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An environmental-economic accounting of services provided by the living infrastructure in the ACT: public urban forests and irrigated open spaces

Final report

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Acronyms

ACT	Australian Capital Territory
BAU	Business as usual
BCA	Benefit-cost analysis
BCR	Benefit-cost ratio
BT	Benefit transfer
DBH	Diameter at Breast Height
ED	Emergency department
ES	Ecosystem services
IOS	Irrigated open space
NPV	Net present value
SEEA	System of Environmental-Economic accounting
TCCS	Transport Canberra and City Services
TEEB	The Economics of Ecosystem and Biodiversity
ULE	Useful life expectancy
UV	Unimproved value
WTP	Willingness-to-pay

Executive summary

The ACT Government commissioned CSIRO to undertake a pilot project to value two types of urban living infrastructure using the United Nation's System of Environmental-Economic Accounting framework and quantifying the estimated whole-of-life contribution these assets make to Canberra.

Whole-of-life benefits and costs of green living infrastructure

Natural assets, such as parks, trees, and lakes, are a type of city infrastructure called 'living infrastructure'. Living infrastructure provides multiple socioeconomic, cultural, and environmental benefits to urban dwellers, such as cooling and wind protection, reduced air pollution and stormwater runoff, carbon storage, habitat for native species, space for recreation and enjoyment of nature. Green infrastructure also provides direct and indirect benefits to the city in the form of increased property values generating additional tax revenue, mental and physical wellbeing, cultural value, and amenity which in turn reduce pressure on public health services. However, since most of those benefits are not directly consumed or experienced by people, they are often overlooked or undervalued in strategic city planning decisions (Villamagna et al., 2013). This could result in the gradual deterioration of living assets, reduction of the provision of ecosystem services[1], and increasing liabilities and risks.

By considering living assets as part of the city's managed infrastructure, decisions regarding the planning, design, maintenance, renewal, termination, or expansion of the services from such assets can be improved (ACT Government, 2018). This requires the identification and valuation of the benefits and costs of living assets to facilitate a comparison of their returns to society with investment in other types of urban infrastructure. Such information can also guide gradual investments to avoid asset deterioration and the challenges of replacing large proportions of the living infrastructure that have reached or exceeded the end of their useful life.

This analysis focuses on two components of the living infrastructure denominated as green infrastructure: 1) urban forests on public ACT land (hereafter urban forests) excluding trees in nature reserves and, 2) irrigated open spaces (public-access irrigated grass areas which include parks, sportsgrounds and ovals).

Data and valuation framework

Use of the System of Environmental-Economic Accounting (SEEA) for green assets valuation

In 2016, Australia adopted the SEEA to support the analysis and policy of natural resources management within standard accounting rules applicable to other economic sectors (United Nations, 2017).

[1] Ecosystem services are the benefits provided to humans through the transformations of resources (or environmental assets, including land, water, vegetation and atmosphere) into a flow of essential goods and services e.g. clean air, water, and food (Constanza et al. 1997).

The SEEA framework guides the integration of environmental information to create indicators of the use and availability of natural resources and their effects on the economy and society (OECD, 2013).

This approach was used in this report to measure and value the services and costs of urban forests and irrigated open spaces, and to assess the implications of alternative asset management scenarios. The measurement component involved an assessment of the extent and condition of the assets (e.g. area covered, location). The valuation component involved the estimation of the monetary worth of the flows of ecosystem services from the green infrastructure and their comparison with the costs associated with their establishment, operation and removal. The scenario assessment component included the estimation of the temporal change in asset extent and condition under alternative asset management strategies and the impacts of such change on the provision of ecosystem services. The modelled scenarios accounted for climatic, socioeconomic, demographic, and policy trends specific to the ACT.

Data for this project were obtained from multiple ACT agencies, CSIRO's databases, reports, and peer-reviewed articles. Estimates of the current urban forest services are based on spatially explicit tree condition information collected between 2010 and 2012. Such data was updated to represent the characteristics of the urban forest in 2018 using tree cohort changes and 2012-2018 plantings and removals information. Tree data coupled with local socioeconomic, pollution and climate information were used in the i-Tree Eco software (USDA Forest Service, 2018) to value key services provided by the urban forest. The i-Tree results were complemented with estimates of the health and property impacts of urban forests based on studies implemented in other Australian regions.

