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WP5

Deliverable No 5.1.: CBA and approach for monetizing the socio-economic value of tree planting in Cities

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Disclaimer

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List of Acronyms

AQ	Air Quality
BGN	Bulgarian lev
CAPEX	Capital Expenditures
CBA	Cost benefit analysis
DBH	Diameter at Breast Height
EC	European Commission
EU-ETS	European Union – Emission Trading System
EVA	Economic Valuation of Air pollution
MCA	Multi Criteria Analysis
NPV	Net Present Value
USDA	United States Department of Agriculture
OPEX	Operational Expenses
UHI	Urban heat island effect
WP	Work Package
WTP	Willingness To Pay

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Executive Summary

This deliverable reports on the main findings of the literature search related to benefits assessment of planting trees, valorisation of ecosystem services and concerning existing business cases on financing tree planting and greening of our cities to build resilience against climate change.

The literature search involved screening of nearly 100 papers, articles and reports, addressing different subjects from assessing specific ecosystem services such as trees ability to remove air pollutant, to impact on property prices and tree planting as climate adaptation measure. While other studies have looked at the benefit of trees for the mental health and human wellbeing in general.

In particular one initiative, the American based i-Tree approach, has converted the value of some of the eco-system services provided by the city trees into monetary values. The i-Tree has similarities to 100KTREEs, wherefore we have dedicated a chapter to describe their approach and concept.

The literature review has reassured the vision of the 100KTREEs to provide valorisation of the key ecosystem services provided by city trees, e.g. the value of cooling effect; the value of oxygen production and removal of pollutants; the value of water absorption and the value of CO2 absorption.

The deliverable outlines our proposed approach for assessing the monetary value of these key ecosystem services to be used in the 100KTREEs modelling tool.

We distinguish between, on the one hand, ecosystem services provided by the trees of which some can be valued in monetary terms, others only qualitatively. On the other hand, the different types of direct and indirect benefits. While the valuation of the ecosystem services provided by the trees, can be said to be a bottom-up approach, the benefit assessment takes a more holistic approach by including also more city strategic benefits.

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1 Introduction

1.1 Purpose and audience of the document

The aim of this document is to report on the findings of the first two task of WP5, namely Task 5.1 Planting Tree business cases, and Task 5.2 Literature Review. This will lead to a description of the method to be used in 100KTREEs for the valorization of tree planting, notably the value of key ecosystem services, e.g.

1.2 Relation to other activities

Input for the two tasks reported in this deliverable comes from literature research and specific reports and insights into i-Tree.

The output of this deliverable, the 100KTREEs valorization approach, will be used in Task 5.3 and eventually as input into the Modelling Tool (WP4).

1.3 Structure of the document

The two tasks (T5.1 and T5.2) have been running in parallel during the first 12 months of the 100KTREEs project. We have used Zotero for structuring the results of the literature research. A total number of nearly 100 titles have been included in the literature research. The main topics areas including abstracts of a selection of the interesting items are included in Annex A.

Chapter 2 will briefly provide an overview of the traditional market and non-market valuation methodologies as well as an overview of the element of a cost-benefit-analysis.

The chapter concludes by describing how we intend to use the CBA approach in the 100TREEs project.

Chapter 3 provides a first framework to assess benefits of tree planting in cities.

Chapter 4 will report on the i-Tree approach to valorize the eco-system services. Through our literature review we came across the i-Tree project developed by the USDA Forestry Service. Their approach to valorization trees is explained in this chapter.

Chapter 5 summaries costs side of planting trees and maintenance cost based on existing literature and documentation from among other Copenhagen estimates and Sofia.

Chapter 6 outlines our proposed approach for valorizing urban trees with a focus on converting the ecosystem services expressed in physical values into monetary values. We have also initiated an approach looking at how 100KTREEs can contribute to the City indexes related to 'green'cities.

Chapter 7 concludes the report by listing next steps.

2 Valuation approaches

2.1 Scenarios and valuation methodologies

At the core of the 100kTree business models is the valuation of the trees in different planting and maintenance scenarios in the target cities. The business case will be positive when the distribution of costs and benefits is perceived as positive over a defined timeframe and geographic area. In other words, from a value perspective, the benefits of decreasing e.g. flood and heat risk, but also improvement in access to green space and mental health in the city should outweigh the costs associated with it (e.g. using the land, planting and maintaining the tree). Important considerations are needed in terms of who is paying for or benefiting of what and the degree to which the benefits can be captured, and costs and risks can be shared. This implies that we cannot see the value of tree planting scenarios independent of the governance structures and communities they are related to.

As such, the creation of a shared understanding of values, costs, benefits and the dynamics of governance and communities, are essential to define business models and governance structures that can promote planting and maintenance of urban trees at scale. WP5 will start from the core values of trees using market and non-market valuation methodologies and then expand to combine plural valuation methodologies into cost-benefit (CBA) and multi-criteria assessments (MCA).

2.2 Market valuation methodologies

As opposed to the non-market valuation, market valuation uses the market value of a given item, product, asset, or resource. This implicitly assumes that the item or resource is a tradeable product available in the market. Nevertheless, depending on the type of item, product, asset or resource, different market valuation approaches can be used.

METHOD	DESCRIPTION	EXAMPLES/ RELEVANCE FOR 100KTREEs
Comparable Sales Method	Using market data from similar assets to estimate value.	A close substitute of a tree in the City could be a green wall, green roof, planter
Income Capitalization Method	Estimating the present value of expected future income from an asset	Only relevant if we can monetize the value of the eco-system services provided by the city tree
Discounted Cash Flow Method	Projecting future cash flows and discounting them to present value.	A tree could have a very long lifetime, there are examples of city trees more than 100 years old
Exchange-Traded Market Method	Using market prices of similar assets traded on an exchange.	An example of this could be the replacement value of an ecosystem service, f.ex. the shading effect of trees and greening and the savings on energy used for air-conditioning.
Surplus Approach Method	Subtracting the cost of production from the market value of output.	The relationship between the cost of producing and planting the tree related to the market value.

2.3 Non-market valuation methodologies

In the wider perspective, beyond the value of the individual tree, the object of analysis for the ‘resource’ could be formulated as ‘wild nature’ or restoring biodiversity in the urban context.

There are several non-market valuation methodologies, as briefly shown below with some examples and relevance for 100KTREEs.

METHOD	DESCRIPTION	RELEVANCE FOR 100KTREEs
Cost-Based Method	Estimating the cost of restoring or replacing a resource.	Equal to the costs of planting a tree or restoring xm2 wild nature or biodiversity
Contingent Valuation Method	Surveying people to determine their willingness to pay (WTP) for a resource.	An approach to understand what citizens are willing to pay for green and blue infrastructure in cities
Hedonic Pricing Method:	Analyzing the relationship between market prices and environmental attributes.	An approach of assessing the value of house prices according to proximity to green areas has been done by a study from Aarhus University under the Green City project.
Benefit Transfer Method	Using existing valuation estimates from similar resources in other locations	From a meta analysis study (Bockarjova et al., 2020) based on 60 primary studies that has collected data from 41.000 respondents, estimates the economic value on urban nature

2.4 Aggregation and decision making: CBA and MCA assessment

As trees provide a myriad costs and benefits, it becomes important to aggregate these into a single metric that allows for comparison of different scenarios and guide decision makers into selecting the preferred tree planting scenarios for operationalisation into investment plans. The aggregation methods used in WP5 are both monetary (cost-benefit assessment, CBA) and non-monetary (multi-criteria assessment, MCA) as introduced below.

Cost-Benefit Assessment (CBA) is a method of evaluating the costs and benefits of a project or policy intervention to determine its overall feasibility and effectiveness. The approach to conduct a CBA typically includes the following steps:

- Define the problem and scope of the project or intervention.
- Identify and quantify all costs and benefits, both tangible and intangible.
- Establish a common metric, such as monetary value, to compare costs and benefits.
- Determine a discount rate to adjust for the time value of money.
- Calculate the net present value (NPV) of the costs and benefits to determine if the benefits outweigh the costs.
- Evaluate the results and make a decision based on the NPV.
- Consider and address any uncertainty and risks in the analysis.
- Monitor and evaluate the results of the project or intervention over time to ensure it meets expectations.

Multi-criteria assessment is an alternative method to CBA, which is seen as more versatile as it does not depend on the monetisation of the underlying criteria. Criteria are closely linked to the plural values that exist in relation to tree planting and that decision makers consider when making investment decisions.

Unlike CBA, multi-criteria assessment refers to a set of techniques aiming to obtain a ranking of scenarios (in this case tree planting) when the effects of these scenarios cannot be translated to a single measuring rod (for example monetary units), but are expressed in units which reflect as good as possible the nature of the criteria concerned. As such the analysis helps to take explicit account of political viewpoints and priorities.

MCA aims to rank scenarios with respect to their overall performance to the different criteria. MCA starts with determining the performance of the alternative scenarios with respect to the individual criteria (e.g. flood risk reduction, mental health benefit). The performance values are attributed using modelling or stakeholder-based valuation tools. As different criteria and values are often expressed in different units (such as percentages (%) for shortages, euros (EUR) for investments, volumes (m3) for the amount of water diverted), a technique called standardization or normalization is used to translate scores to the same unit. Another feature of MCA is that criteria can receive different weights, reflecting the importance that is given by decision makers to them (e.g. ministry of health will be more concerned with air pollution and heat risk reduction then with flood risk, which would be crucial for water utility). This reflection of preferences in the aggregation process is one of the key advantages of MCA when comparing to CBA.

2.5 Valuation, CBA and MCA in the 100KTREEs Project

100KTREEs will be using a mix of market and non-market valuation approaches as well as aggregation methods (CBA and MCA). To assess the ecosystem service provided by the trees, we will use the physical values coming from the modelling results as provided in WP4 and convert these into monetary values using the given unit prices derived from our literature study.

We will be looking at value creation for the individual citizen and for society at large including businesses and other economic sectors.

Cost benefit assessment in 100KTREEs will depend on the use case and the focus of analysis. Once we have all the variables defined, we can calculate the costs and benefits of a given intervention. This will be further elaborated in the What If scenarios in T 5.5

Examples of What If scenarios (to be further developed):

- What are the costs and the benefits of planting 10 city trees in sealed ground in a busy street in central Copenhagen?
- What are the replacement costs of 10 old trees in central Sofia?
- What is the impact of planting 100.000 trees in Copenhagen or Sofia on health costs?

These ecosystem values associated with trees will be discussed based on literature and more specifically for the 2 Pilot cities in the next chapters.

2.6 Results of Literature review

The literature search involved screening of nearly 100 papers, articles and reports, addressing different subjects from assessing specific ecosystem services such as tree's ability to remove air pollutant, to impact on property prices and tree planting as climate adaptation measure. While other studies have looked at the benefit of trees for the mental health and human wellbeing in general. We have used ZOTERO to organise the reviewed papers and reports and are regarding the literature review as a continuously activity feeding the project common knowledge.

In particular one initiative, the American based i-Tree approach, has converted the value of some of the eco-system services provided by the city trees into monetary values. The i-Tree has similarities to 100KTREEs, wherefore we have dedicated a chapter to describe their approach and concept.

The literature review has reassured the vision of the 100KTREEs to provide valorisation of the key ecosystem services provided by city trees, e.g. the value of cooling effect; the value of oxygen production and removal of pollutants; the value of water absorption and the value of CO2 absorption.

Annex A includes examples of the main papers and reports reviewed. For the purpose of 100KTREEs and input for specific monetary values of the ecosystems services, the input from literature was relatively modest. The main results are summarised in Chapter 6 related to the set of eco system values provided by trees and the monetary values to be used in the 100KTREEs model.

Further literature review will be done in subsequent Tasks in WP5 related to Human wellbeing and life quality.

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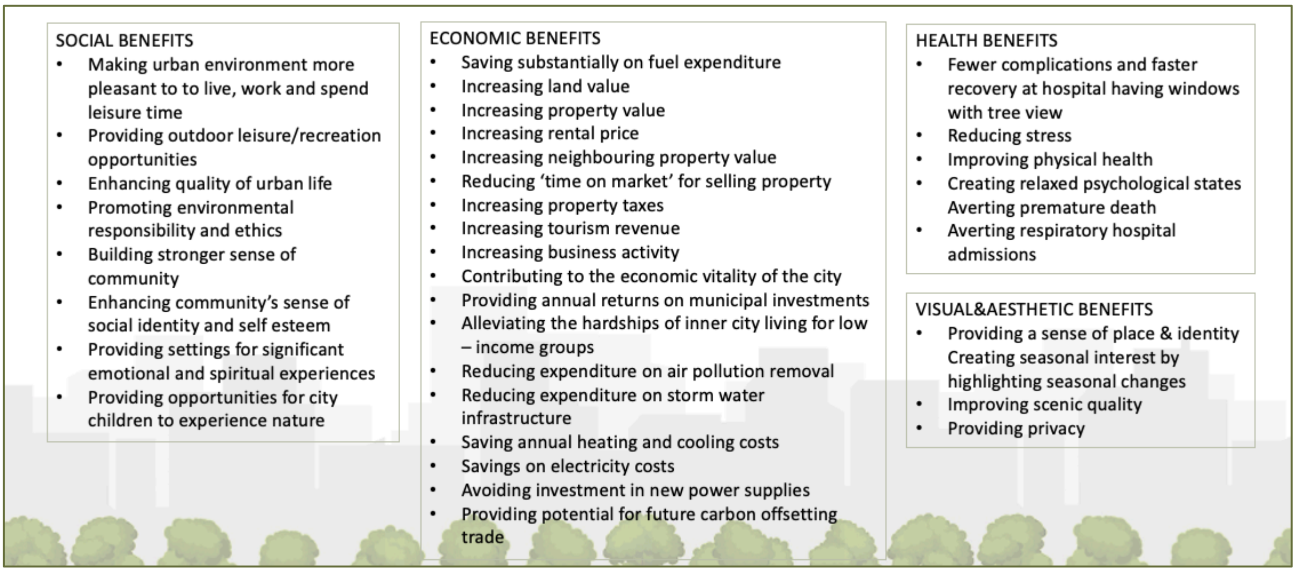
3 Trees and their value in cities – an overview

In this section we discuss the different values of trees in urban areas – both positive and negative values or benefits and costs. The results are based on literature review and stakeholder interviews tailored to the 2 demonstration cities in the 100kTree project. The section starts with presenting general benefits and costs of trees and ends with specific consideration of the costs of planting and maintaining trees in Copenhagen and Sofia.

