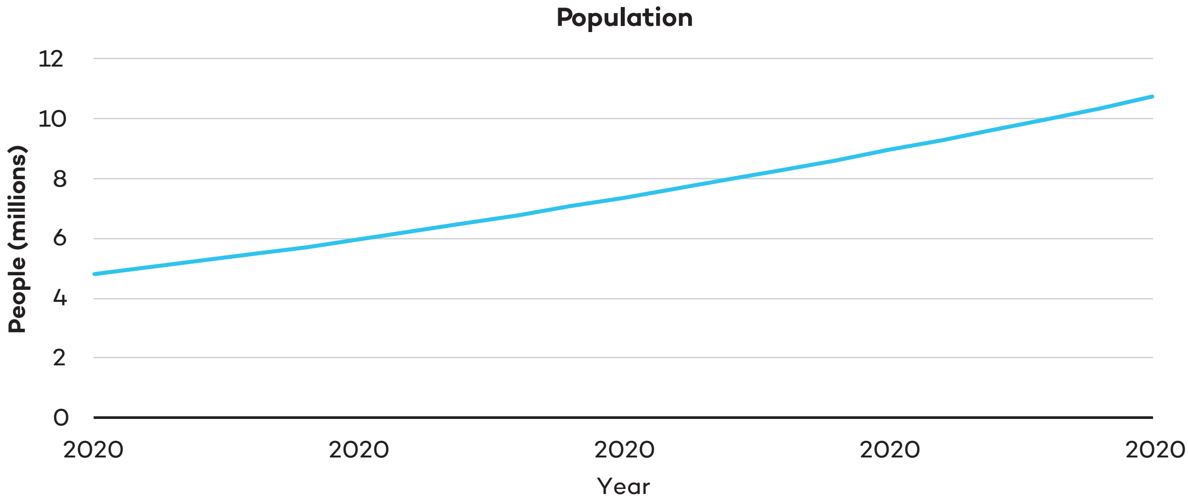
Parameter	Unit	Value	Explanation, assumptions and sources
Rainwater harvesting installation cost	USD/m^3 (ETB/m^3)	61 (2,772.7)	Parker et al. (2013) provide the average construction cost for rainwater harvesting tanks of varying sizes in East Africa. Across all sizes, the average cost per litre was USD 0.061.
Rainwater harvesting maintenance cost	USD/m^3/ year (ETB/ m^3/ year)	6.1 (277.27)	Assumed to be 10% of construction costs
Labour cost percentage for rainwater harvesting	percentage	27.3%	For each tank construction cost included in their analysis, Parker et al. (2013) indicate the percentage of the total cost that went toward labour. We assume that the cost of labour is equal to wages earned and take the average percentage across all tanks in the Parker et al. (2013) study. We assume that the labour cost percentage is the same for construction and maintenance.
Annual average CO_2 emissions per diesel/petrol cars	t CO_{2e}/car/ year	3.95	We assume that 1 kg of petrol or diesel emits 3.169 kg CO_2 and that petrol cars consume 49 g of fuel per km, while diesel cars consume 55 g of fuel per km (Ntziachristos et al., 2019). We use these numbers to calculate the average CO_2 emissions per km and multiply by annual kilometres driven per car (24,000 km).
$PM_{2.5}$ mass removed per hectare of trees	g/ha/year	2,510	Nowak et al. (2013) report the mass of $PM_{2.5}$ removed per m^2 of tree cover in 10 U.S. cities per year. We take the average across all 10 cities.
Annual average $PM_{2.5}$ emissions per diesel/petrol car	g/year	1,023.6	A mini petrol car with Euro 4 technology emits 0.0011 g $PM_{2.5}$/km, and a medium/ large diesel car with Euro 1 technology emits 0.0842 g $PM_{2.5}$/km (Ntziachristos et al., 2019). We average these numbers and assume that each car drives 24,000 km per year (Addis Ababa Institute of Technology, 2012; Jida et al., 2020) to calculate annual $PM_{2.5}$ emissions per diesel/petrol car to calculate annual emissions.