The extent, location, and characteristics of irrigated open spaces were identified through spatially explicit datasets provided by the ACT. Current and projected management costs and benefits were estimated using local usage data and indirect benefits (e.g. higher property prices) based on research from other Australian cities. The scenario analysis of alternative management strategies relies on Benefit-Cost Analyses to identify the net return of investments into urban forests and irrigated open spaces.

Current extent, benefits, and costs of the ACT's green infrastructure

Urban forests

In 2018, the urban forest was composed of 767,636 trees (42% native to Australia), covering around 21% of publicly managed land (excluding nature reserves). The most common native tree species are: *Eucalyptus mannifera, Casuarina cunninghamiana,* and *Eucalyptus polyanthemos* which account for 25%, 5% and 4% of the tree population, respectively. *Quercus palustris, Fraxinus oxycarpa,* and *Pinus radiata* are the most common non-native (exotic) tree species, each accounting for around 2% of the 2018 tree stock.

The flow of ecosystem services of the urban forest in 2018 was estimated at $27.12 million. A breakdown of ecosystem services benefits by type that was included in this analysis is presented in Table 1.

Table 1. Estimated value of the services provided by ACT public forests in 2018

Benefits	**Biophysical flows**	**Total value (2018 $)**	**Per tree basis (2018 $)**
Carbon sequestration[1]	39,068 tonnes of CO_2	2,145,011	2.79
Avoided stormwater runoff[2]	236,355 m^3	295,402	0.38
Pollution removal[3]	154 tonnes	863,382	1.12
Building energy savings[4]	120,369 MWh	9,096,938	11.85
Avoided energy emissions[5]	33,319 tonnes of CO_2	514,392	0.67
Land rate premium[6]	105,518 houses	14,191,296	18.98
Cooling effect (avoided heat-related morbidity) [7]	Assumed 3 hot days	12,644	0.01

Description of benefits and data sources:

1. The annual CO_2 sequestered in tree biomass was valued using the social cost of carbon estimate recommended by the ACT's Climate Change Council (Revesz et al., 2017).
2. Stormwater intercepted in tree biomass was valued using the average cost per m^3 of water treatment in the ACT (pers.comm. ACT Environment, Planning and Sustainable Development Directorate, 2018).
3. Ozone, carbon monoxide, nitrogen dioxide, particulate matter less than 2.5 microns removed by trees estimated using ACT pollution and climate data for 2010 (latest dataset available in i-Tree). The values are based on international estimates of the health impacts of urban pollution adjusted by the 2018 urban population in the ACT (ABS, 2017).
4. Building energy savings from micro-climate effects generated by trees within a 20 m radius of buildings (building footprints were estimated using LIDAR data). Energy savings were valued using average residential prices of gas and electricity (ActeAGL, 2017; ICRC, 2018).
5. CO_2 emissions avoided in the energy sector due to energy savings were valued using the social cost of carbon.
6. Land rate premium on detached homes with verge trees estimates are based on tree premium estimates in Perth, and land value data in the ACT
7. Health benefits (from avoided hospital visits due to heat-related morbidity) from increase canopy cover to create cooling effects are based on hospital admission data from Brisbane, and hospital costs in the ACT

While a significant effort was implemented to account for a large range of services provided by urban forests, multiple benefits were not included due to data and/or methodological limitations. Therefore, the results underestimate the value of the services provided by urban forests. Some ecosystem services not included in this analysis are mental health and well-being, tourism, educational and cultural values, biodiversity (e.g. species diversity, habitat, and habitat corridors), reduced electricity supply infrastructure spend from building energy savings and noise reduction. The assumptions regarding the carbon sequestration potential of investment in public trees used in this study are very conservative. In addition, the study limited considerations of the likely future climate change impacts to the costs associated with heat related morbidity only, which therefore further underestimates the ecosystem service benefits urban forests will provide for the ACT into the future.

International studies have shown that these benefits have an economic value to society but such value is highly dependent on local economic and environmental conditions making them difficult to transfer for other regions. Further research could be undertaken to improve the local data and modelling so that these factors can be better quantified in the future and included, with rigour, in future work.