3.1 Benefits of trees and tree planting

Broadly speaking we talk about different types of benefits associated with trees and greening of urban areas. They are generally subdivided as social benefits, economic benefits, health benefits and visual & aesthetic benefits (Figure 3-1). Indeed, a literature review and analysis of recent public and policy discourse is filled with claims that a green city with street trees, pocket parks and parks are just making you feel better that it encourages outdoor life and sports activities, which again have positive impact on human health and adds to the overall quality of life.

Figure 3-1Different type of benefits



Numerous studies exist that evaluate benefits for planting trees in urban environments. We have identified and assessed more that 50 studies and have grouped them into the following subject areas:

- Meta studies
- Reducing Air Pollution
- Reducing Energy Costs and UHI
- Improving Property Values
- Social benefits and human wellbeing
- City's Tree strategies
- CBA and economic assessment

Detail of the literature study is presented in annex 1 – Literature study on benefits of trees in cities.

4 Costs of planting trees

The costs of planting trees in urban areas varies according to the context in which the tree will be planted, the size of tree and the species.

4.1 Costs of planting trees in Copenhagen

In the Copenhagen Tree Planting strategy (Copenhagen Municipality, 2020), the distinction is made between trees planted in sealed areas, trees planted directly in the soil, trees in parks, and finally a partnership trees.
Furthermore, the costs are divided into implementation costs and yearly maintenance costs. The costs of planting trees include cost of tree, cost of planting, and establishment maintenance.

Table 4-1 Overview of costs of planting different types of trees in Copenhagen

Planting context	*Implementation costs per tree (EUR)*	*Yearly Maintenance costs (EUR)*
Tree planted in sealed area	€3.350-€16.775	€70-€268
Examples		
 **Gadetræ solitært, Nørrebrogade**	 **Gadetræer på række, Valby Langgade**	 **Gadetræer i sammenhængende grupper, Bryggervangen.**
Installation of planting hole including growth medium under the pavement, planting of the tree with grate and tree-support. *Total price per tree €12.150*	*Installation of planting hole and planting of tree in an open border with elevated curbstone.* *Total price per tree €8.725*	*As part of cloudburst and urban space project where 9000M2 asphalt was converted into a green are with 600 new trees.* *Average price per tree: €3.500*
Tree planted in soil		
Examples		
		
Establishment of new trees. Price depending on size of tree and soil work required. *Price per tree: €360-€1545*	*Planting of additional 18 new trees in existing green area.* *Price per tree: €3500*	

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City Park tree		
Example		
		
14ha city forest, total price for the establishment of the city forest and planting of 47000 trees: €710.000 or €15 per tree.		

The table below summarises the costs of tree planting in Copenhagen, subject to further updates or verifications before they will be used in the model.

Table 4-2 Summary of Costs of tree Planting Copenhagen

Tree Planting Costs in Copenhagen **Type of tree**	**Cost of planting (CAPEX)**	**Yearly maintenance costs (OPEX)**
Tree planted in sealed soil including root space system	€3.350-€16.780	€67-€268
Tree planted directed in soil	€134-€2.685	€14-€134
City forest/park	€2-€67	>€1

4.2 Costs of tree planting in Sofia

Basically, it costs around 180 BGN/ 90 EUR to plant 1 tree, and the maintenance of a tree on an yearly basis costs around 450 BGN/225 EUR.

All these cost estimations are not market values but rather based on best price proposal of the public procurement procedures. The cost prices needs to be further verified by the City of Sofia before used as input to the model.

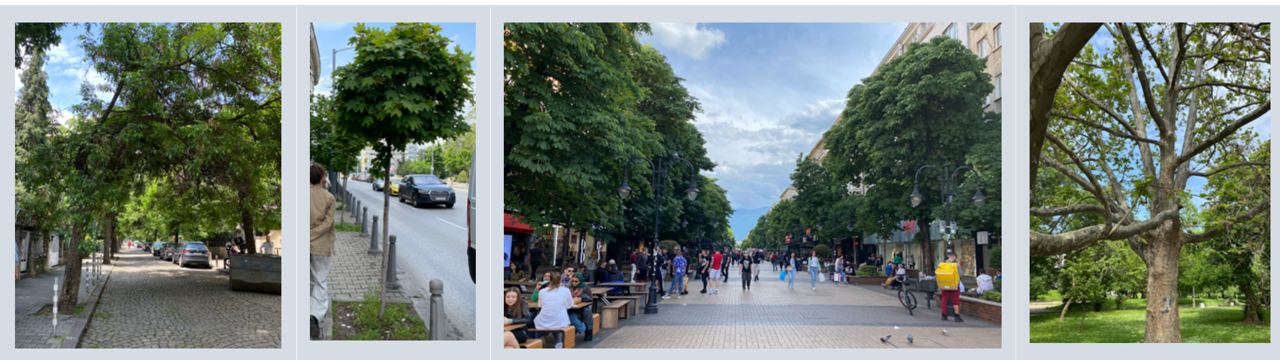

Figure 4-1Examples of city trees and park trees in Sofia

4.3 Examples of Urban Tree planting schemes

Many cities in the European Union have implemented tree planting strategies as part of their environmental and sustainability plans. Some examples include:

CITY	
Paris, France	Launched the "Paris, Capital of Forests" initiative in 2013, aiming to plant 100,000 trees by 2020.
Hamburg, Germany	Has a goal of planting 1,000 new trees per year as part of its urban greening strategy.
Vienna, Austria:	Has a target of increasing its green spaces, including planting more trees, as part of its "Green Vienna" initiative.
Amsterdam, Netherlands	Has a plan to increase its green spaces, including planting more trees, as part of its "Green Amsterdam" strategy.
Stockholm, Sweden	Has a plan to increase its green spaces, including planting more trees, as part of its "Stockholm 2030" sustainable development strategy
Copenhagen, Denmark:	Has a target of planting more trees and increasing its green spaces as part of its sustainable city development plan.

These strategies will be further elaborated and investigated to understand the status, barriers encountered, and possible finance strategies applied. This will be included in D5.2.

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5 Existing tools for tree valuation and business cases

5.1 The i-Tree approach to monetizing the value of trees

i-Tree is a free peer-reviewed software suite developed by USDA Forest Service in 2006 which can quantify and value of the Urban Forrest and some of their ecosystem services. i-Tree uses empirical equations on tree leaf area index and biomass to estimate the avoided runoff, air pollution removal, carbon sequestration and energy effects. The tool requires measurements on tree attributes (Height, dbh, crown size etc.) as well as meteorological and population data for these ecosystem services (Videntjenesten, 2018).

The i-Tree suite consists of different models as Eco, Canopy, Planting, Species, MyTree, Design, Landscape, OurTrees, Hydro+ and CoolAir (All Tools, 2023). The tool has been initially proposed for studying the US urban forest structure, but in 2018, the main models (Eco & Canopy) have been integrated with some cities in Europe. The model has a built-in function to translate the value of trees based on four ecosystem services into US based monetary methods. There are two main tools that have been adapted to Europe from i-Tree: i-Tree Eco and i-Tree Canopy (Nowak, 2021).

5.2 The tools adapted to EU

i-Tree Eco is the main model designed for assessing individual trees' ecosystem services. It evaluates tree structure, provides forecasting models, and delivers management insights based on existing inventories or collected field data. The tool has been adapted with necessary information on species, location, pollution and precipitation data for most European cities. The methods and calculations are the same regardless of the country chosen. The valuation of ecosystem services is based on US values, but users can provide their own benefit prices on electricity, heating, carbon and avoided runoff to localize their results when setting up an i-Tree project (I-Tree Eco, 2023).

Ecosystem Analyses:	Structure and composition analyses:	Forecasting modeling options including:	Management information including:
Pollution removal and human health impacts Carbon sequestration and storage Hydrology effects (avoided run-off, interception, evaporation, transpiration) Building energy effects Tree bio-emissions Ultraviolet radiation (UV) tree effects	Species condition and distribution Leaf area and biomass Species importance values Diversity indices and relative performance	Tree planting inputs Extreme event impacts for weather and pests Annual mortality adjustments	Pest risk analysis User defined optional fields Cost benefit analysis

i-Tree Eco operates in two methods: a complete inventory for detailed registration of each tree, ideal for smaller areas, and a sample inventory that uses random plot sampling for city-wide estimates (*I-Tree Eco*, 2023). While the complete inventory is more accurate, it is resource-intensive, typically applied to parks and specific tree populations. The sample inventory, involving about 250 random plots, is less precise but more practical for larger urban areas, with an average uncertainty of about 10% (*I-Tree Eco Sample Inventories*, 2023). The user needs to provide the following information for a full inventory analysis:

- Mandatory data: Tree species, tree stem diameter at breast height
- Recommended data: Crown diameter, tree height, stem height (to crown base), crown height, percent missing crown, top dead (%)
- For in-depth analyses: Proportion of the crown that receives sunlight, the location of the tree in relation to buildings, land use (Videntjenesten, 2018).

Using mandatory data, the tool then estimates the leaf biomass and LAI of the trees based on the empirical equations from forest measurements as well as correction factors related to the region of the study. Similarly, the recommended data attributes act as adjustment factors to predict the ecosystem services according to LAI and biomass (Rötzer et al., 2021)

<u>Pros:</u>

The tool is free to use for everyone and there are freely available guides and user manuals online. The program itself is easy to use after a small introduction but for the gathering of tree species an expert is needed.

<u>Cons/limitations:</u>

The accuracy of the analysis depends on the user's ability to assess correctly in terms of the percentage of the tree missing or dead and being able to identify the tree species correctly. The data gathering is very time/resource demanding and can only be done in the late spring to early fall as leaves on the trees is required to determine tree health. The energy effect is based on US research (US building practices, energy use, emission ect.) which makes it not suitable for Europe. The pollution data available for Denmark is limited to year 2013 to 2015 and the weather data is limited up to year 2021. Human health values are based on the US Environmental Protection Agency BenMAP model and are not available for international projects.

I-Tree Canopy is a web-based tool that uses random point sampling on Google Earth imagery to assess land cover, particularly tree canopy, within a specific area defined by the user. This module is used in larger study areas (city scale) when less detailed tree data is available. The tool allows for historical land cover comparisons using past maps. Although the model depends on 250 site measurements, the accuracy of the canopy estimate improves as more points are assessed (Nowak, 2021). After doing about 30 projects in i-Tree Canopy A manual review of approximately 1,200 points, typically requiring 2-3 hours, is standard for achieving a standard error below 1.5% in Danish cities, although this number may vary with the size of the surveyed area.

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The annual carbon sequestration and storage estimates are based on US data and methods like standardized rate for carbon storage per tree cover area (7.69 kg C/m^2) which is applied to the tree cover quantity to estimate carbon storage. To estimate the annual carbon sequestration standard values are used (kg C/m^2 tree cover/year) (Nowak, 2021). i-Tree Canopy calculates the estimated removal of carbon storge, air pollution and the hydrological impacts based on the area of tree cover. The estimated total effect of the trees (kg) is calculated by using a local standardized removal rate (e.g., kg/m^2 of canopy cover) that is multiplied by the canopy cover (m^2). The calculations for air pollution removal the program uses the i-Tree Eco used air pollution and weather data to estimate the average pollution removal effect per unit of the canopy cover (g/m^2 or \$/m^2 of canopy cover) (Nowak, 2021). The hydrology estimates are based on the tree surface coverage and weather data from the United States and a standardized removal rate (e.g., m^3 water/m^2 tree cover) that is multiplied by the tree cover in m^2 to make an estimate of the total local tree effect (m^3). The estimate of the hydrological effect uses weather data to assess the average effect per tree cover unit (m^3/m^2 or \$/m^2 tree cover) (Nowak, 2021). Detailed methods in (Hirabayashi *et al.*, 2022).

Pros:

The tool is free and there are free YouTube guide videos and user manuals available for everyone. It is very quick and easy to use.

Cons/limitations:

The accuracy of the analysis depends on the user's ability to classify correctly. The benefit prices for air pollution, hydrology and carbon needs to be defined by the user to be more precise, most people do not have these prices, or it would take them time to find. i-Tree Canopy calculates the effects of an urban forest by categorizing the land cover. This means that the model doesn't account for the actual physical characteristics of the trees or the specific details of their locations, such as their height or Leaf Area Index (LAI). Instead, the model offers a general estimate by averaging the extent of urban forestry across a city and the potential benefits it might offer.

5.3 Assumptions on ecosystem services and valuation in I-Tree

The tree functions like growth are estimated based on tree attributes like height and leaf area is measured by the user in the field or estimated by i-Tree (based on the user's measurements) combined with local environmental data like the weather. The tree functions are converted to services like carbon removal based on local data such as pollution concentration (only local data from 2013-2015). These services are then converted to benefits such as cleaner air, based on other data like human population data. Finally, the benefits are converted to values based on various economic procedures (Nowak, 2021).

Most EU countries are fully integrated into i-Tree Eco with the necessary species information, pollution and precipitation data has been preprocessed and available directly in the application. The methods and calculations will be the same regardless of the country chosen but will incorporate pollution, precipitation, and demographic information defined by the user. The valuation of ecosystem services is based on US values but users can provide their own benefit prices to localize their results when setting up an i-Tree Eco project. The human health values are based on the US Environmental Protection Agency BenMAP model (Nowak, 2021).