Parameter	Unit	Value	Explanation, assumptions and sources
Average cost to drive a diesel/petrol car 1 km	USD/km (ETB/km)	0.03 (1.3)	We assume that diesel costs USD 0.47 per litre and petrol costs 0.41 per litre (GlobalPetrolPrices.Com, 2021a, 2021b). Furthermore, we assume petrol cars consume 49 g of fuel per km, while diesel cars consume 55 g of fuel per km (Ntziachristos et al., 2019). The density of petrol is 750 g/litre, while that of diesel is 850 g/litre. We multiply the cost of fuel per litre by the density to determine cost per g, which we multiply by the fuel consumed per km. Finally, we average the values for diesel and petrol cars.
Average cost to drive an electric vehicle 1 km	USD/km (ETB/km)	0.001 (0.045)	It has been reported that in Ethiopia, driving an electric vehicle costs USD 0.1 per 100 km or USD 0.001 per km ("Electric Car Maker Sees Transportation 'Revolution' in Ethiopia," 2010). We can arrive at the same number using an electricity price of 0.007 USD per kWh (GlobalPetrolPrices.Com, 2021a) and electric vehicle efficiency of 100 km per 15 kWh (Energuide, 2021). Multiplying 0.007 USD per kWh by 15 kWh per 100 km, we get USD 0.105 per 100 km.
Annual kilometres driven per car	km/car/year	24,000	We follow the assumptions of Addis Ababa Institute of Technology (2012) and Jida et al. (2020).
Diesel/petrol car purchase price	USD/car (ETB/car)	16,000 (727,272.7)	In 2017, a Toyota Vitz cost about USD 16,000 in Ethiopia (Igunza, 2017).
Electric vehicle purchase price	USD/car	27,000 (1,227,272.7)	In 2012, a Nissan Leaf electric vehicle was reported to cost USD 27,000 in Ethiopia (Addis Ababa Institute of Technology, 2012).

Population

We use 2021–2035 population projections from the United Nations, Department of Economic and Social Affairs, Population Division (2018) for Addis Ababa. From these data, we observe that after 2025, the population growth rate declines at an approximately constant rate of 0.0006 per year. We assume that population growth will continue to decrease linearly at this rate to project population growth through 2040. The resulting population projection is shown in Figure C1.

Figure C1. Addis Ababa projected population, 2020–2040



Source: Authors' diagram based on data from United Nations, Department of Economic and Social Affairs, Population Division (2018).

Appendix D. Additional Results

1. Cost-Benefit Analysis Tables

Table D1. Undiscounted integrated cost-benefit analysis for the RCP 8.5 scenario. Trees have positive net benefits, and results are similar to the RCP 4.5 climate scenario.

	25 million trees planted		11 million trees planted	
Tree survival rate	84%	30%	84%	30%
Total surviving trees (million)	21	7.5	9.24	3.3
Added Benefits				
Fruit production (million ETB)	607	217	293	105
Planting wages (million ETB)	95	95	42	42
Maintenance wages (million ETB)	3,335	1,668	1,584	792
Total added benefits (million ETB)	**4,037**	**1,979**	**1,919**	**938**
Avoided Costs				
Mortality from air pollution (million ETB)	215	77	100	36
Flood damages to property (million ETB)	109	58	67	30
Mortality from flooding (million ETB)	333	177	202	90
Bus fares due to decreased walkability (million ETB)	55	45	51	25
Carbon sequestration (million ETB)	1,966	893	1,023	433
Total avoided costs (million ETB)	**2,678**	**1,249**	**1,444**	**613**
Added benefits + avoided costs (million ETB)	**6,716**	**3,228**	**3,362**	**1,552**
Direct costs				
Planting costs (million ETB)	500	500	220	220
Maintenance costs (million ETB)	4,400	2,200	2,090	1,045
Total direct costs (million ETB)	**4,900**	**2,700**	**2,310**	**1,265**
NET BENEFITS (MILLION ETB)	**1,816**	**528**	**1,052**	**287**
BENEFIT-TO-COST RATIO	**1.37**	**1.20**	**1.46**	**1.23**
BENEFIT-TO-COST RATIO EXCLUDING AVOIDED COSTS	**0.82**	**0.73**	**0.83**	**0.74**

Table D2. Comparison of costs and benefits of planting 25 million trees with 30% survival and grey infrastructure alternatives (28,199 m^3 of rainwater harvesting capacity and 26,603 electric vehicles) under RCP 4.5. Grey infrastructure generates more benefits than trees but is also more expensive. Ultimately, grey infrastructure has a higher benefit-to-cost ratio.

Grey infrastructure comparison: High trees planted, low survival, RCP 4.5

		Grey Alternatives			
	Trees	Rainwater harvesting	Electric vehicles	Grey total (harvesting + vehicles)	Difference (trees – grey)
Added benefits (million ETB)					
Fruit production	217	-	-	-	217
Additional water supply	-	7	-	7	-7
Wages	1,762	62	-	62	1,701
Total added benefits	**1,979**	**69**	**-**	**69**	**1,910**
Avoided Costs (million ETB)					
Mortality from air pollution	77	-	183	183	-106
Flood damages to property	42	45	-	45	-3
Mortality from flooding	119	124	-	124	-5
Bus fares due to decreased walkability	45	-	-	-	45
Carbon sequestration	893	-	893	893	-
Fuel cost	-	-	15,211	15,211	-15,211
Total avoided costs	**1,175**	**169**	**16,287**	**16,456**	**-15,280**
Added benefits + avoided costs	**3,155**	**238**	**16,287**	**16,524**	**-13,370**
Direct costs (million ETB)					
Tree planting costs	500	-	-	-	500
Tree maintenance costs	4,400	-	-	-	4,400
Rainwater harvesting construction costs	-	147	-	147	-147
Rainwater harvesting maintenance costs	-	280	-	280	-280
Electric vehicle purchase cost	-	-	29,282	29,282	-29,282
Total direct costs	**2,700**	**227**	**13,301**	**13,528**	**-10,828**
NET BENEFITS (MILLION ETB)	**455**	**11**	**2,985**	**2,996**	**-2,542**
BENEFIT-TO-COST RATIO	**1.17**	**1.05**	**1.22**	**1.22**	**-0.05**