The whole-of-life cost of managing the ACT's urban forests comprises two types of costs: 1) fixed costs, which include one-off costs of planting, establishment, and removal of trees, and 2) variable costs, which are ongoing maintenance and externality costs occurring on an annual basis until the end of the life of a tree. These costs are based on what is realistically required to manage the urban forest leading to discrepancies between the figures used in the analysis and actual budgetary expenditure. Table 2 summarises the whole-of-life cost of trees, as provided by Transport Canberra and City Services (TCCS). Note that these cost estimates do not include project management resource costs.

Table 2. Breakdown of the whole-of-life cost of trees by native and exotic species

Cost item	Native (2018 $)	Exotic (2018 $)
Cost to plant and establish (one-off cost $/tree)		
• Tree purchase (native)	40	90
• Planting	130	160
• Consolidation	80	80
• Watering	180	300
• Formative pruning	75	75
Total (planting and establishment)	**505**	**705**
Cost to maintain (average annual $ per tree)		
• Maintenance	35.83	71.66
• Street sweeping cost	2.12	4.25
Total (cost of maintenance)	**37.95**	**75.91**
Cost to remove a tree (one-off cost $/tree)	**1,210**	**1,210**
Externality cost (average annual $ per tree)		
• Stormwater pipe maintenance	1.35	3.83
• Path replacement, grinding, patching	1.38	3.90
• Shopping centre precinct – pavers	0.18	0.52
• Tree claim payments	0.13	0.13
• Insurance excess payments	0.03	0.03
Total (annual spend on externality cost per tree)	**3.07**	**8.41**

Irrigated open spaces

The area of irrigated open spaces used in this analysis consists of 380 ha of sports grounds and 104 ha of non-sport grounds. The current annual flow of ecosystem services benefits provided by irrigated open spaces consists of:

- Increased land prices of around $3.4 per house per year for houses that are within 740 m of an irrigated sports oval and within 1.8 kilometres of an irrigated playground (calculated based on premiums estimated for Adelaide and adjusted for Canberra house prices and housing stock).
- Recreational benefits of $76,000 per ha for irrigated sports ground, and $24,000 per ha of nonsports ground (estimated based on Canberra recreational statistics).
- Revenue from sports ground hire of $4,600 per ha (source: pers. comm. TCCS, 2018)

These results underestimate the full benefits as multiple ecosystem services benefits were not included in the analysis due to biophysical and economic data limitations. Specifically, the omitted ecosystem services are: species diversity, habitat, and habitat corridors; avoided stormwater runoff; building energy savings; mental health and well-being benefits; tourism, cultural and symbolic values; and noise reduction. We expect the mental health and well-being benefits to be high for irrigated open spaces, but there is currently insufficient information in the literature to provide an accurate economic estimate.

The cost structure of irrigated open spaces – both for sports ground and for other uses - consists of both a one-off cost to establish the area and the necessary infrastructure, such as an irrigation system, and the annual cost of maintenance, including irrigation. All costs are provided by TCCS, except for cost estimates for turf establishment which were extrapolated from Logan City Council, Queensland (2015).

The cost of establishing a sports ground is approximately $600,000 per ha. This includes the cost of purchasing and planting turf, irrigation and drainage systems, and sports infrastructures. The cost of setting up a non-sports ground is estimated to be $123,400 per ha which includes purchasing and planting turf and setting up the irrigation system. Unlike trees, irrigated open spaces do not grow and accumulate capital asset value. Therefore, the capital value of irrigated open spaces is assumed to be equal to the cost of establishing each type of irrigated open space (i.e. sports or non-sports grounds). The annual maintenance cost is around $38,000 per ha for sports ground and $13,000 per ha for non-sports ground. The cost of irrigation is around $13,400 and $5,600 per ha per year for sports and non-sports ground, respectively. Table 3 provides a breakdown of the costs to set up and maintain irrigated open spaces.