Ecosystem service Valuation		Comment
Carbon	i-Tree Eco calculate carbon storage based on tree species and biomass. The biomass is calculated from the user measured tree data and literature. The tree dry-weight biomass is converted to stored carbon by multiplying by 0.5. The carbon sequestration is limited to 40 kg C/ cm d.b.h. growth once the tree reaches 7,500 kg of carbon to prevent overestimation (Nowak, 2021). The annual carbon sequestration is estimated by tree species, average diameter growth, diameter class, growth, decomposition and tree condition. The sequestration values are added to the storage value. To estimate future annually carbon sequestration the d.b.h. is increased based on an annual growth rate (Nowak, 2021). The valuation of Carbon storage and carbon sequestration are based on estimated or customized carbon values based on the social cost of carbon as reported by the Interagency Working Group *et al.* (2016). The social cost associated with a pollutant (e.g., CO2) refers to an estimate of total (global) economic damage attributable to incremental increase in the level of that particular pollutant in a given year (Nowak, 2021). The current CO2 value is estimated at $51.23 per tonne based on the estimated social costs of carbon for 2020 with a 3 percent discount rate to reflect 2018 dollars. The user can adjust the value by taking a ratio of the desired value (DR) per tonne CO2 to the $51.23/tonne CO2 (updated value = i-Tree reported value x DR/51.23) (Nowak, 2021).	
Air pollution	i-Tree estimates the value of the removal of NO2, SO2, O3, PM2.5 and PM10. The valuation of pollution removal is estimated in one of two ways: 1.Externality values – which is the cost to the society of the pollution that is not accounted for in the market price of the goods or services that produced the pollution. i-Tree Eco uses estimates of externality values (Urban Forest Effects and Values, 2011; U.S. Congress, Office of Technology Assessment, 1994) for the valuation of CO ($1,599/tonne) in 2011 dollars);	The available pollution and weather year for adapted partner country projects is limited to the year of pollution data that was provided by partner countries for integration in the Eco model. The newest year for Denmark is 2015.

	these values are updated based on the producer price index (U.S. Bureau of Labor Statistics, 2017). 2.Health values - where the calculations is based on the number of incidents avoided and the total dollar value of several health factors related to the pollutants. These estimates are based on health-care expenses, productivity losses associated with specific adverse health events, and on the value of a statistical life in the case of mortality as derived from the U.S. EPA BenMAP model (Nowak et al., 2014; US EPA, 2016). For projects in the EU user-defined local pollution values are used or a European median externality values (van Essen et al., 2011) or BenMAP regression equations (Nowak et al., 2014) that incorporate user-defined population estimates. The human health impacts of air pollution removal are based on a US specific model created by the Environmental Protection Agency and are not available for international projects (Nowak, 2021).	
Hydrology	Eco estimates rainfall intercepted, stored, transpired, evaporated and the avoided runoff. The avoided runoff calculations are based on only leaf interception, tree condition and without tree cover. The rest is based on leaf plus bark data, tree condition, and local hourly weather data. The impervious cover under the trees is assumed to be 25,5%. The estimates are process-based in that way that each individually simulated and the linked with the other processes. (Nowak, 2021). The calculations are based on numerous calculation which are detail in Hirabayashi *et al.* (2022), (Hirabayashi, 2013), (Wang et al., 2008) and (Yang et al., 2011). The benefit price of avoided runoff is based on either user provided value for $\$/m^3$ or if the user does not have a price, the programme provides a value. (Nowak, 2021). i-Tree Eco uses the U.S. national average dollar value of $0.008936/gallon to estimate the value avoided runoff due to trees (Nowak, 2021).	Modelled in WP4, using specific scenario data from WP2 and WP3
Energy effect	i-Tree Eco makes these assumptions based on distance and direction to buildings, height of the tree, tree condition. This part of the model has not been adapted to the outside of the US and should therefore be used with caution. Users outside US will receive results which are based on the U.S. climate region, typical construction practices, energy composition and emission factors (Nowak, 2021). The monetary value of the energy savings is custom prices per MWH or MBTU are utilized. The price can be user modified. (Nowak, 2021).	The energy effect of trees is considered under the cooling effect in WP4. We model the distribution of temperature and heat island based on changes in shade, humidity and evapotranspiraton and translate this heat stress in to heat or cooling load for buildings.

Oxygen production	The oxygen production is estimated from carbon sequestration based on atomic weights: net O2 release (kg/yr) = net C sequestration (kg/yr) × 32/12 (Nowak, 2021).	No valuation of this service only a quantification. The oxygen production in complete inventory projects does not account for decomposition and is based on gross carbon sequestration (Nowak, 2021).
Tree-bio-emissions	Trees emit volatile organic compounds that potentially form ozone and other pollutant. The VOC emission depend on species (Nowak, 2021).	No valuation of this disservice only a quantification.
Ultraviolet radiation	i-Tree Eco can quantify the effects trees have on mitigating the intensity of ultraviolet radiation on the ground within different land types. Eco calculates ultraviolet radiation based on canopy cover, UV index values, hourly cloud cover and solar zenith angle data. All of these datasets are combined with equations and thereby predict the UV protection factor and what changes the trees make in the UV index (Nowak, 2021).	No valuation of this service only a quantification. The uncertainty of the estimates are unknow.

Conclusion:

-Tree Eco is easy to use but not user-friendly, as it requires a lot of time and resources that most municipalities do not have. The program requires many tree measurements before any analysis can be made. Although all the gathered structural data is essential to make the calculations more accurate, it needs to be done in a less time-consuming way. Additionally, there is no planning tool to determine the impact of planting additional trees in a project/area.

Many of the data and methods used in the program are outdated, such as air pollution data from the EU, which is from 2015, and weather data from 2021. This data is constantly changing, and therefore i-Tree will become further outdated each year.

Most EU countries are fully integrated into i-Tree Eco, with the necessary species information, pollution, and precipitation data pre-processed and available directly in the application. The methods and calculations will be the same regardless of the country chosen, but pollution, precipitation, and demographic information defined by the user will be incorporated. The valuation of ecosystem services is based on US values, but users can provide their own benefit prices to localize their results when setting up an i-Tree Eco project. The i-Tree approach, while practical, leads to inconsistencies since it is based on a one-size-fits-all assumption derived from US-centric cost data. Therefore, a different approach for cost assignment to ecosystem services is needed for European cities.

5.4 Scenario generation and comparison in i-Tree

I-Tree has a set of variables that can be modified to generate different tree planting scenarios. They are grouped in 3 categories as per below:

- Structure and composition of the trees (including species, distribution and variation)
- Climate conditions (weather forecasting) and mortality of trees
- Management and/or maintenance information (related to pests, user defined parameters such as interference with buildings and utility lines and maintenance costs)

Tables below discuss the elements composing planting and assessment scenarios in more detail.

Structure and composition analyses	Comments

Species condition and distribution	i-Tree eco calculates the condition of the species (Nowak, 2021).	
Leaf area and biomass	Leaf area and biomass is used in calculation of the ecosystem services. It is based on, among other, user measurement of the tree like crown with and height (Nowak, 2021).	
Species importance values	The importance value is calculated for each tree species as the sum of the species contribution to the total leaf area and tree population. The importance value is calculated= (percent of total number of trees comprised by species x 100) + (percent of total population leaf area comprised by a species x 100) (Nowak, 2021).	
Diversity indices and relative performance	i-Tree Eco estimates tree species diversity indices and takes into account the native range of species (Nowak, 2021).	There is no valuation of species diversity
Replacement value / structural valuation	Replacement value is the value of a tree based on the physical resource itself (e.g., the cost of having to replace a tree with a similar tree). Replacement values were based on valuation procedures of the Council of Tree and Landscape Appraisers, which uses tree species, diameter, condition, and location information (Nowak, Crane, & Dwyer, 2002) and (Nowak, Crane, Stevens, et al., 2002) (Nowak, 2021). The structural value is based on trunk area and tree species multiplied by location rating and health condition (Nowak, 2021).	No Special Evaluation for Europe: Country specific species values and costs Need for tree experts in accurate pricing of trees

Forecasting modeling options including:		**Comment**
Tree planting inputs	The user can input a planting rate to simulate how the urban forest develops over time (Nowak, 2021).	
Extreme event impacts for weather and pests	i-Tree eco can simulate what a pest/disease outbreak would do to the tree population to see the mortality rate. The software can also simulate storm events like hurricane to see the mortality rate (Nowak, 2021).	
Annual mortality adjustments	The user can make user-defined mortality rates to see how their tree population develops over time. I-Tree uses user-measured dieback and tree size to calculate the mortality rate (Nowak, 2021).	

Management information including:		**Comment**
Pest risk analysis	The full potential pest risk analysis is only available in the US as it is based on pest range maps from 2012 and know likely mortality pest host species. i-Tree looks at the tree species registered and compare the species to know pest in the US that effect that species. The analysis looks at the number of trees that are susceptible, the replacement value of those trees and the leaf area in both % and ha that would disappear (Nowak, 2021).	This analysis tells the potential pest risk and not the actual number of trees infected. The structural value of susceptible species for each pest is calculated.

User defined optional fields	When registering a tree, the user can also register: - Maintenance recommended - Maintenance task - Sidewalk conflict - Utility conflict - Pests The user can also register if the tree is a street tree, public or private tree, the land use. (Nowak, 2021).	Everything is a manual registration
Maintenance costs	The valuation is based on what the urban forest provides in ecosystem services (money) compared to what the trees cost to manage (planting, pruning, remove, pest control, irrigation, repair, cleanup, legal, administrative, inspections and other). (Nowak, 2021).	

5.5 Limitations of existing tools and approaches

i-Tree Eco is very time and resource demanding. It requires the user to psychically go out and take the required measurements of each tree. It is possible to use existing tree inventory data, but most tree inventories don't have alle the measurements. It is therefore important to improve on this point because most municipalities don't have the tine or the resources to make this kind of project.

i-Tree cannot value every single tree ecosystem service like house prices, the biodiversity effect, the effect on revenue and so on but it is a very good start and more than what has been possible up to now. i-Tree Eco uses structure data to make their calculations more precise - such as Species, DBH, Tree height, crown diameter, stem height, crown height, how much of the tree is dead or missing, for far to the nearest building, sides of sunlight and so on. This would be something important to incorporate. It is very time and resource demanding to go out and take the field measurement of every single tree in a city. You can choose to do a plot inventory but the uncertainty is around 10% for 200 plots (I-Tree Eco Sample Inventories, 2023). In addition, it can be very subjective as each person will assess, for example, what percentage of trees are dead or missing differently. It is imperative that forest structure be accurately assessed. Inaccurate measurement of structure will lead to inaccurate estimates of subsequent services and values.

The tools adapted for Europe does not support planning regarding where to plant and what to plant. i-Tree does have a tool called i-Tree Landscape which can help with where to plant but it can only be used in the United States. The tool i-Tree species can define trees with special abilities such as been good at air pollution removal. The tool has not been adapted to Europe but can still be used and maybe incorporated. i-Tree Eco and Canopy is for existing trees but it does not help with what potential trees would give. i-Tree does have a tool called i-Tree planting which calculates what potential trees would give, but the tool has not been adapted to EU. The user can however customize the benefit prices and thereby make it usable in the EU but it would take time for the user to find and calculates all the necessary benefit prices. The data about energy reduction cannot be used in the EU.

A lot of the used data/methods is old. Air pollution data in EU is from 2015 and the weather data from 2021. The number can have changed since.

I-Tree offers estimates of ecosystem services from urban forests and trees. Yet, its tree-centered approach does not account for the variability of tree impact on local environmental factors like flooding and air pollution levels.

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To address i-Tree's limitations, two aspects must be considered:

Localized Analysis: It is essential to analyze a tree's specific impact on its immediate surroundings, including how it affects stormwater runoff, energy use, air pollution, and noise. This requires geospatial tools capable of adjusting a tree's role based on its location and surrounding environment. Currently, i-Tree calculates ecosystem services using assumptions about Leaf Area Index and tree biomass, relying on user-input attributes and adjustment factors (e.g. distance to the building). For instance, its air pollution model uses pollution data and attributes removal rates to trees without considering the variable distribution and dispersion of pollutants, which are influenced by not only the trees but also the structure of urban canopy and buildings. Hence, there is a need for models that accurately reflect urban structure, and then estimate the benefits of trees in terms of ecosystem services. This may lead to more reliable estimations on ES.

Economic Valuation: Developing new methods to assign economic value to ecosystem services is crucial, particularly in adapting these valuations to different cities, urban scenarios, and geographical contexts. I-Tree's simplified approach to monetization, while practical, leads to inconsistencies since it's based on a one-size-fits-all assumption derived from US-centric cost data. A different approach for cost assignment to ecosystem services is hence needed for European cities.

Ecosystem services	Improvements related to Europe
Structural valuation	• Considering social costs and value of trees • Impact of trees on property value
Air Quality	• Assessing the distribution of pollutants within a city according to meteorological data (wind) and urban canopy structure • Monetization based on the EU health costs, and externality values based on the pollution source
Flood inundation	• Assessing the distribution of flood within the city and the role of trees in flood inundation • Distributed value for avoided runoff depending on other social factors according to the location (e.g. Vulnerability)
Carbon sequestration and O2 production	• Improved carbon gain through tailored models for European trees
Noise absorption	• Quantifying the role of urban trees in the absorption of the noise • Assessing the impact of noise reduction on mental health and other social benefits
Energy Effects	• Assessment of trees' role in the local temperature and humidity • Automatic estimation of the energy effects according to the surrounding area • Differentiated values for the unit cooling service provided by urban trees

Another significant factor in tree valuation is the variability of monetary values over time, as ecosystem services may become significant with changing climate conditions. Therefore, models that incorporate future climate scenarios and quantify the evolving role of trees are essential. We need dynamic monetary valuation methods for ecosystem services to gain foresight into the future worth of urban forests. Such models will enable us to anticipate and plan for the long-term economic impact of climate change on urban greenery.

6 The 100KTREEs valorisation approach

This section presents the 100kTREEs valuation and valorisation approach based on

- The selected ecosystem services associated to trees in cities
- The different tree configurations considered (street trees, cluster trees, city parks) and their associated costs
- The valuation methods used, distinguishing between ecosystem services that can readily be converted into monetary values and those needing other valuation techniques

6.1 Selected ecosystem services and tree benefits

Based on our research we can identify several eco system service delivered by trees in an urban context. These are ecosystem services related to:

- Carbon sequestration
- Removal of pollutants and the emission of oxygen due to the photosynthesis of the leaves.
- Stormwater buffering
- Creation of habitats and biodiversity
- Noise reduction
- Micro climate and energy impact

Combined, these ecosystem services provide social benefits, health benefits, economic benefits, and visual and aesthetic benefits. These will be further elaborated in Chapter **Error! Reference source not found.**.