Table D3. Comparison of costs and benefits of planting 11 million trees with 84% survival and grey infrastructure alternatives (31,403 m^3 of rainwater harvesting capacity and 30,492 electric vehicles) under RCP 4.5. Grey infrastructure generates more benefits than trees but is also more expensive. Ultimately, trees have a higher benefit-to-cost ratio.

Grey infrastructure comparison: Low trees planted, high survival, RCP 4.5

		Grey Alternatives			
	Trees	Rainwater harvesting	Electric vehicles	Grey total (harvesting + vehicles)	Rainwater harvesting
Added benefits (million ETB)					
Fruit production	293	-	-	-	293
Additional water supply	-	8	-	8	-8
Wages	1,626	69	-	69	1,557
Total added benefits	**1,919**	**77**	**-**	**77**	**1,842**
Avoided Costs (million ETB)					
Mortality from air pollution	100	-	210	210	-110
Flood damages to property	49	50	-	50	-1
Mortality from flooding	136	138	-	138	-2
Bus fares due to decreased walkability	51	-	-	-	51
Carbon sequestration	1,023	-	1,023	1,023	-
Fuel cost	-	-	17,435	17,435	-17,435
Total avoided costs	**1,359**	**188**	**18,668**	**18,856**	**-17,497**
Added benefits + avoided costs	**3,278**	**265**	**18,668**	**18,933**	**-15,655**
Direct costs (million ETB)					
Tree planting costs	220	-	-	-	220
Tree maintenance costs	2,090	-	-	-	2,090
Rainwater harvesting construction costs	-	87	-	87	-87
Rainwater harvesting maintenance costs	-	165	-	165	-165
Electric vehicle purchase cost	-	-	15,246	15,246	-15,246
TOTAL DIRECT COSTS	**2,310**	**253**	**15,246**	**15,499**	**-13,189**
NET BENEFITS (MILLION ETB)	**968**	**12**	**3,422**	**3,434**	**-2,466**
BENEFIT-TO-COST RATIO	**1.42**	**1.05**	**1.22**	**1.22**	**0.20**

Table D4. Comparison of costs and benefits of planting 11 million trees with 30% survival and grey infrastructure alternatives (13,923 m³ of rainwater harvesting capacity and 12,894 electric vehicles) under RCP 4.5. Grey infrastructure generates more benefits than trees but is also more expensive. Ultimately, grey infrastructure has a higher benefit-to-cost ratio.

Grey infrastructure comparison: Low trees planted, low survival, RCP 4.5

		Grey Alternatives			
	Trees	Rainwater harvesting	Electric vehicles	Grey total (harvesting + vehicles)	Difference (trees–grey)
Added benefits (million ETB)					
Fruit production	105	-	-	-	105
Additional water supply	-	3	-	3	-3
Wages	834	31	-	31	803
Total added benefits	**938**	**34**	**-**	**34**	**904**
Avoided Costs (million ETB)					
Mortality from air pollution	36	-	89	89	-53
Flood damages to property	22	22	-	22	-0
Mortality from flooding	60	61	-	61	-1
Bus fares due to decreased walkability	25	-	-	-	25
Carbon sequestration	433	-	433	433	-
Fuel cost	-	-	7,373	7,373	-7,373
Total avoided costs	**576**	**83**	**7,894**	**7,977**	**-7,402**
Added benefits + avoided costs	**1,514**	**117**	**7,894**	**8,011**	**-6,497**
Direct costs (million ETB)					
Tree planting costs	220	-	-	-	220
Tree maintenance costs	1,045	-	-	-	1,045
Rainwater harvesting construction costs	-	39	-	39	-39
Rainwater harvesting maintenance costs	-	73	-	73	-73
Electric vehicle purchase cost	-	-	6,447	6,447	-6,447
TOTAL DIRECT COSTS	**1,265**	**112**	**6,447**	**6,559**	**-5,294**
NET BENEFITS (MILLION ETB)	**249**	**5**	**1,447**	**1,452**	**-1,203**
BENEFIT-TO-COST RATIO	**1.20**	**1.05**	**1.22**	**1.22**	**-0.02**

Table D5. Comparison of costs and benefits of planting 25 million trees with 84% survival and grey infrastructure alternatives (53,161 m^3 of rainwater harvesting capacity and 58,564 electric vehicles) under RCP 8.5. Grey infrastructure generates more benefits than trees but is also more expensive. Trees have a higher benefit-to-cost ratio than electric vehicles and the combination of electric vehicles and rainwater tanks. Rainwater tanks on their own have the highest benefit-to-cost ratio because they avoid large losses from flooding.