Table 3. Break-down of costs of irrigated open spaces by type of use (sports and non-sports)

	Sports (2018 $)	Non-sports (2018 $)
Cost to plant and establish (one-off cost $/ha)		
Set up turf, irrigation, drainage, sports infrastructure	600,000	
Turf – supply & install		13,399*
Topsoil		80,000*
Irrigation system (including pumps and bores)		30,000*
Total establishment	**600,000**	**123,399***
Maintenance cost (annual per ha)		
Irrigating	13,418	5,600
Mowing	9,480	189
Waste Hoppers	789	
Cleaning	718	
Fertiliser and amendments, including soil testing	925	925
Pest and disease control - materials	740	740
Aeration	1,700	1,700
Dethatching	750	750
Annual renovation-top soil/ seed/ (spring and autumn)	1,850	1,850
Irrigation repairs-materials	1,171	1,171
Repairs and maintenance – buildings and floodlights	925	
Management staff field/office/bookings	5,859	
Total maintenance (annual)	**38,325**	**12,925**
*Estimates based on Logan City Council figures (all other costs figures are provided by TCCS)		

Benefit-cost analysis of alternative management scenarios

Scenario descriptions

Benefit-cost analyses were applied to compare the value of the benefits of urban forests and irrigated open spaces with the cost of managing and preserving them for current and future generations. Three scenarios were evaluated to identify the long-term (2018-2125) costs and benefits of alternative management strategies of urban forests, and two scenarios for irrigated open spaces (management horizon 2018-2070). The management horizon for urban forests is larger than the one for irrigated spaces to account for the life-span of trees planted in 2045. Those scenarios account for projected socio-economic and climate change trends. The impact of carbon-neutral energy policy on the value of avoided emissions from energy savings was also included in the analysis. Tree replanting is assumed to occur only from 2018 to 2045, and only maintenance and removal costs are considered afterwards. The increase of irrigated open spaces area both for sports and non-sports use is assumed to occur as a one-off event in 2045.

Urban Forest Scenario 1. Business as usual: From 2013 to 2017 around 1700 trees were removed and 1300 planted annually. This trend is projected to continue resulting in a gradual decline of the health, extent, and flow of ecosystem services from this asset. The proportion of trees at the end of their useful life expectancy will gradually reach critical levels resulting in need of costly risk reduction actions and removal and replanting of a large proportion of the urban forest.

Urban Forest Scenario 2. Maintaining the current extent of the forest: To maintain the overall condition and flow of services of the ACT's urban forest observed in 2018, trees at the end of their useful life are removed and similar numbers of trees are planted, i.e. the objective is to maintain the tree stock observed in 2018. An underlying (non-modelled) assumption is that tree species selection under this scenario aims at achieving a more efficient configuration of the urban forest and that replanting prioritises a spatially balanced distribution of the urban forest.

Urban Forest Scenario 3. Increasing tree canopy cover to 30%: The distribution and composition of the urban forest are proactively managed to gradually increase tree canopy cover from 21% to 30% of publicly managed land (excluding nature reserves). Improvements in the extent and health of the asset increase its resilience to climate change impacts and enhance the provision of ecosystem services. Replanting and removals (based on useful life expectancy) target the development of a balanced distribution of trees age, size, and species composition.

Similarly, we evaluate the implications of two alternative management strategies for irrigated open spaces assuming current trends in socioeconomic, population and climate change projections.

Irrigated Open Space Scenario 1. Business as usual: This scenario assumes that the current distribution and extent of irrigated open spaces does not change. Benefits are modelled based on property price increases, sports ground hires, and recreational use.

Irrigated Open Space Scenario 2. 50% increase in the area of irrigated open spaces: In response to projected population growth, increasing average temperatures, and increasing bushfire risks, the total area of irrigated open spaces increases 50% by 2045 (around 240 additional hectares). The area and location of new irrigated open spaces target the mitigation of heat island effects, the reduction of bushfire spread risks, enhancement of amenity values, and the promotion of active recreation in socioeconomically vulnerable regions.

The cost of establishing and maintaining the new spaces are compared with potential recreational use benefits and increases in property value for residential properties located in the vicinity of the new assets.

Benefit-cost analysis: Findings

Findings from the benefit-cost analysis are presented in terms of a benefit-cost ratio. A benefit-cost ratio (BCR) greater than one indicates a management scenario where the whole-of-life benefit outweighs the cost. The greater the benefit-cost ratio, the greater the return of the investment. To account for variations in the assumptions, we provide the mean benefit-cost ratio, along with its lower and upper bound values.