Figure 6-1 The eco-system services provided by City trees

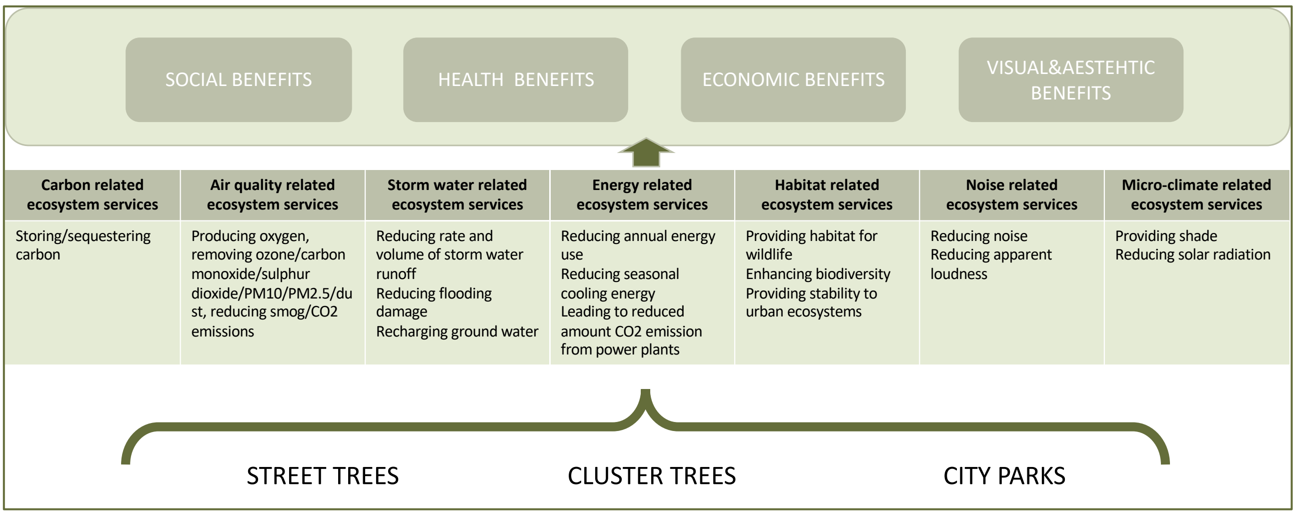


Figure 6-2 Different types of benefits of City trees

The modelling of the physical values of the trees in question will be modelled according to the defined tree attributes as defined in WP3 and based on environmental context in which the trees are growing. Once the physical values are determined these will be converted into monetary values according to the cost and benefit values listed in Table 6-1

Some of the physical parameters is a 'one-to-one' conversion, e.g., carbon capture, while other impacts such as energy savings of air conditions in summer months due to the cooling effect of trees needs to be modelled according to the position of buildings related to the trees or parks.

6.2 Valuation methods – monetization

The following parameters will be the main focus of the 100KTREEs project. Further research on Biodiversity indicators will lead to conclusion on how or if we can model this and eventually provide some kind of valorization assessment. For the time being we are planning to include valorization of noise, human wellbeing/life quality.

	Main function	Physical parameter	Monetary value
CARBON CAPTURE	Absorbing and storage of CO_2	kg CO_2/yr	Market value of carbon Around €85 per tonnes carbon
POLUTANTS REMOVAL	Reducing air pollution	µg/m^3/yr of pollutants: PM_{10}, $PM_{2.5}$, NO_2, O_3	Monetary value will vary according to number of citizens and pollution sources per city. See Chapter 6.2.1
HYDROLOGY	Reducing amount of water going to the sewage system	M^3 of water	Run-off water fees in different cities
COOLING	Shadow at street level Cooling of houses, more difficult	Energy consumption kWh/yr	Price of kWh in each city Copenhagen: tbd Sofia: tbd
STRUCTURAL VALUE	Equals the replacement value of a tree	Trunk size, height of tree, size of canopy, tree specie	Copenhagen: tbd Sofia: tbd
BIODIVERSITY	Providing habitat for living organisms	Number of species and variation of species	No monetary value Indicators can be used.

Table 6-1 From physical value to cost and benefit values

6.2.1 Carbon capture

Carbon is traded on the European Union Emission Trading System (EU-ETS). Prices varies over time with a mean value around €85 per metric ton of carbon.

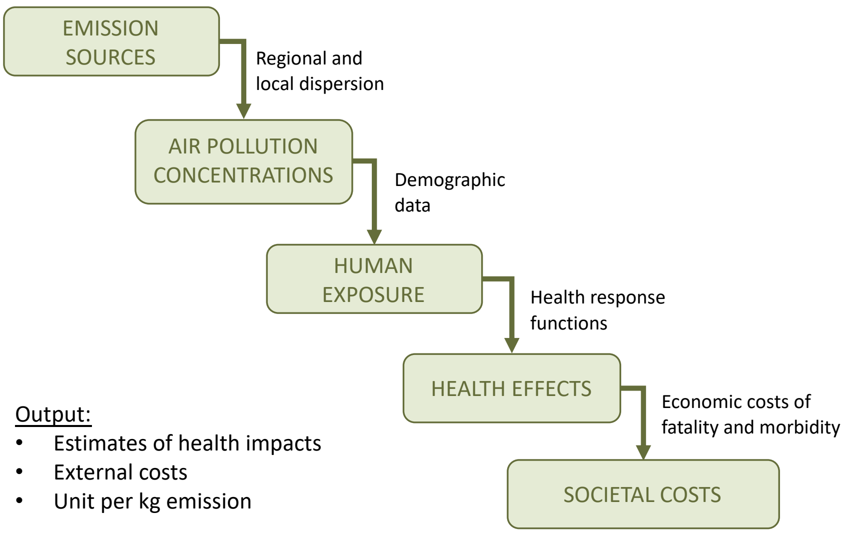
Figure 6-3 Carbon prices as traded on EU-ETS from 2022-2023

6.2.2 Air pollution

Various studies have estimated the health costs of air pollution, e.g. CE Delft, EVA model, EC Handbook on the external costs of Transport.

Using the impact pathway method, the logic of calculating the health impacts and the external costs is depicted below.

Figure 6-4 Impact pathway – air pollution (inspired by the EVA model)



Based on such approach, CE Delft has calculated the unit costs of pollutant across 432 cities in Europe.

Below the results from Copenhagen and Sofia.

Denmark

City	Total annual damage	Per capita damage	Damage as % of GDP	PM2.5 2018 (µg/m3/year)	PM10 2018 (µg/m3/year)	NO2 2018 (µg/m3/year)	O3 2018 (µg/m3/year)	Population (in year)	GDP per capita (PPP)	Foot-notes
Århus	€ 306.8 mln	€ 975	3.0%	12.70	22.42	18.68	9.12	314545 (2012)	€ 32,000	
København	€ 785.4 mln	€ 1,431	3.1%	12.91	26.30	23.43	7.20	549050 (2012)	€ 46,000	
Odense	€ 188 mln	€ 981	3.4%	14.28	22.94	13.82	12.14	191610 (2012)	€ 29,000	b

Bulgaria

City	Total annual damage	Per capita damage	Damage as % of GDP	PM2.5 2018 (µg/m3/year)	PM10 2018 (µg/m3/year)	NO2 2018 (µg/m3/year)	O3 2018 (µg/m3/year)	Population (in year)	GDP per capita (PPP)	Foot-notes
Burgas	€ 200.2 mln	€ 987	8.2%	20.12	32.30	12.96	8.53	202766 (2017)	€ 12,000	abc
Plovdiv	€ 354.8 mln	€ 1,033	8.6%	19.17	46.54	19.07	6.61	343424 (2017)	€ 12,000	ac
Ruse	€ 199.9 mln	€ 1,379	9.9%	24.14	38.87	20.05	12.51	144936 (2017)	€ 14,000	ac
Shumen	€ 92.9 mln	€ 1,208	8.6%	21.04	33.78	17.36	10.23	76967 (2017)	€ 14,000	abc
Sofia	€ 2575.3 mln	€ 2,084	7.7%	21.70	34.85	24.90	6.65	1236047 (2017)	€ 27,000	abc
Stara Zagora	€ 153.8 mln	€ 1,124	8.0%	21.28	22.24	15.91	3.40	136781 (2017)	€ 14,000	
Varna	€ 330.6 mln	€ 986	7.0%	15.94	26.98	24.27	13.24	335177 (2017)	€ 14,000	ac
Vratsa	€ 59 mln	€ 1,100	7.9%	18.21	29.25	20.39	7.67	53570 (2017)	€ 14,000	abc

Footnotes:

a) Average PM10 emissions from EEA have been adjusted for reported figures in Urban Audit data (Eurostat)

b) Average PM2.5 emissions have been imputed using an average factor of PM2.5/PM10

c) Average NO2 emissions from EEA have been adjusted for reported figures in Urban Audit data (Eurostat)

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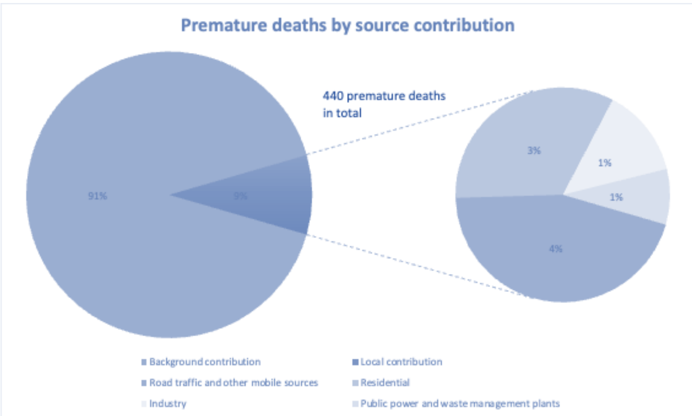
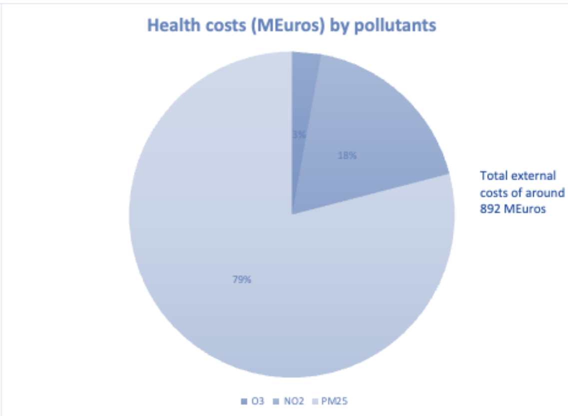
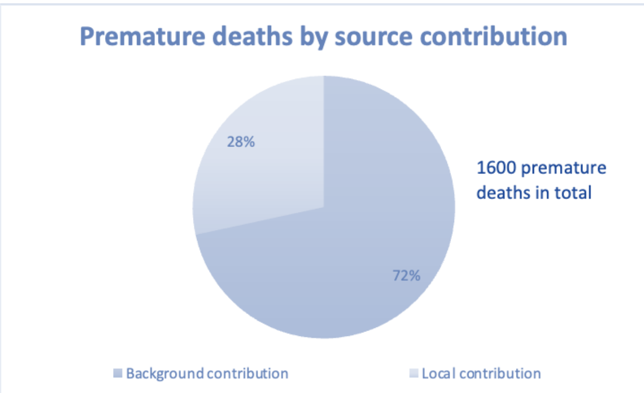
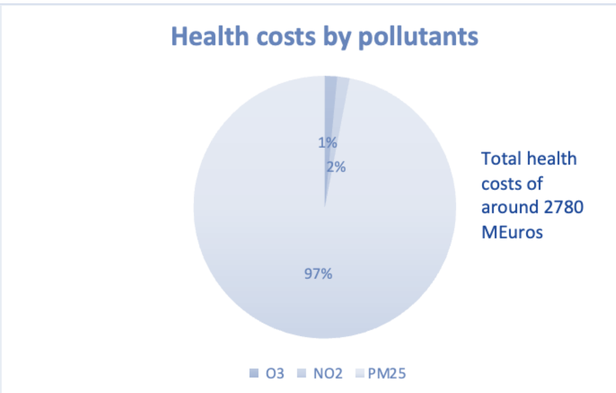
Similar results were achieved from the CURE project (Cure Horizon, 2020), even if newer data was used for population data and more precise emission data was used. E.g. in the CURE project, the emission data, e.g. the air quality data used Copernicus data as input to the ATMO-street model. Pollution sources includes road traffic, industry, power plants and residential heating.

<table>
<tr><th>Main findings from the CURE project</th><th></th></tr>
<tr><td>The City of Copenhagen experienced around 440 acute premature deaths from short term exposure of O3 and PM2.5 and chronic premature deaths from long-term exposure of PM2.5 in year 2019. This was mostly due to background contributions from outside the city (~90%). The local contributions stemmed from road traffic (~45%), residential combustion (~33%), industry (~13%) and power and waste management (~8%). The total health costs in the City of Copenhagen due to all air pollution from both Danish and foreign emission sources amounted to around <u>892 Million EUR</u>.</td><td>The City of Sofia experienced around 1600 acute premature deaths from short term exposure of O3 and PM2.5 and chronic premature deaths from long-term exposure of PM2.5 in year 2018. Here it was a bit more divided between background (~70%) and local (~30%) contributions. The local contributions stem mainly from residential combustion (~87%) and road traffic (~12%), only minor local contribution from industry and public power and waste management (>1%). The total health costs in the City of Sofia due to all air pollution from both Bulgarian and foreign emission sources was around <u>2780 Million EUR</u> in 2018.</td></tr>
<tr><td>
</td><td>
</td></tr>
<tr><td colspan="2">Copenhagen 2019. Left: premature deaths by source contribution. Middle: pollution sources for local contribution. Right: health costs (MEuros) by pollutants.</td></tr>
<tr><td>
</td><td>
</td></tr>
<tr><td colspan="2">Sofia 2018. Left: premature deaths by source contribution. Right: health costs (MEuros) by pollutants.</td></tr>
</table>

As can be seen, despite different data inputs and year of data used, the order of magnitude of the results are similar:

Total health costs in Copenhagen were in the CE Delft model estimated to M€785 compared to M€892 in the CURE project.	*Total health costs in Sofia were in the CE Delft study estimated to M€2.575 compared to M€2.780 in the CURE project.*

6.3 Comparison iTree and 100KTREEs valorization approach

Besides improving the accuracy of modelling of the physical values of trees in 100KTREEs compared to iTree (to be documented in WP4), we will also use more accurate cost prices for the physical values in the 100KTREEs valorization model.