Grey infrastructure comparison: High trees planted, high survival, RCP 8.5

		Grey Alternatives			
	Trees	Rainwater harvesting	Electric vehicles	Grey total (harvesting + vehicles)	Difference (trees–grey)
Added benefits (million ETB)					
Fruit production	607	-	-	-	607
Additional water supply	-	13	-	13	-13
Wages	3,430	117	-	117	3,313
Total added benefits	**4,037**	**130**	**-**	**130**	**3,907**
Avoided Costs (million ETB)					
Mortality from air pollution	215	-	403	403	-188
Flood damages to property	109	116	-	116	-6
Mortality from flooding	333	346	-	346	-13
Bus fares due to decreased walkability	55	-	-	-	55
Carbon sequestration	1,966	-	1,966	1,966	-
Fuel cost	-	-	33,486	33,486	-33,486
Total avoided costs	**2,678**	**462**	**35,854**	**36,316**	**-33,638**
Added benefits + avoided costs	**6,716**	**592**	**35,854**	**36,446**	**-29,730**
Direct costs (million ETB)					
Tree planting costs	500	-	-	-	500
Tree maintenance costs	4,400	-	-	-	4,400
Rainwater harvesting construction costs	-	147	-	147	-147
Rainwater harvesting maintenance costs	-	280	-	280	-280
Electric vehicle purchase cost	-	-	29,282	29,282	-29,282
TOTAL DIRECT COSTS	**4,900**	**427**	**29,282**	**29,710**	**-24,810**
NET BENEFITS (MILLION ETB)	**1,816**	**164**	**6,572**	**6,736**	**-4,921**
BENEFIT-TO-COST RATIO	**1.37**	**1.38**	**1.22**	**1.23**	**0.14**

Table D6. Comparison of costs and benefits of planting 25 million trees with 30% survival and grey infrastructure alternatives (28,199 m³ of rainwater harvesting capacity and 26,603 electric vehicles) under RCP 8.5. Grey infrastructure generates more benefits than trees but is also more expensive. Nevertheless, grey infrastructure has a higher benefit-to-cost ratio when so few trees survive.

Grey infrastructure comparison: High trees planted, low survival, RCP 8.5

		Grey Alternatives			
	Trees	**Rainwater harvesting**	**Electric vehicles**	**Grey total (harvesting + vehicles)**	**Difference (trees–grey)**
Added benefits (million ETB)					
Fruit production	217	-	-	-	217
Additional water supply	-	7	-	7	-7
Wages	1,762	62	-	62	1,701
Total added benefits	**1,979**	**69**	**-**	**69**	**1,910**
Avoided Costs (million ETB)					
Mortality from air pollution	77	-	183	183	-106
Flood damages to property	58	61	-	61	-3
Mortality from flooding	177	184	-	184	-7
Bus fares due to decreased walkability	45	-	-	-	45
Carbon sequestration	893	-	893	893	-
Fuel cost	-	-	15,211	15,211	-15,211
Total avoided costs	**1,249**	**245**	**16,287**	**16,532**	**-15,283**
Added benefits + avoided costs	**3,228**	**314**	**16,287**	**16,601**	**-13,372**
Direct costs (million ETB)					
Tree planting costs	500	-	-	-	500
Tree maintenance costs	2,200	-	-	-	2,200
Rainwater harvesting construction costs	-	78	-	78	-78
Rainwater harvesting maintenance costs	-	149	-	149	-149
Electric vehicle purchase cost	-	-	13,301	13,301	-13,301
TOTAL DIRECT COSTS	**2,700**	**227**	**13,301**	**13,528**	**-10,828**
NET BENEFITS (MILLION ETB)	**528**	**87**	**2,985**	**3,072**	**-2,544**
BENEFIT-TO-COST RATIO	**1.20**	**1.38**	**1.22**	**1.23**	**-0.03**

Table D7. Comparison of costs and benefits of planting 11 million trees with 84% survival and grey infrastructure alternatives (31,403 m³ of rainwater harvesting capacity and 30,492 electric vehicles) under RCP 8.5. Grey infrastructure generates more benefits than trees but is also more expensive. Trees have a higher benefit-to-cost ratio than electric vehicles and rainwater tanks.