A summary of the benefit-cost analyses is as follows:

- Under Business as usual tree management conditions indicates a negative long-term return for the ACT, with a benefit-cost ratio of between 0.56 and 0.74 (mean of 0.65)
- Under Maintaining the current extent of the forest indicates a near positive long-term return for the ACT, with a benefit-cost ratio of between 0.98 and 1.07 (mean of 1.02)
- Under Increasing tree canopy cover to 30% of the public land indicates a positive long-term return for the ACT, with a benefit-cost ratio of between 1.15 and 1.25 (mean of 1.19)
- Under Business as usual irrigated open space management conditions indicates a positive longterm return for the ACT, with a benefit-cost ratio of between 2.51 and 2.77 (mean of 2.64)
- Under 50% increase in the area of irrigated open spaces conditions indicates a positive longterm return for the ACT, with a benefit-cost ratio of between 2.32 and 2.56 (mean of 2.44)

If the current urban forest were to be damaged or destroyed (e.g. in a bushfire) the cost of replacing the entire forest with trees of the same species, age composition, and condition would be equal to its capital asset value. The ACT's urban forest is estimated to have a current capital asset value of $3.4 billion. Increasing the number, condition and life-expectancy of trees through more replanting and better maintenance is expected to increase the capital asset value of the ACT's urban forest. Table 4 provides the estimated current and future asset value of the ACT's urban forest under three different tree management scenarios.

Table 4. Change in capital asset value of trees over time for different scenarios (2018 $)

	BAU ($)	Maintain ($)	30% Canopy Cover ($)
Capital asset value (2018)	3,407,216,706	3,407,216,706	3,407,216,706
Capital asset value (2045)	3,698,574,731	4,056,626,314	4,497,278,880
Change in capital asset value (NPV over 20182045)	245,849,804	419,802,396	689,258,782

All three scenarios start with the same capital asset value of $3.4 billion. By 2045, which is the end of planned replanting, the capital asset value for the Increasing tree canopy cover to 30% scenario increases by $689 million, which is $443 million greater than the Business as usual scenario and $269 million greater than the Maintaining the current extent of the forest scenario. Despite net tree losses in the Business as usual scenario, a proportion of the forest continues to grow which result in increases in capital asset value. Such increase reaches a maximum around 2043 and then gradually declines.

To understand the whole-of-life benefits and costs of the trees planted between 2018 and 2045, we examined the net present value (NPV) of the benefits and costs of each tree management scenario up until the year 2125, the year at which trees planted in 2045 reach the end of their useful life. Table 5 presents a summary of the NPV of the benefits and costs, and the change in capital asset value of the three tree management scenarios.

Table 5. NPV of benefits and costs of tree management scenarios (2018-2125)

Item	NPV $ (2018-2125)		
	BAU	Maintain	30% Canopy Cover
Total cost (planting, maintenance and removal)	774,564,540	1,342,329,177	1,659,474,370
Change in capital asset value	-232,314,866	268,076,877	698,411,172
Ecosystem services benefits (excl. change in capital asset value)	734,954,924	1,107,671,430	1,278,695,644
Total benefit (ecosystem services benefit + change in capital asset value)	502,640,059	1,375,748,307	1,977,106,816

Capital asset value changes impact the NPV of each management scenario. As shown in the case of the Business as usual scenario, there is a forgone benefit of $232 million dollars (in 2018 NPV terms) by 2125 because of the net tree loss (400 trees per year to 2045, and 1,700 trees afterwards). Social losses due to declines in liveability and city character caused by tree loss are also expected but not quantified in the analysis. On the other hand, the Increasing tree canopy cover to 30% scenario, shows a total benefit of $1.97 billion with gains in capital asset value accounting for around 35% of such figure.

The differences among the scenarios can also be observed on the average per tree cost and benefit estimates (Figure 1). The cost of the Business as usual scenario are always higher than the modelled set of benefits. While the costs of the Maintaining the current extent and the Increasing tree canopy cover to 30% scenarios are larger than the Business as usual scenario from 2018 to 2070, those scenarios generate positive social benefits post 2055. The average per tree benefits increase significantly due to the increasing benefits of carbon sequestration under projected climate change trends and the reduction in the number of standing trees.