The following table provides the main differences in the iTree approach compared to the 100KTREEs approach in valorizing key ecosystem services.

Table 6-2 Comparison of the valorisation approaches of iTree and 100KTREEs

Comparison on valorization approaches	**iTree**	**100KTREEs**
Structural valuation	Evaluation based on US value and costs	Based on country and city specific prices
Air pollution removal	Health costs are based on US EPA costs of mortality and hospitalization costs	Based on European costs prices City specific demography and pollution sources
Carbon sequestration	Carbon is based on US prices	According to emission allowances (EUA) traded at European Union Emissions Trading Scheme (ETS)
Energy effects	Energy prices based on US conditions	Based on city specific energy prices
Storm water management	Water Runoff prices based on US prices	Based on city specific runoff tariffs
Property prices	Not included	Will not be included as part of the valorization of the trees as it is private benefits as opposed to societal benefits. Relevant, however for the business case.

6.4 Overall rating and attractiveness of the city

Various city ratings are available:

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- Safe Cities Index[1]
- European Cities SDG Index[2]

Below examples from the SCI Index as published by the Economist.

How we can use such City ranking frameworks will be further investigated in WP5.

[1] https://safecities.economist.com/wp-content/uploads/2019/08/Aug-5-ENG-NEC-Safe-Cities-2019-270x210-19-screen.pdf

[2] https://euro-cities.sdgindex.org/#/

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Insights from the index

The SCI2019 results

The complete scores are as follows:

Figure 3: SCI2019

All data are normalised to a scale of 0 to 100, where 100 = best health

Very high (75.1–100) | High (50.1–75) | Medium (25.1–50) | Low (0–25)

Overall score		1) Digital security		2) Health security		3) Infrastructure security		4) Personal security	
1 Tokyo	92.0	1 Tokyo	94.4	1 Osaka	88.5	1 Singapore	96.9	1 Singapore	95.3
2 Singapore	91.5	2 Singapore	93.1	2 Tokyo	87.5	2 Osaka	94.5	2 Copenhagen	93.6
3 Osaka	90.9	3 Chicago	92.9	3 Seoul	85.2	3 Barcelona	94.4	3 Hong Kong	91.9
4 Amsterdam	88.0	4 Washington, DC	92.2	=4 Amsterdam	81.6	4 Tokyo	94.3	4 Tokyo	91.7
5 Sydney	87.9	=5 Los Angeles	91.4	=4 Stockholm	81.6	5 Madrid	94.2	5 Wellington	91.5
6 Toronto	87.8	=5 San Francisco	91.4	6 Frankfurt	81.2	6 Frankfurt	93.7	6 Stockholm	91.3
7 Washington, DC	87.6	7 Dallas	91.3	7 Washington, DC	81.1	=7 Melbourne	93.5	7 Osaka	91.1
=8 Copenhagen	87.4	8 New York	91.1	8 Singapore	80.9	=7 Sydney	93.5	8 Toronto	90.8
=8 Seoul	87.4	9 Toronto	90.6	9 Zurich	80.8	9 Wellington	93.2	9 Amsterdam	89.4
10 Melbourne	87.3	10 London	90.2	10 Taipei	80.2	10 Washington, DC	93.1	10 Sydney	89.1
11 Chicago	86.7	=11 Melbourne	89.4	=11 Copenhagen	79.8	11 Chicago	93.0	11 Abu Dhabi	88.9
12 Stockholm	86.5	=11 Osaka	89.4	=11 Sydney	79.8	=12 New York	92.5	12 Dubai	88.6
13 San Francisco	85.9	=11 Sydney	89.4	=13 Brussels	79.3	=12 Toronto	92.5	13 Zurich	87.8
14 London	85.7	14 Amsterdam	89.0	=13 Melbourne	79.3	14 Seoul	92.4	14 Frankfurt	87.7
15 New York	85.5	15 Copenhagen	87.3	15 Paris	78.7	15 Los Angeles	92.2	15 Seoul	87.5
16 Frankfurt	85.4	16 Stockholm	85.5	16 London	78.0	16 Amsterdam	92.0	16 Melbourne	86.8
17 Los Angeles	85.2	17 Seoul	84.7	17 Toronto	77.4	17 San Francisco	91.7	17 Brussels	86.3
=18 Wellington	84.5	18 Zurich	80.8	18 San Francisco	77.2	18 Hong Kong	91.1	18 Madrid	86.2
=18 Zurich	84.5	19 Wellington	80.2	19 Chicago	77.1	19 London	90.4	19 Barcelona	86.0
20 Hong Kong	83.7	20 Paris	80.0	=20 Madrid	76.1	20 Copenhagen	89.0	20 Taipei	85.8
21 Dallas	83.1	21 Frankfurt	78.9	=20 New York	76.1	21 Brussels	88.9	21 Paris	85.2
22 Taipei	82.5	22 Hong Kong	78.8	22 Dallas	75.9	22 Zurich	88.5	22 London	84.3
23 Paris	82.4	23 Taipei	77.0	23 Los Angeles	75.8	23 Stockholm	87.5	=23 Shanghai	84.0
24 Brussels	82.1	=24 Abu Dhabi	74.1	24 Barcelona	75.2	24 Taipei	87.1	=23 Washington, DC	84.0
25 Madrid	81.4	=24 Dubai	74.1	25 Rome	75.1	25 Paris	85.9	25 Beijing	83.9
26 Barcelona	81.2	26 Brussels	74.0	26 Milan	74.9	=26 Abu Dhabi	83.2	26 Chicago	83.8
27 Abu Dhabi	79.5	27 Milan	72.5	27 Hong Kong	73.2	=26 Dubai	83.2	=27 Dallas	83.3
28 Dubai	79.1	=28 Barcelona	69.2	28 Wellington	72.9	28 Rome	83.1	=27 San Francisco	83.3
29 Milan	78.1	=28 Madrid	69.2	29 Abu Dhabi	71.8	29 Milan	82.8	29 Milan	82.4
30 Rome	76.4	30 Rome	67.5	30 Moscow	71.5	30 Dallas	81.9	30 New York	82.2
Average	**71.2**	**Average**	**67.2**	31 Dubai	70.5	31 Istanbul	75.8	31 Kuala Lumpur	81.8
31 Beijing	70.5	31 Buenos Aires	65.0	32 Buenos Aires	69.8	32 Moscow	73.6	32 Los Angeles	81.3
32 Shanghai	70.2	32 Santiago	64.6	33 Beijing	68.0	**Average**	**72.5**	33 Kuwait City	80.4
33 Santiago	69.8	33 Istanbul	61.9	**Average**	**68.0**	33 Beijing	72.1	34 Rome	79.8
34 Buenos Aires	69.7	34 Johannesburg	60.2	34 Shanghai	67.5	34 Shanghai	72.0	35 Santiago	79.4
35 Kuala Lumpur	66.3	35 Mexico City	58.4	35 Kuwait City	64.8	35 Buenos Aires	71.2	36 Ho Chi Minh City	78.7
36 Istanbul	66.1	36 Beijing	58.1	=36 Rio de Janeiro	64.7	36 Santiago	71.0	**Average**	**77.0**
37 Moscow	65.8	37 Shanghai	57.4	=36 Sao Paulo	64.7	37 Kuala Lumpur	64.7	37 Mumbai	76.2
38 Kuwait City	64.5	38 Riyadh	56.5	=38 Kuala Lumpur	64.4	38 Mexico City	61.5	38 Riyadh	75.9
39 Riyadh	62.5	39 Kuwait City	56.4	=38 Santiago	64.4	39 Johannesburg	57.8	39 Moscow	75.3
40 Mexico City	61.6	40 Bangkok	56.2	40 Mexico City	64.1	40 Rio de Janeiro	57.7	40 Manila	74.7
41 Rio de Janeiro	60.9	41 Bogota	54.7	41 Baku	64.0	41 Sao Paulo	57.2	41 New Delhi	73.6
42 Sao Paulo	59.7	42 Quito	54.5	42 Riyadh	62.9	42 Kuwait City	56.4	42 Buenos Aires	72.9
43 Manila	59.2	43 Kuala Lumpur	54.4	43 Istanbul	61.7	43 Ho Chi Minh City	55.4	43 Jakarta	71.7
44 Johannesburg	58.6	44 Rio de Janeiro	52.7	44 Lima	60.7	44 Riyadh	54.8	44 Casablanca	69.5
=45 Lima	58.2	45 Manila	52.1	45 Bangkok	59.9	45 Bogota	53.9	45 Lima	69.3
=45 Mumbai	58.2	46 Baku	51.7	46 Quito	59.4	46 Manila	53.6	46 Rio de Janeiro	68.4
=47 Bangkok	57.6	=47 Mumbai	51.0	47 Bogota	59.1	47 Lima	53.0	47 Sao Paulo	67.5
=47 Ho Chi Minh City	57.6	=47 New Delhi	51.0	48 Manila	56.6	48 Bangkok	52.5	48 Istanbul	65.2
49 Baku	56.4	49 Lima	49.8	49 Ho Chi Minh City	56.3	49 Jakarta	52.3	49 Baku	63.7
50 Quito	55.3	50 Sao Paulo	49.4	50 Mumbai	55.8	50 Mumbai	50.0	50 Johannesburg	63.2
51 Bogota	55.1	51 Casablanca	44.9	51 New Delhi	54.6	51 Quito	49.9	51 Mexico City	62.3
52 New Delhi	55.0	52 Karachi	43.1	52 Johannesburg	53.2	52 Casablanca	49.6	52 Bangkok	61.8
53 Jakarta	54.5	53 Caracas	42.9	53 Jakarta	51.7	53 Cairo	48.2	53 Cairo	59.3
54 Casablanca	53.5	54 Moscow	42.8	54 Casablanca	50.0	54 Baku	46.3	54 Quito	57.5
55 Cairo	48.6	55 Jakarta	42.3	55 Caracas	48.1	55 Karachi	46.1	55 Dhaka	57.4
56 Dhaka	44.6	56 Lagos	42.2	56 Cairo	46.1	56 Yangon	45.3	56 Bogota	52.8
57 Karachi	43.5	57 Dhaka	41.9	57 Dhaka	45.1	57 New Delhi	40.7	57 Yangon	52.3
58 Yangon	41.9	58 Cairo	40.7	58 Yangon	42.3	58 Lagos	37.4	58 Karachi	45.9
59 Caracas	40.1	59 Ho Chi Minh City	40.2	59 Karachi	39.0	59 Dhaka	34.2	59 Caracas	42.1
60 Lagos	38.1	60 Yangon	27.8	60 Lagos	34.1	60 Caracas	27.3	60 Lagos	38.7

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7 Conclusions and next steps

7.1 Main conclusion

We have performed a thorough literature review related to valorization of ecosystem services provided by trees, impacts of tree planting in the urban environment, and to a certain degree financing of tree planting.

In first instance we are focusing on assigning monetary values to the physical parameters related to the ecosystem services provided by trees. We have concluded that this can be done for certain parameters, such as carbon, air quality pollutants, water run-off and energy savings. A first set of such values can be used as the starting point and as input for the modelling tool (WP4).

For other less tangible ecosystem services, such as biodiversity and human wellbeing, other non-monetary values can be applied. For biodiversity different indicators will be further investigated in WP5. For human wellbeing and life quality, this will also be further investigated in Task 5.4.

We have closely investigated the American i-Tree approach for valorizing trees and highlighted the main positive aspects and the weaknesses of the i-Tree approach with respect to valorization methods.

We have made a benefit framework that serves as reference for assessing both tangible and intangible benefits. This framework will be further elaborated in WP5 to include also causal relationships between benefit items. For example, investments into planting trees along bike paths through a city district, might cause more citizens to change transport mode, that again will have positive impact on physical activity of the individual.

We have identified various City Indexes related to sustainability, ‘green’ cities, etc that might be interesting to investigate further to access the strategic benefits of cities to invest in ‘greening’.

7.2 Next steps

Calculate monetary value of different types of trees in Copenhagen and Sofia, Solitary tree, Cluster tree, Park trees, different species and age&size of trees.

Including costs of planting and maintenance to calculate net monetary value at present time and over100 years.

Biodiversity

The 100KTREEs project will also address biodiversity and how biodiversity can be measured by means of indicators, etc. However, for valorization purposes, at least for the time being, we will not make any attempts to convert biodiversity into a monetary value.

Human well-being, mental health

There are many studies addressing the positive impact of trees and nature on mental health and human wellbeing.

Converting such positive impacts into monetary values is difficult and associated with a high degree of uncertainty. Human well-being and mental health impacts are therefore will be further elaborated in T5, but it is not likely to be included directly in the valorization of trees in the 100KTREEs project.

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Reference

All Tools. (2023). Itreetool. https://www.itreetools.org/tools

Bockarjova, M., Botzen, W. J. W., & Koetse, M. J. (2020). Economic valuation of green and blue nature in cities: A meta-analysis. *Ecological Economics*, *169*, 106480. https://doi.org/10.1016/j.ecolecon.2019.106480

Copenhagen Municipality. (2020). *Tree Priority Plan 2020-2025*. https://www.kk.dk/sites/default/files/agenda/cc6dba97-ad5c-471e-a0bc-1f93706fd46b/7f534583-e6df-498a-923b-184cdef3c41c-bilag-2.pdf

Cure Horizon. (2020). *COPERNICUS FOR URBAN RESILIENCE IN EUROPE*. https://cure-copernicus.eu/

Henning, J., Heinlin, K., Bloniarz, D., Heppler, J., & Greenfield, E. (2023). *Introduction to i-Tree*. https://www.itreetools.org/documents/898/i-Tree_Academy_Spring_2023_-_Session_1__i-Tree_Introduction_slides.pdf

Hirabayashi, S. (2013). *I-Tree Eco Precipitation Interception Model Descriptions*.