Grey infrastructure comparison: High trees planted, low survival, RCP 8.5

		Grey Alternatives			
	Trees	Rainwater harvesting	Electric vehicles	Grey total (harvesting + vehicles)	Difference (trees–grey)
Added benefits (million ETB)					
Fruit production	293	-	-	-	293
Additional water supply	-	8	-	8	-8
Wages	1,626	69	-	69	1,557
Total added benefits	**1,919**	**77**	**-**	**77**	**1,842**
Avoided Costs (million ETB)					
Mortality from air pollution	100	-	210	210	-110
Flood damages to property	67	68	-	68	-1
Mortality from flooding	202	205	-	205	-2
Bus fares due to decreased walkability	51	-	-	-	51
Carbon sequestration	1,023	-	1,023	1,023	-
Fuel cost	-	-	17,435	17,435	-17,435
Total avoided costs	**1,444**	**273**	**18,668**	**18,941**	**-17,497**
Added benefits + avoided costs	**3,362**	**349**	**18,668**	**19,017**	**-15,655**
Direct costs (million ETB)					
Tree planting costs	220	-	-	-	220
Tree maintenance costs	2,090	-	-	-	2,090
Rainwater harvesting construction costs	-	87	-	87	-87
Rainwater harvesting maintenance costs	-	165	-	165	-165
Electric vehicle purchase cost	-	-	15,246	15,246	-15,246
TOTAL DIRECT COSTS	**2,310**	**253**	**15,246**	**15,499**	**-13,189**
NET BENEFITS (MILLION ETB)	**1,052**	**97**	**3,422**	**3,519**	**-2,467**
BENEFIT-TO-COST RATIO	**1.46**	**1.38**	**1.22**	**1.23**	**0.23**

Table D8. Comparison of costs and benefits of planting 11 million trees with 84% survival and grey infrastructure alternatives (13,923 m³ of rainwater harvesting capacity and 12,894 electric vehicles) under RCP 8.5. Grey infrastructure generates more benefits than trees but is also more expensive. Trees have approximately the same benefit-to-cost ratio as electric vehicles and the combination of electric vehicles and rainwater tanks. Rainwater tanks on their own have the highest benefit-to-cost ratio because they avoid large losses from flooding.

Grey infrastructure comparison: Low trees planted, low survival, RCP 8.5

		Grey Alternatives			
	Trees	Rainwater harvesting	Electric vehicles	Grey total (harvesting + vehicles)	Difference (trees–grey)
Added benefits (million ETB)					
Fruit production	105	-	-	-	105
Additional water supply	-	3	-	3	-3
Wages	834	31	-	31	803
Total added benefits	**938**	**34**	**-**	**34**	**904**
Avoided Costs (million ETB)					
Mortality from air pollution	36	-	89	89	-53
Flood damages to property	30	30	-	30	-1
Mortality from flooding	90	91	-	91	-1
Bus fares due to decreased walkability	25	-	-	-	25
Carbon sequestration	433	-	433	433	-
Fuel cost	-	-	7,373	7,373	-7,373
Total avoided costs	**613**	**121**	**7,894**	**8,015**	**-7,402**
Added benefits + avoided costs	**1,552**	**155**	**7,894**	**8,049**	**-6,497**
Direct costs (million ETB)					
Tree planting costs	220	-	-	-	220
Tree maintenance costs	1,045	-	-	-	1,045
Rainwater harvesting construction costs	-	39	-	39	-39
Rainwater harvesting maintenance costs	-	73	-	73	-73
Electric vehicle purchase cost	-	-	6,447	6,447	-6,447
TOTAL DIRECT COSTS	**1,265**	**112**	**6,447**	**6,559**	**-5,294**
NET BENEFITS (MILLION ETB)	**287**	**43**	**1,447**	**1,490**	**-1,203**
BENEFIT-TO-COST RATIO	**1.23**	**1.38**	**1.22**	**1.23**	**-0.00**