Hirabayashi, S., Kroll, C. N., Nowak, D. J., & Endreny, T. A. (2022). *I-Tree Eco Dry Deposition Model Descriptions*.

Interagency Working Group, Council on Environmental Quality, Department of Agriculture, Department of Commerce, Department of Energy, Department of the Interior, Department of Transportation, Department of the Treasury, Environmental Protection Agency, National Economic Council, Office of Management and Budget, Office of Science and Technology Policy, & Council of Economic Advisers. (2016). *Technical Update of the Social Cost of Carbon for Regulatory Impact Analysis*. https://www.epa.gov/sites/default/files/2016-12/documents/sc_co2_tsd_august_2016.pdf

I-Tree Eco. (2023). https://www.itreetools.org/tools/i-tree-eco

I-Tree Eco Sample Inventories. (2023). https://www.itreetools.org/tools/i-tree-eco/i-tree-eco-sample-inventories

Lindgren, B. W., & McElrath, G. W. (1969). *Introduction to probability and statistics* (Third edition.). Macmillan.

Nowak, D. J. (2021). *Understanding i-Tree: 2021 Summary of programs and methods* (NRS-GTR-200-2021; p. NRS-GTR-200-2021). U.S. Department of Agriculture, Forest Service, Northern Research Station. https://doi.org/10.2737/NRS-GTR-200-2021

Nowak, D. J., Crane, D. E., & Dwyer, J. F. (2002). *Compensatory value of urban trees in the United States*. https://joa.isa-arbor.com/browse.asp?Journals_ID=1

Nowak, D. J., Crane, D. E., Stevens, J. C., & Ibarra, M. (2002). *Brooklyn's urban forest* (NE-GTR-290; p. NE-GTR-290). U.S. Department of Agriculture, Forest Service, Northeastern Research Station. https://doi.org/10.2737/NE-GTR-290

Nowak, D. J., Hirabayashi, S., Bodine, A., & Greenfield, E. (2014). Tree and forest effects on air quality and human health in the United States. *Environmental Pollution*, *193*, 119–129. https://doi.org/10.1016/j.envpol.2014.05.028

Rötzer, T., Moser-Reischl, A., Rahman, M. A., Grote, R., Pauleit, S., & Pretzsch, H. (2021). Modelling Urban Tree Growth and Ecosystem Services: Review and Perspectives. In F. M. Cánovas,

U. Lüttge, M.-C. Risueño, & H. Pretzsch (Eds.), *Progress in Botany Vol. 82* (pp. 405–464). Springer International Publishing. https://doi.org/10.1007/124_2020_46

Urban Forest Effects and Values. (2011). *I-Tree Ecosystem Analysis*.

U.S. Bureau of Labor Statistics. (2017). *Producer Price Index Home: U.S. Bureau of Labor Statistics*. https://www.bls.gov/ppi/

U.S. Congress, Office of Technology Assessment. (1994). Studies of the Environmental Costs of Electricity. *Washington, DC: U.S. Government Printing Office*.

US EPA, O. (2016, November 16). *Air Topics* [Collections and Lists]. https://www.epa.gov/environmental-topics/air-topics

van Essen, H., Arno Schroten, Matthijs Otten, Daniel Sutter, Christoph Schreyer, Remo Zandonella, Markus Maibach, & Claus Doll. (2011). *External costs of transport in Europe*.

Videntjenesten. (2018, May 7). *I-Tree sætter tal på bytræers økosystemtjenester*. Københavns Universitet. https://videntjenesten.ku.dk/park_og_landskab/planlaegning_og_forvaltning/forvaltning_og_ressourcestyring/03.03-89_videnblad/

Wang, J., Endreny, T. A., & Nowak, D. J. (2008). Mechanistic Simulation of Tree Effects in an Urban Water Balance Model [1]. *JAWRA Journal of the American Water Resources Association*, *44*(1), 75–85. https://doi.org/10.1111/j.1752-1688.2007.00139.x

Yang, Y., Endreny, T. A., & Nowak, D. J. (2011). iTree-Hydro: Snow Hydrology Update For The Urban Forest Hydrology Model1: itree-Hydro: Snow Hydrology Update for the Urban Forest Hydrology Model. *JAWRA Journal of the American Water Resources Association*, *47*(6), 1211–1218. https://doi.org/10.1111/j.1752-1688.2011.00564.x

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Annex A – Literature study on benefits of trees in cities

The following provides an overview of the main sources used as input to this deliverable D5.1. More items are included in Zotero, the library will stay active for continuously literature study throughout the WP 5 execution.

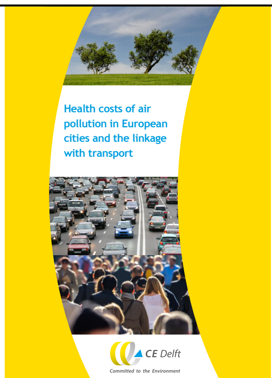
Meta studies

Reference	Abstract/conclusions
Roy, Sudipto, Jason Byrne, and Catherine Pickering. 'A Systematic Quantitative Review of Urban Tree Benefits, Costs, and Assessment Methods across Cities in Different Climatic Zones'. *Urban Forestry & Urban Greening* 11, no. 4 (January 2012): 351–63. https://doi.org/10.1016/j.ufug.2012.06.006.	Urban trees can potentially mitigate environmental degradation accompanying rapid urbanization via a range of tree benefits and services. But uncertainty exists about the extent of tree benefits and services because urban trees also impose costs (e.g. asthma) and may create hazards (e.g. windthrow). Few researchers have systematically assessed how urban tree benefits and costs vary across different cities, geographic scales and climates. This paper provides a quantitative review of 115 original urban tree studies, examining: (i) research locations, (ii) research methods, and (iii) assessment techniques for tree services and disservices. Researchers published findings in 33 journals from diverse disciplines including: forestry, land use planning, ecology, and economics. Research has been geographically concentrated (64% of studies were conducted in North America). Nearly all studies (91.3%) used quantitative research, and most studies (60%) employed natural science methods. Demonstrated tree benefits include: economic, social, health, visual and aesthetic benefits; identified ecosystem services include: carbon sequestration, air quality improvement, storm water attenuation, and energy conservation. Disservices include: maintenance costs, light attenuation, infrastructure damage and health problems, among others. Additional research is required to better inform public policy, including comparative assessment of tree services and disservices, and assessment of urban residents and land managers' understanding of tree benefits and costs.

Reducing Air Pollution

Trees are known to absorb air pollutants, such as nitrogen dioxide, sulfur dioxide, and particulate matter. By planting trees in urban areas, businesses can help reduce air pollution and improve air quality for their employees and the surrounding community.

Reference	Abstract/conclusions
Escobedo, Francisco J., John E. Wagner, David J. Nowak, Carmen Luz De La Maza, Manuel Rodriguez, and Daniel E. Crane. 'Analysing the Cost Effectiveness of Santiago, Chile's Policy of Using Urban Forests to Improve Air Quality'. *Journal of Environmental Management* 86, no. 1 (January 2008): 148–57. https://doi.org/10.1016/j.jenvman.2006.11.029.	Santiago, Chile has the distinction of having among the worst urban air pollution problems in Latin America. As part of an atmospheric pollution reduction plan, the Santiago Regional Metropolitan government defined an environmental policy goal of using urban forests to remove particulate matter less than 10 mm (PM10) in the Gran Santiago area. We used cost effectiveness, or the process of establishing costs and selecting least cost alternatives for obtaining a defined policy goal of PM10 removal, to analyze this policy goal. For this study, we quantified PM10 removal by Santiago's urban forests based on socioeconomic strata and using field and real-time

	pollution and climate data via a dry deposition urban forest effects model. Municipal urban forest management costs were estimated using management cost surveys and Chilean Ministry of Planning and Cooperation documents. Results indicate that managing municipal urban forests (trees, shrubs, and grass whose management is under the jurisdiction of Santiago's 36 municipalities) to remove PM10 was a cost-effective policy for abating PM10 based on criteria set by the World Bank. In addition, we compared the cost effectiveness of managing municipal urban forests and street trees to other control policies (e.g. alternative fuels) to abate PM10 in Santiago and determined that municipal urban forest management efficiency was similar to these other air quality improvement measures
Yang, Jun, Joe McBride, Jinxing Zhou, and Zhenyuan Sun. 'The Urban Forest in Beijing and Its Role in Air Pollution Reduction'. *Urban Forestry & Urban Greening* 3, no. 2 (January 2005): 65–78. https://doi.org/10.1016/j.ufug.2004.09.001.	Tree planting has been proposed by the municipal government as a measure to alleviate air pollution in Beijing, the capital of China. This study examines that proposal. It is based on the analyses of satellite images and field surveys to establish the characteristics of current urban forest in the central part of Beijing. The influence of the urban forest on air quality was studied using the Urban Forest Effects Model. The results show that there are 2.4 million trees in the central part of Beijing. The diameter distribution of the trees is skewed toward small diameters. The urban forest is dominated by a few species. The condition of trees in the central part of Beijing is not ideal; about 29% of trees were classified as being in poor condition. The trees in the central part of Beijing removed 1261.4 tons of pollutants from the air in 2002. The air pollutant that was most reduced was PM10 (particulate matters with an aerodynamic diameter smaller than 10 mm), the reduction amounted to 772 tons. The carbon dioxide (CO_2) stored in biomass form by the urban forest amounted to about 0.2 million tons. Future research directions to improve our understanding of the role of individual tree species in air pollution reduction are discussed.
	In 2018, on average every inhabitant of a European city suffered a welfare loss of over € 1,250 a year owing to direct and indirect health losses associated with poor air quality. This is equivalent to 3.9% of income earned in cities. It should be noted that there is a substantial spread in these figures among cities: in the Romanian capital Bucharest total welfare loss amounts to over € 3,000 per capita/year, while in Santa Cruz de Tenerife in Spain it is under € 400/cap/yr. In many cities in Bulgaria, Romania and Poland the health related social costs are between 8-10% of income earned. Most of these costs relate to premature mortality: for the 432 cities investigated, the average contribution of mortality to total social costs is 76.1%. Conversely, the average contribution of morbidity (diseases) is 23.9%.
'Planting Healthy Air: A Global Analysis of the Role of Urban Trees in Addressing Particulate Matter Pollution and Extreme Heat', 2016.	Perhaps it is easiest to summarize our results relative to the main questions we set out to answer in this report: Which cities and neighborhoods can natural infrastructure help the most? Our results stressed the importance of targeting, at multiple scales. The benefits that trees provide are localized, generally within a few hundred meters of the planting. We recommend, therefore, that trees not be

	described as a way to clean up and cool an entire city's airshed. Rather, tree planting is a targeted tool that can be used to provide benefits to specific people in specific places. Locations with a high ROI of tree planting have, among other things, a high number of people that live near the planting and can benefit from it. We have tried to list in more detail in the body of the report planting guidelines that cities can use to ensure they are targeting their tree-planting efforts appropriately, to maximally deliver benefits to their citizens. Where is natural infrastructure a cost-effective investment, relative to common built infrastructure alternatives? We find that street trees are a cost-competitive strategy for reducing particulate matter concentrations and temperature mitigation. The benefits that trees deliver, in terms of $/ton of PM removed or $/degree of temperature mitigation, are in the same range as major built infrastructure alternatives. More importantly, street trees are able to deliver benefits both to PM and temperature mitigation, while grey infrastructure alternatives generally are not. How much vegetation is enough? We did not find one single level of investment that is "enough." Rather, tree planting for healthy air is an investment, and like any investment has a curve of potential payoffs. Many cities currently have relatively modest investment in urban forestry, and we find that air-quality benefits suggest a significant increase in investment is warranted. However, where cities end up along this investment curve is a choice they will have to make, based upon their budget and their priorities. How much investment, in dollar terms, is needed? Again, there was no clear single level of investment that is needed. However, we were able to show that even a relatively modest additional annual global investment of $100 million for tree planting and maintenance, targeted toward the cities and neighborhoods where it would deliver the most benefits, could help improve the lives of millions. What fraction of the air-quality problem can vegetation solve? Street trees have the potential to solve a modest portion of the air-quality problem. While the environmental community needs some humility, since the scope for nature-based solutions is modest relative to the scale of the global challenge, there are still millions of people who can be cost-effectively helped by street trees. In conclusion, tree planting constitutes a part of a cost-effective portfolio of interventions aimed at controlling particulate matter pollution and mitigating high temperatures in cities. While trees cannot and should not replace other strategies to make air healthier, trees can be used in conjunction with these other strategies to help clean and cool the air. Moreover, trees provide a multitude of other benefits beyond healthier air. In the right spot, trees can both help make our air healthier and our cities more verdant and livable. They are an important way that we can make our coming urban world—the cities in which most of us will live—resilient, livable, and thriving.
Jensen, Steen Solvang, Jørgen Brandt, Lise M Frohn, Matthias Ketzel, Morten Winther, Marlene Schmidt Plejdrup, and Ole-Kenneth Nielsen.	The total external costs in Copenhagen Municipality due to all air pollution from both Danish and foreign emission sources is around DKK 8.8 billion in 2017. The external costs are primarily due to particles. Secondary particles and sea salt give rise to DKK 5.4 billion in external costs, and the

'Helbredseffekter og eksterne omkostninger af luftforurening i Københavns Kommune', n.d.	directly emitted particles (PM2.5) give rise to DKK 1.8 billion. The majority of the external costs are due to premature deaths, as a result of both long-term and short-term exposure, as the valuation for these is relatively high compared to, for example, the valuation of morbidity and sick days. In total, the external costs related to premature death are around DKK 8.1 billion, while morbidity is a total of around DKK 0.7 billion.

Reducing energy costs and UHI

Trees can provide shade in urban areas, reducing the amount of energy needed to cool buildings during the summer months. This can lead to significant cost savings for property owners, especially those with larger buildings.

Reference	Abstract/conclussions
McPherson, E. G., & Simpson, J. R. (1999). Potential energy savings in buildings by an urban tree planting programme in California. Urban Forestry & Urban Greening, 8(2), 109-123. doi: 10.1016/S1618-8667(02)00115-1	In this study, we have developed summary tables (sorted by heating- and cooling-degree-days) to estimate the potential of heat-island-reduction (HIR) strategies (i.e., solar-reflective roofs, shade trees, reflective pavements and urban vegetation) to reduce cooling-energy use in buildings. The tables provide estimates of savings for both direct effect (reducing heat gain through the building shell) and indirect effect (reducing the ambient air temperature). To perform this analysis, we focused on three building types that offer the most savings potential: residences, offices, and retail stores. Each building type was characterized in detail by Pre-1980 (old) or 1980+ (new) construction vintage and with natural gas or electricity as heating fuel. Energy savings were highest for the old buildings (15-25%), new buildings (5%-10%)
Pandit, Ram, and David N. Laband. 'Energy Savings from Tree Shade'. Ecological Economics 69, no. 6 (April 2010): 1324–29.	Trees cast shade on homes and buildings, lowering the inside temperatures and thus reducing demand for power to cool these buildings during hot times of the year. Drawing from a large sample of residences in Auburn, Alabama, we develop a statistical model that produces specific estimates of the electricity savings generated by shade-producing trees in a suburban environment. This empirical model links residential energy consumption during peak summer (winter) months to average energy consumption during nonsummer/non-winter months, behaviors of the occupants, and the extent, density, and timing of shade cast on the structures. Our estimates reveal that tree shade generally is associated with reduced (increased) electricity consumption in the summertime (wintertime). In summertime, energy savings are maximized by having dense shade. In wintertime, energy consumption increases as shade percentage in the morning, when outdoor temperatures are at their lowest, increases.
Donovan, Geoffrey H., and David T. Butry. 'The Value of Shade: Estimating the Effect of Urban Trees on Summertime Electricity Use'. *Energy and Buildings* 41, no. 6 (June 2009): 662–68. https://doi.org/10.1016/j.enbuild.2009.01.002.	We estimated the effect of shade trees on the summertime electricity use of 460 single-family homes in Sacramento, California. Results show that trees on the west and south sides of a house reduce summertime electricity use, whereas trees on the north side of a house increase summertime electricity use. The current level of tree cover on the west and south sides of houses in our sample reduced summertime electricity use by 185 kWh (5.2%), whereas north-side trees increased electricity

	use by 55 kWh (1.5%). Results also show that a London plane tree, planted on the west side of a house, can reduce carbon emissions from summertime electricity use by an average of 31% over 100 years.
Akbari, H., and S. Konopacki. 'Calculating Energy-Saving Potentials of Heat-Island Reduction Strategies'. *Energy Policy* 33, no. 6 (April 2005): 721–56. https://doi.org/10.1016/j.enpol.2003.10.001.	In this analysis, we considered three building types that offer the most savings potential: residences, offices, and retail stores. Each building type was characterized in detail by Pre-1980 (old) or 1980+ (new) construction vintage andwith natural gas or electricity as heating fuel. We defined prototypical-building characteristics for each building type and simulated the effects of HIR strategies on building cooling- and heating-energy use and peak power demand using the DOE-2.1E model and weather data for about 240 locations in the US. A statistical analysis of previously completedsimulations for five cities was usedto estimate the indirect savings. Our simulations included the effect of (1) solar-reflective roofing material on building (direct effect), (2) placement of deciduous shade trees near south and west walls of building (direct effect), and(3) ambient cooling achievedby urban reforestation and reflective building surfaces and pavements (indirect effect).
Borzino, Natalia, Samuel Chng, Muhammad Omer Mughal, and Renate Schubert. 'Willingness to Pay for Urban Heat Island Mitigation: A Case Study of Singapore'. *Climate* 8, no. 8 (1 July 2020). https://doi.org/10.3390/CLI8070082.	In this study, we assess Singaporeans' willingness to pay (WTP) for UHI mitigation by implementing a contingent valuation analysis. Specifically, we employ a double-bounded dichotomous survey design on a representative sample of 1822 online respondents. We find that Singaporeans are willing to sacrifice on average 0.43% of their annual income to mitigate UHI. The total WTP for mitigation strategies among Singapore citizens and permanent residents is estimated at SGD$783.08 million per year, the equivalent of USD$563.80 per year. Our findings suggest that there is a positive and significant relationship between the size of UHI effects and the citizens' WTP. People living in the region with the highest intensity of UHI are willing to pay 3.09 times more than those living in the region with the lowest UHI intensity. Furthermore, demographic and socio-economic characteristics are significant determinants of Singaporeans' WTP. The WTP increases with income and education but decreases with age. Students, men, and people with children are willing to pay more.

Improving Property value

Trees can increase the value of nearby properties, which could be beneficial for real estate developers or property owners. Studies have shown that trees can add up to 10% to property values.

Reference	Abstracts/conclusions
Donovan, G., & Butry, D. (2010). The value of shade: Estimating the effect of urban trees on real estate prices in Portland, Oregon. Landscape and Urban Planning, 94(3-4), 117-126. doi: 10.1016/j.landurbplan.2009.10.003	We use a hedonic price model to simultaneously estimate the effects of street trees on the sales price and the time-on-market (TOM) of houses in Portland, Oregon. On average, street trees add $8870 to sales price and reduce TOM by 1.7 days. In addition, we found that the benefits of street trees spill over to neighboring houses. Because the provision and maintenance of street trees in Portland is the responsibility of adjacent property owners, our results suggest that if the provision of

	street trees is left solely to homeowners, then there will be too few street trees from a societal perspective.
Donovan, Geoffrey H., and David T. Butry. 'The Effect of Urban Trees on the Rental Price of Single-Family Homes in Portland, Oregon'. *Urban Forestry & Urban Greening* 10, no. 3 (January 2011): 163–68. https://doi.org/10.1016/j.ufug.2011.05.007.	Few studies have estimated the effect of environmental amenities on the rental price of houses. We address this gap in the literature by quantifying the effect of urban trees on the rental price of singlefamily homes in Portland, Oregon, USA. We found that an additional tree on a house's lot increased monthly rent by $5.62, and a tree in the public right of way increased rent by $21.00. These results are consistent with a previous hedonic analysis of the effects of trees on the sales price of homes in Portland, which suggests that homeowners and renters place similar values on urban trees.
PanPandit, Ram, Maksym Polyakov, Sorada Tapsuwan, and Timothy Moran. 'The Effect of Street Trees on Property Value in Perth, Western Australia'. *Landscape and Urban Planning* 110 (February 2013): 134–42. https://doi.org/10.1016/j.landurbplan.2012.11.001.	Trees provide a variety of benefits to urban residents that are implicitly captured in the value of residential properties. We apply a spatial hedonic model to estimate the value of urban trees in 23 suburbs of Perth Metropolitan Area in Western Australia. Results show that a broad-leaved tree on the street verge increases the median property price by about AU$16,889, suggesting a positive neighbourhood externality of broad-leaved trees. However, neither broad-leaved trees on the property or on neighbouring properties nor palm trees irrespective of the locations contributed significantly to sale price. Our result has potential implications on planting and maintaining broad-leaved trees on street verges for neighbourhood development and urban planning to generate public and private benefits of street trees.
Bockarjova, M., W. J.W. Botzen, M. H. van Schie, and M. J. Koetse. 'Property Price Effects of Green Interventions in Cities: A Meta-Analysis and Implications for Gentrification'. *Environmental Science and Policy* 112 (1 October 2020): 293–304. https://doi.org/10.1016/j.envsci.2020.06.024.	Our study conducts a meta-analysis based on 37 primary hedonic pricing studies, to estimate value transfer functions that can assess the effects of nature types on property prices in various urban settings. Urban nature has positive impacts on house value in the areas surrounding it, which depend on population density, distance to, and the type of, urban nature. We illustrate how the estimated benefit transfer function can be applied to natural interventions in a Dutch city, and visualize the obtained effects using mapping. These maps show the distance decay of the cumulative effects of urban nature interventions on the house value at the city and the neighbourhood levels. Our application estimated increases in local property values up to a maximum of 20 % compared with properties not affected by the interventions, with value equivalent of 62,650 USD, at average prevailing price level in a particular area in Utrecht. When new nature is being planned in urban areas our mapping approach can be used for guiding assessments of potential undesirable effects on property values that may lead to green gentrification, and for identifying

	where additional policies may be needed to contribute to environmental justice
Panduro, Toke Emil, Cathrine Ulla Jensen, Thomas Hedemark Lundhede, Kathrine Von Graevenitz, and Bo Jellesmark Thorsen. 'Eliciting Preferences for Urban Parks'. Regional Science and Urban Economics 73 (November 2018): 127–42. https://doi.org/10.1016/j.regsciurbeco.2018.09.001.	The recreational value method developed by University of Aarhus[3], provides a framework to value the recreational value of Parks and Nature. The calculations are based on the hedonic pricing method, which is used both nationally and internationally to assess the benefits and costs of various land uses, including recreational green spaces. The hedonic pricing method assumes that homebuyers prioritize different property attributes, such as size, the number of bathrooms, and location, including access to green, recreational areas. By combining property prices, parameter estimates, and changes in access to parks or natural areas, the value increase or decrease for a planning intervention can be calculated. The total value for all affected households is called the welfare gain, which can be directly incorporated into cost-benefit analyses of different planning scenarios.

Ecosystem services and Nature bases solutions

Reference	Abstract/conclusions
	Transformational change in urban areas is crucial to reversing biodiversity loss and tackling the climate crisis. Cities are increasingly experiencing ecological degradation, often made worse by the effects of the climate breakdown with rising temperatures and more extreme weather. It is widely agreed that the biodiversity and climate crises are inseparable and must be solved together. Urban rewilding is a holistic approach with the potential to increase biodiversity within built-up areas and, at the same time, tackle the climate crisis. Narratives that engage residents and invite their participation can act as accelerators for the success of a project. Urban rewilding has the potential to underpin a wider movement of reconnecting people with nature. The COVID-19 pandemic has shown how crucial urban nature is for city dwellers, especially for their health and wellbeing. Residents can be invited to design and create urban rewilding projects to ensure these spaces meet the needs of the local community and, at the same time, provide valuable areas for nature to flourish for years to come. – Forming partnerships between cities, private and public bodies, government and community groups provides a valuable pool of resources and expertise for the implementation and maintenance of urban rewilding projects. In addition, these projects can involve local universities to carry out monitoring, partner with charities to access volunteers and call upon local people as citizen

[3] https://dce.au.dk/fileadmin/dce.au.dk/Udgivelser/Videnskabelige_rapporter_500-599/SR559.pdf

	scientists to ensure urban rewilding is successful in the long term. – Demonstrating the socio-economic value of the urban rewilding project is critical to accessing available private and public sector funding. Cities are increasingly impacted by extreme weather events such as storms and flooding. Urban rewilding is a low-cost strategy to mitigate future climate impacts. At the start of any rewilding project, research should be done to ascertain whether government grants or funding are available. Secondary funding sources could come from businesses and corporations looking to invest in local community projects. Urban rewilding projects could also consider self-funding streams, such as setting up adjoining sustainable cafés or providing learning resources.
Badura, Tomas, Eliška Krkoška Lorencová, Silvia Ferrini, and Davina Vačkářová. 'Public Support for Urban Climate Adaptation Policy through Nature-Based Solutions in Prague'. *Landscape and Urban Planning* 215 (1 November 2021). https://doi.org/10.1016/j.landurbplan.2021.104215.	In this study, we investigated perception of and economic preferences for adaptation to climate change in one of Europe's capital cities to inform its planning policy. Through a choice experiment, we elicit the preferences of a sample (n = 550) from Prague, Czech Republic, for a citywide policy which would increase the use of six commonly used nature-based solutions (NBS) in public spaces and on public buildings across the city. Three attributes were used to describe this policy: (i) the locations where NBS would predominantly be implemented, (ii) the species diversity of these measures, and (iii) their implied costs for households. Our results showed that the NBS policy is widely supported by the public over the status quo and that this preference is mirrored in citizens' concerns about climate change and the risks posed by heatwaves particularly. Species diversity matters in the portrayed scenarios, suggesting that (bio)diverse NBS generate additional public value over single species measures and that policy which targets biodiversity may gain support. Implementation of NBS in public spaces (e.g., street trees, rain gardens) is preferred over measures implemented on public buildings (green roofs and facades). Furthermore, adverse experiences with heatwaves has increased support for the policy. The presented results provide evidence that adaptation planning through NBS is likely to generate significant public value which is expected to increase with the intensifying effects of climate change.

Human wellbeing and mental health

Planting trees in urban areas can provide employees with a place to relax and recharge having a positive impact on human wellbeing and mental health.

Reference	Main findings
Boosting Employee Productivity: Kuo, F. E., & Sullivan, W. C. (2001). Aggression and violence in the inner city: Effects of environment via mental fatigue.	This study investigated that possibility in a setting and population with relatively high rates of aggression: inner-city urban public housing residents. Levels of aggression were compared for 145 urban public housing residents randomly assigned to buildings with varying levels of nearby nature (trees and

	grass). Attentional functioning was assessed as an index of mental fatigue. Residents living in relatively barren buildings reported more aggression and violence than did their counterparts in greener buildings. Moreover, levels of mental fatigue were higher in barren buildings, and aggression accompanied mental fatigue. Tests for the proposed mechanism and for alternative mechanisms indicated that the relationship between nearby nature and aggression was fully mediated through attentional functioning
Bockarjova, Marija, W. J.Wouter Botzen, Harriet A. Bulkeley, and Helen Toxopeus. 'Estimating the Social Value of Nature-Based Solutions in European Cities'. *Scientific Reports* 12, no. 1 (1 December 2022). https://doi.org/10.1038/s41598-022-23983-3.	By implementing nature-based solutions (NBS), cities generate value for their residents, such as health and wellbeing. We estimate the aggregate social value to urban residents of 85 NBS projects implemented across Europe and find that the majority yield attractive social returns on investment.

Climate financing

Many businesses today are focused on sustainability and environmentally friendly practices. Planting trees in urban environments can help businesses demonstrate their commitment to these values and improve their brand image.