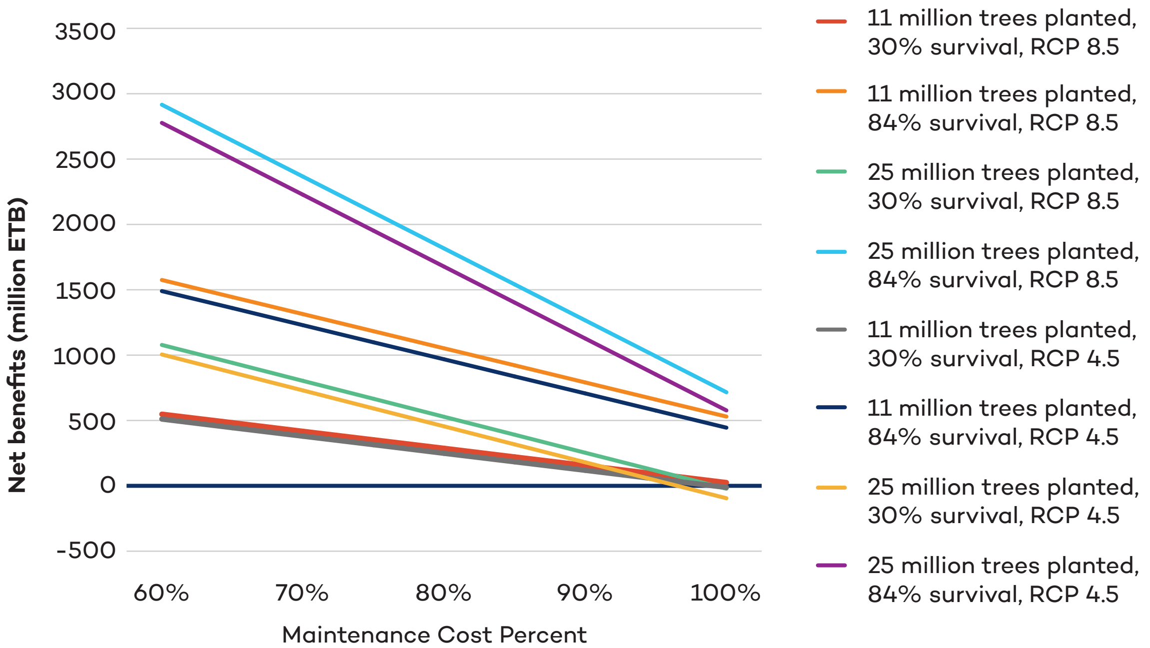
2. Sensitivity Analysis

There were no data available for the percentage reduction in walking on hot days and the decrease in hot days per °C of average cooling due to trees. We, therefore, made assumptions about these parameter values and acknowledge that there is considerable uncertainty in the avoided cost of bus fares. However, we note that this benefit is small, and even if it were zero, all scenarios would still have positive net benefits. Excluding this avoided cost would decrease the benefit-to-cost ratios by less than 2%, and all would still be greater than one. Thus, the assumptions made for these inputs do not affect the conclusions.

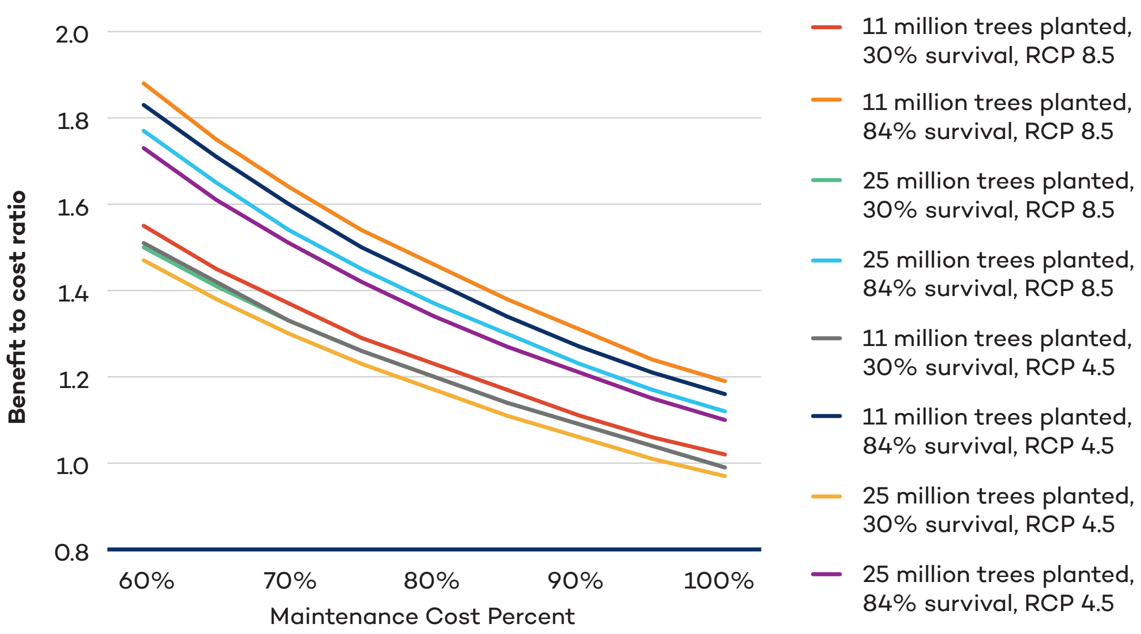
We also did not have access to data for the cost of maintenance. We assumed that for each tree maintained, the cost would be 80% of the planting cost per tree. Figure D 1 shows that the net benefits and benefit-to-cost ratio change when this maintenance cost percentage is varied from 60%–100%. However, if the maintenance cost is no greater than 95% of the planting cost, then tree planting has positive net benefits with a benefit-to-cost ratio greater than one. With high survival, net benefits are positive even when maintenance costs per tree are equal to planting costs per tree. Thus, regardless of maintenance costs, we can conclude that trees very likely generate value for money, particularly if survival is ensured.

Figure D1. Sensitivity analysis for the maintenance cost percentage. Net benefits and the benefit-to-cost ratio are sensitive to maintenance costs, but trees generate value for money when maintenance costs are less than 95% of planting costs.

(a) Calculated net benefits for all tree planting and climate scenarios and a range of maintenance cost values.