Reference	Abstract/conclusions
'CLIMATE FINANCE AND SUSTAINABLE CITIES 2019 FORUM OF THE STANDING COMMITTEE ON FINANCE', 2019.	Studies show that there are financial resources, particularly from the private sector, that could be harnessed to fill the financing gap. According to a representative of the New Cities Foundation, there is unprecedented appetite in the private sector, including among institutional investors and pension funds, for investment in climate-resilient infrastructure. However, several barriers to mobilizing and accessing finance for infrastructure investment and sustainable development in cities remain, particularly in developing countries, such as: • Lack of financial autonomy (e.g., taxation policy managed by the national government; cities not permitted to take on debt); • Limited financial and human resources and technical capacity to formulate investment-ready climate projects or issue municipal bonds; • Poor creditworthiness or lack of credit, resulting in limited access to the global financial market; • Regulations enacted by cities being bound by national priorities; • Lack of awareness of and capacity to utilize: • International sources of climate finance through bilateral and multilateral channels; • Innovative financial instruments that can help cities to collaborate more closely with financial institutions and corporations and harness the potential of private markets.

Annex B Unit cost prices

Notes on Rainwater runoff fees in EU.

Copenhagen: €3 per m3

Sofia: to be investigated

Cities in Germany[4]

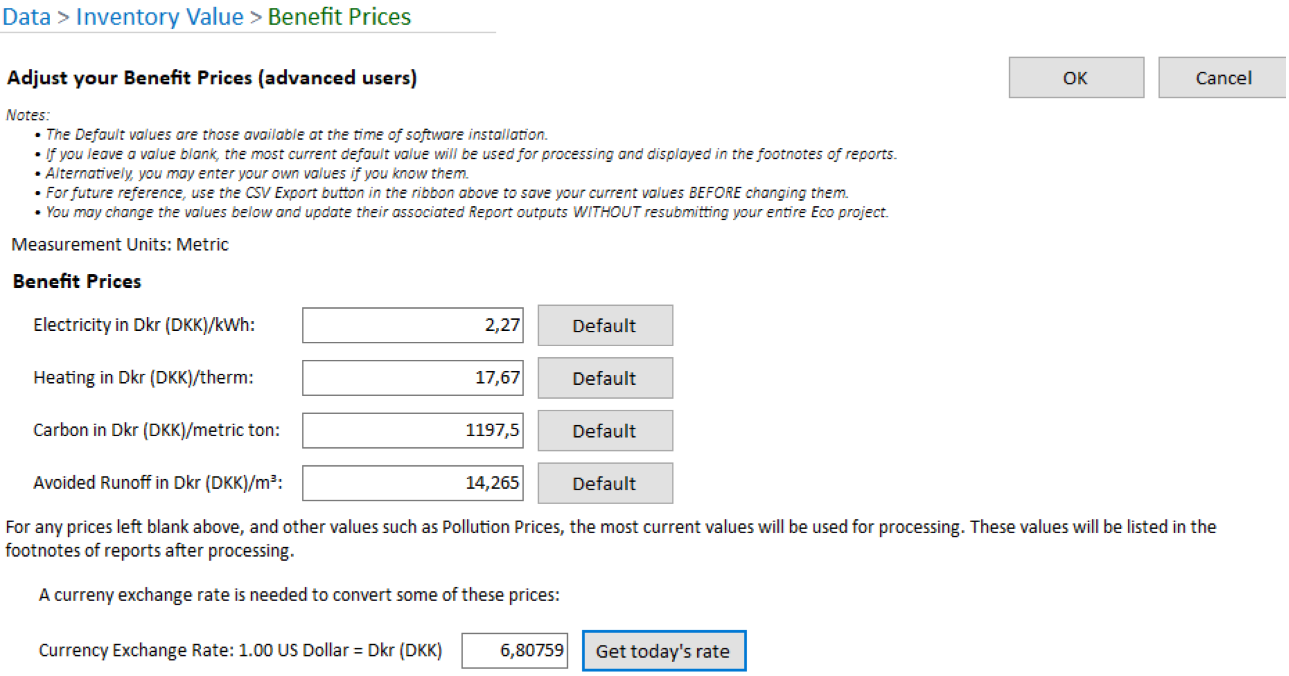
Table 1: Comparison of rainwater fees in 2020 for 13 large German cities, sorted by their number of inhabitants ([1]Destatis 2020).

City	Area (km²)[1]	Inhabitants[1]	Rainwater fee (€ /m²/a)
Berlin	891.12	3.664,088	1.81
Hamburg	755.09	1.852,478	0.73
Munich	310.70	1.488,202	1.30
Cologne	405.10	1.083,498	1.27
Frankfurt a.M.	248.31	764,104	0.50
Bremen	318.21	680,130	0.79
Stuttgart	207.32	630,305	0.73
Düsseldorf	217.41	620,523	0.98
Leipzig	297.80	597,493	0.94
Dortmund	280.71	587,696	1.43
Essen	210.34	582,415	1.78
Dresden	328.48	556,227	1.56
Potsdam	188.24	182,112	1.23

[4] https://programme2014-20.interreg-central.eu/Content.Node/D.C.2.4-Fair-rainwater-fees-for-a-sustainable-RWM-(2)-(1).pdf

Annex C i-Tree Eco Benefit prices

Screenshoots from i-Tree Eco projects in Sofia and Copenhagen:


Data > Inventory Value > Benefit Prices

Adjust your Benefit Prices (advanced users)

OK | Cancel

Notes:
- *The Default values are those available at the time of software installation.*
- *If you leave a value blank, the most current default value will be used for processing and displayed in the footnotes of reports.*
- *Alternatively, you may enter your own values if you know them.*
- *For future reference, use the CSV Export button in the ribbon above to save your current values BEFORE changing them.*
- *You may change the values below and update their associated Report outputs WITHOUT resubmitting your entire Eco project.*

Measurement Units: Metric

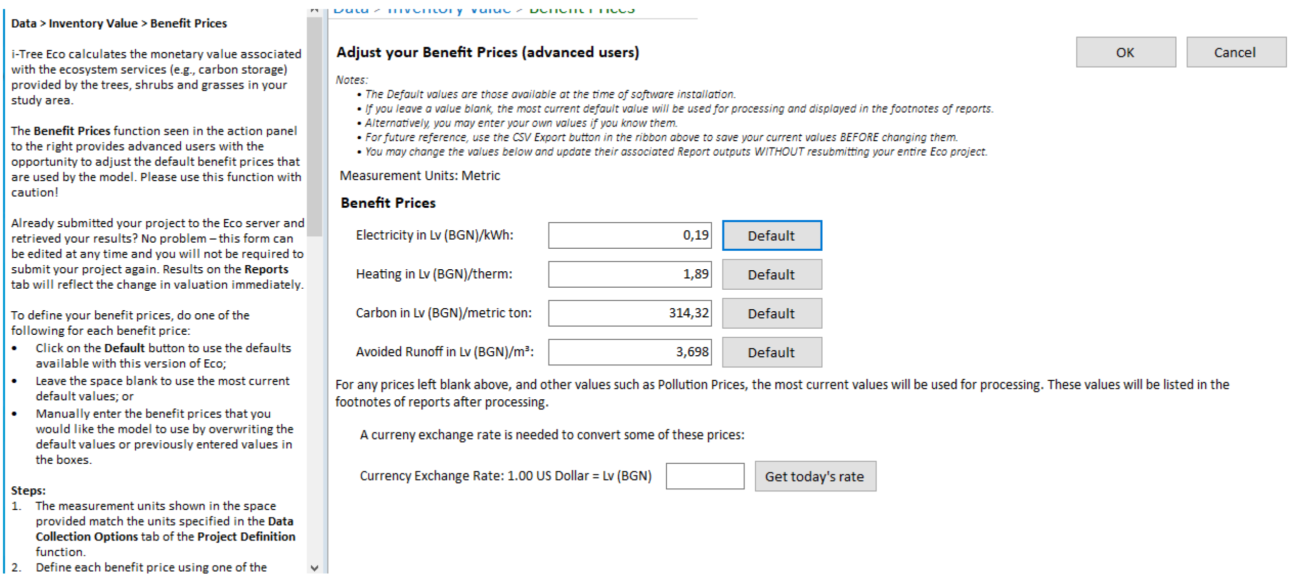
Benefit Prices

Electricity in Dkr (DKK)/kWh:	2,27	Default
Heating in Dkr (DKK)/therm:	17,67	Default
Carbon in Dkr (DKK)/metric ton:	1197,5	Default
Avoided Runoff in Dkr (DKK)/m³:	14,265	Default

For any prices left blank above, and other values such as Pollution Prices, the most current values will be used for processing. These values will be listed in the footnotes of reports after processing.

A curreny exchange rate is needed to convert some of these prices:

Currency Exchange Rate: 1.00 US Dollar = Dkr (DKK) 6,80759 Get today's rate


Data > Inventory Value > Benefit Prices

i-Tree Eco calculates the monetary value associated with the ecosystem services (e.g., carbon storage) provided by the trees, shrubs and grasses in your study area.

The **Benefit Prices** function seen in the action panel to the right provides advanced users with the opportunity to adjust the default benefit prices that are used by the model. Please use this function with caution!

Already submitted your project to the Eco server and retrieved your results? No problem – this form can be edited at any time and you will not be required to submit your project again. Results on the **Reports** tab will reflect the change in valuation immediately.

To define your benefit prices, do one of the following for each benefit price:
- Click on the **Default** button to use the defaults available with this version of Eco;
- Leave the space blank to use the most current default values; or
- Manually enter the benefit prices that you would like the model to use by overwriting the default values or previously entered values in the boxes.

Steps:
1. The measurement units shown in the space provided match the units specified in the **Data Collection Options** tab of the **Project Definition** function.
2. Define each benefit price using one of the

Adjust your Benefit Prices (advanced users)

OK | Cancel

Notes:
- *The Default values are those available at the time of software installation.*
- *If you leave a value blank, the most current default value will be used for processing and displayed in the footnotes of reports.*
- *Alternatively, you may enter your own values if you know them.*
- *For future reference, use the CSV Export button in the ribbon above to save your current values BEFORE changing them.*
- *You may change the values below and update their associated Report outputs WITHOUT resubmitting your entire Eco project.*

Measurement Units: Metric

Benefit Prices

Electricity in Lv (BGN)/kWh:	0,19	Default
Heating in Lv (BGN)/therm:	1,89	Default
Carbon in Lv (BGN)/metric ton:	314,32	Default
Avoided Runoff in Lv (BGN)/m³:	3,698	Default

For any prices left blank above, and other values such as Pollution Prices, the most current values will be used for processing. These values will be listed in the footnotes of reports after processing.

A curreny exchange rate is needed to convert some of these prices:

Currency Exchange Rate: 1.00 US Dollar = Lv (BGN) Get today's rate

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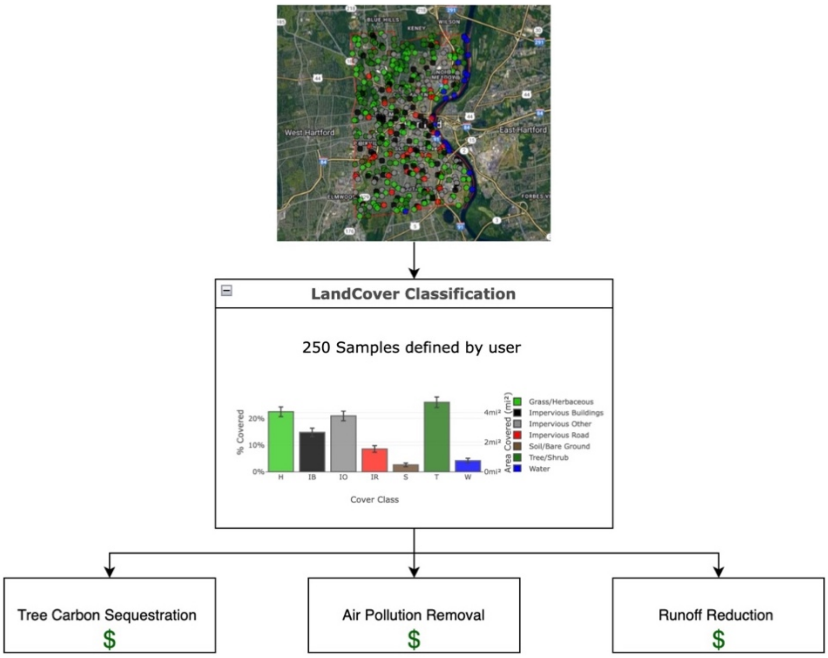
Annex D Required data for i-Tree Eco

Table: schematic overview of required data for modelling with i-Tree (Henning et al., 2023)

	DERIVED VARIABLES		ECOSYSTEM SERVICES										
DIRECT MEASURES	Leaf Area	Leaf Biomass	Carbon Storage	Gross Carbon Sequestration	Net Carbon Sequestration	Energy Effects	Air Pollution Removal	Avoided Runoff	Transpiration	VOC Emissions	Compensatory Value	Wildlife Suitability	UV Effects
Species	D	D	D	D	D	D	I	I	I	D	D		
Diameter at breast height (d.b.h.)			D	D	D						D	D	
Total height	D	D	C	C	C	D	I	I	I	I		D	
Crown base height	D	D	C				I	I	I	I			
Crown width	D	D	C				I	I	I	I			
Crown light exposure			C	D	D								
Percent crown missing	D	D	C	C	C	D	I	I	I	I			
Crown health (condition/ dieback)				D	D						D	D	
Field land use				D							D	D	
Distance to building						D							
Direction to building						D							
Percent tree cover						D	D	D				D	D
Percent shrub cover							D					D	
Percent building cover						D							
Ground cover composition							I					D	

Annex E Required data for i-Tree Eco

i-Tree Canopy for method for the statistical estimate of each surface



The statistical estimate of each surface type for the area is calculated as:

% = n/N

Where:

n = number of points chosen for the cover class

N = total number of points analysed among all cover classes.

The standard error (SE) of the estimate is calculated as:

SE = √ (pq/N)

p = n/N, and

q = 1 – p (Lindgren & McElrath, 1969)

Tree cover percentage is multiplied by the area analyzed to define the total tree cover area (Nowak, 2021).

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