(b) Calculated benefit-to-cost ratio for all tree planting and climate scenarios and a range of maintenance cost values



Source: Authors' diagram.

3. Financial Analyses Results

Table D9. S-NPV and S-IRR of different tree planting programs under RCP 4.5 climate scenario accounting for all added benefits, added avoided costs, and investment and maintenance costs. All monetary values are in 2020 USD thousands.

	Tree planting scenarios over 20 years			
RCP scenario	4.5	4.5	4.5	4.5
Total trees planted	25 million	25 million	11 million	11 million
Survival after first year scenario	84 %	30 %	84 %	30 %
PRESENT VALUE of ADDED BENEFITS and AVOIDED COSTS				
Added benefits				
Tree planting wages	1,920	1,920	917	917
Annual tree maintenance wages	57,955	28,977	27,774	13,887
Fruit production	10,478	3,742	5,025	1,795
	70,353	34,640	33,716	16,599
Avoided costs and other benefits				
Carbon storage benefit (trees)	36,442	16,554	20,347	8,604
Avoided mortality from air pollution	3,865	1,380	1,804	644
Avoided flood damages to infrastructure	1,170	620	724	321
Avoided mortality from floods	3,389	1,798	2,069	917
Avoided bus fares due to cooling	996	805	913	457
	45,862	21,157	25,856	10,943
Total added benefits and avoided costs	**116,215**	**55,797**	**59,572**	**27,542**
PRESENT VALUE of COSTS				
Tree planting costs	10,131	10,131	4,840	4,840
Annual maintenance cost of trees	76,453	38,227	36,639	18,320
Investment opportunity cost	13,861	13,861	6,622	6,622
Total costs	**100,446**	**62,219**	**48,101**	**29,782**
S-NPV (no investment opportunity cost)	29,630	7,439	18,093	4,382
S-NPV (all benefits and costs)	15,769	-6,422	11,471	-2,240
NPV[11]	-16,232	-13,718	-7,763	-6,561

[11] Note that NPV calculation is the difference between the total added benefits and total monetary costs (tree planting costs and annual maintenance cost of trees).

	Tree planting scenarios over 20 years			
S-IRR[12] (no investment opportunity cost)	87.4 %	32.2 %	106.2 %	37.0 %
S-IRR (all benefits and costs)	33.8 %	** [13]	47.0 %	-3.4 %

Table D10. S-NPV and S-IRR of different grey alternatives under RCP 4.5 climate scenario accounting for all added benefits, added avoided costs, and investment and maintenance costs. All monetary values are in 2020 USD thousands.

	Grey alternative scenarios over 20 years			
RCP scenario	4.5	4.5	4.5	4.5
Rainwater harvesting capacity installed (m^3)	53,161	28,199	31,403	13,923
Diesel cars replaced with electric vehicles	58,564	26,603	30,492	12,894
PRESENT VALUE of ADDED BENEFITS and AVOIDED COSTS				
Added benefits				
Rainwater harvesting installation wages	885	469	523	232
Annual rainwater harvesting maintenance wages	1,340	711	791	351
	2,224	1,180	1,314	583
Avoided costs and other benefits				
Carbon avoided benefit (electric vehicles)	38,320	17,407	19,952	8,437
Avoided mortality from air pollution	7,282	3,308	3,791	1,603
Avoided flood damages to infrastructure	1,259	668	744	330
Avoided mortality from floods	3,569	1,893	2,108	935
Annual additional water	233	124	138	61
Annual cost savings of driving electric vehicles	587,034	266,659	305,647	129,249
	637,698	290,059	332,380	140,615
Total added benefits and avoided costs	**639,922**	**291,239**	**333,694**	**141,197**

[12] Note that IRR calculations for tree survival scenarios were adjusted so that initial investments were made in year prior to realization of benefits.

[13] The double asterisk denotes multiple IRRs. Multiple S-IRRs and IRRs occur when period net flows alternate between positive and negative over the time horizon of the project.

	Grey alternative scenarios over 20 years			
PRESENT VALUE of COSTS				
Capital cost – Rainwater harvesting capacity	3,243	1,720	1,916	849
Capital cost – Electric vehicle shift	644,208	292,630	335,415	141,837
Annual cost of rainwater harvesting	4,910	2,604	2,900	1,286
Investment opportunity cost	885,836	402,728	461,533	195,222
Total costs	**1,538,197**	**699,683**	**801,764**	**339,194**
S-NPV (no investment opportunity cost)	-12,438	-5,716	-6,537	-2,775
S-NPV (all benefits and costs)	-898,275	-408,444	-468,070	-197,997
NPV[14]	-650,136	-295,775	-338,917	-143,389
S-IRR (no investment opportunity cost)	8.3 %	8.3 %	8.3 %	8.3 %
S-IRR (all benefits and costs)	0.9 %	0.9 %	0.9 %	0.9 %

Table D11. S-NPV and S-IRR of different tree planting programs under RCP 8.5 climate scenario accounting for all added benefits, added avoided costs, and investment and maintenance costs. All monetary values are in 2020 USD thousands.

	Tree planting scenarios over 20 years			
RCP scenario	8.5	8.5	8.5	8.5
Total trees planted	25 million	25 million	11 million	11 million
Survival after first year scenario	84 %	30 %	84 %	30 %
PRESENT VALUE of ADDED BENEFITS and AVOIDED COSTS				
Added benefits				
Tree planting wages	1,920	1,920	917	917
Annual tree maintenance wages	57,955	28,977	27,774	13,887
Fruit production	10,478	3,742	5,025	1,795
	70,353	34,640	33,716	16,599
Avoided costs and other benefits				
Carbon storage benefit (trees)	36,442	16,554	20,347	8,604
Avoided mortality from air pollution	3,865	1,380	1,804	644

[14] Note that NPV is calculation is the difference between the total added benefits and total monetary costs (rainwater harvesting installation costs, increased cost of electric vehicles and annual maintenance cost of rainwater harvesting).

	Tree planting scenarios over 20 years			
Avoided flood damages to infrastructure	1,587	842	982	436
Avoided mortality from floods	4,998	2,651	3,046	1,350
Avoided bus fares due to cooling	996	805	913	457
	47,888	22,232	27,092	11,491
Total added benefits and avoided costs	**118,241**	**56,872**	**60,808**	**28,090**
PRESENT VALUE of COSTS				
Tree planting costs	10,131	10,131	4,840	4,840
Annual maintenance cost of trees	76,453	38,227	36,639	18,320
Investment opportunity cost	13,861	13,861	6,622	6,622
Total costs	**100,446**	**62,219**	**48,101**	**29,782**
S-NPV (no investment opportunity cost)	31,657	8,514	19,329	4,930
S-NPV (all benefits and costs)	17,795	-5,347	12,707	-1,692
NPV[15]	-16,232	-13,718	-7,763	-6,561
S-IRR[16] (no investment opportunity cost)	87.6 %	32.4 %	106.5 %	37.1 %
S-IRR (all benefits and costs)	33.9 %	-0.5 %	47.2 %	2.1 %

Table D12. S-NPV and S-IRR of different grey alternatives under RCP 8.5 climate scenario accounting for all added benefits, added avoided costs, and investment and maintenance costs. All monetary values are in 2020 USD thousands.

	Grey alternative scenarios over 20 years			
RCP scenario	8.5	8.5	8.5	8.5
Rainwater harvesting capacity installed (m^3)	53,161	28,199	31,403	13,923
Diesel cars replaced with electric vehicles	58,564	26,603	30,492	12,894

15 Note that NPV is calculation is the difference between the total added benefits and total monetary costs (tree planting costs and annual maintenance cost of trees).

16 Note that IRR calculations for tree survival scenarios were adjusted so that initial investments were made in year prior to realization of benefits.

	Grey alternative scenarios over 20 years			
PRESENT VALUE of ADDED BENEFITS and AVOIDED COSTS				
Added benefits				
Rainwater harvesting installation wages	885	469	523	232
Annual rainwater harvesting maintenance wages	1,340	711	791	351
	2,224	1,180	1,314	583
Avoided costs and other benefits				
Carbon avoided benefit (electric vehicles)	38,320	17,407	19,952	8,437
Avoided mortality from air pollution	7,282	3,308	3,791	1,603
Avoided flood damages to infrastructure	1,700	902	1,004	445
Avoided mortality from floods	5,230	2,774	3,090	1,370
Annual additional water	233	124	138	61
Annual cost savings of driving electric vehicles	587,034	266,659	305,647	129,249
	639,800	291,174	333,622	141,165
Total added benefits and avoided costs	**642,024**	**292,354**	**334,936**	**141,748**
PRESENT VALUE of COSTS				
Capital cost – Rainwater harvesting capacity	3,243	1,720	1,916	849
Capital cost – Electric vehicle shift	644,208	292,630	335,415	141,837
Annual cost of rainwater harvesting	4,910	2,604	2,900	1,286
Investment opportunity cost	885,836	402,728	461,533	195,222
Total costs	**1,538,197**	**699,683**	**801,764**	**339,194**
S-NPV (no investment opportunity cost)	-10,336	-4,601	-5,295	-2,224
S-NPV (all benefits and costs)	-896,173	-407,329	-466,828	-197,446
NPV[17]	-650,136	-295,775	-338,917	-143,389
S-IRR (no investment opportunity cost)	8.3 %	8.3 %	8.3 %	8.3 %
S-IRR (all benefits and costs)	0.9 %	0.9 %	0.9 %	0.9 %

[17] Note that NPV is calculation is the difference between the total added benefits and total monetary costs (rainwater harvesting installation costs, increased cost of electric vehicles and annual maintenance cost of rainwater harvesting).

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