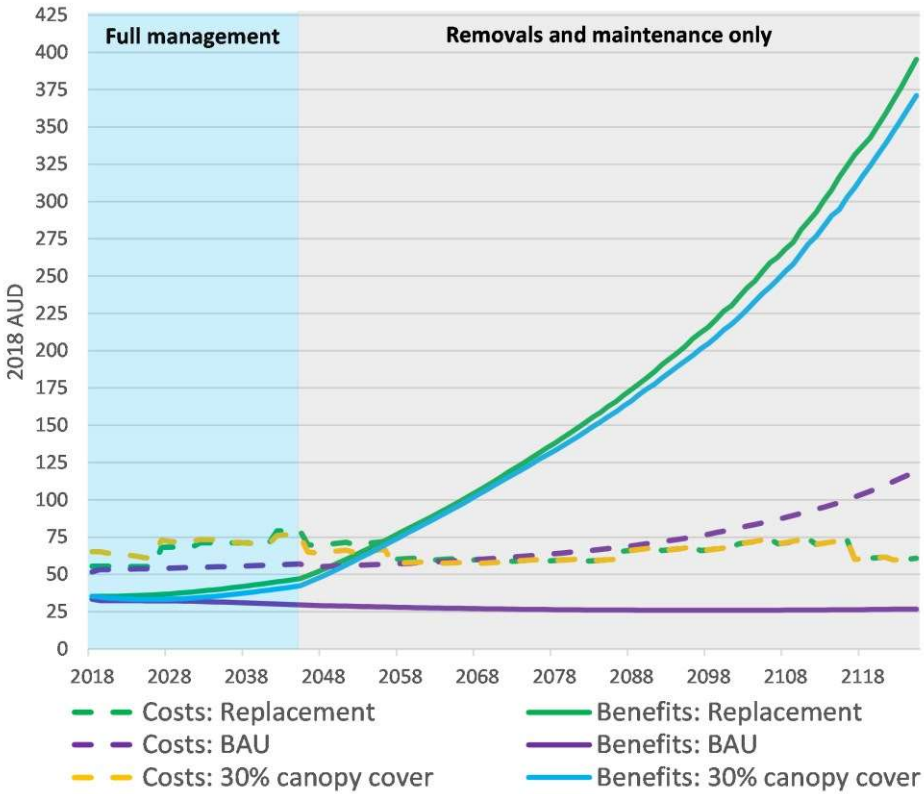

Figure 1 Per tree costs and benefits for the assessed tree management scenarios from 2018 to 2125

To examine how much the costs and benefits translate to cost per person, we examined the net cost per person per week for each of the three tree management scenarios during the 2018-2045 time horizon. The net cost is the total cost minus the total ecosystem services benefits. The current population in the ACT is 420,321 and is estimated to reach 614,633 by 2045 (Chief Minister, Treasury and Economic Development Directorate, 2019). Table 6 presents the number of trees in 2018 and 2045 for the three tree management scenarios. Trees per person decline under all scenarios during 2018-2045, as does cost per person per week (in 2018 $). Under the Business as usual scenario, the net cost to tax payers is negligible (effectively $0), as the cost under the Business as usual scenario is low. However, the decline in the number of trees is substantial. A net loss of 387,946 trees is expected by 2045 under the Business as usual scenario, resulting in an average number of trees per person of 0.62 by 2045 (a drop from 1.83 trees per person in 2018). This situation can be avoided at an additional cost of $0.71 per person per week in 2018 (declining to $0.51 by 2045) under the Maintaining the current extent of the forest scenario. For an extra $1.05 per person per week in 2018 (declining to $0.70 by 2045) the tax payer funds a net increase of 245,984 trees under the Increasing tree canopy cover to 30% scenario, which is 633,930 trees more than BAU in 2045.

Table 6. Net cost per person for each tree management scenario (2018 $)

	No. of trees providing ecosystem services		Net cost/person/YEAR		Net cost/person/WEEK	
	2018	2045	2018	2045	2018	2045
BAU	767,636	379,690	$37.33	$0.85	$0.72	$0.02
Maintain	767,636	767,636	$36.75	$26.40	$0.71	$0.51
30% Canopy cover	767,636	1,013,620	$54.79	$36.22	$1.05	$0.70

Table 7 presents the NPV of the benefits and costs of the two irrigated open space management scenarios. The benefit-cost ratio for both cases is greater than one, indicating a situation where benefits outweigh costs. The scenario where 50% more irrigated open spaces is planned for in 2045 shows a slightly lower benefit-cost ratio than the Business as usual case. Note that land purchase cost is not included in the NPV analysis of irrigated open space expansion.

Table 7. NPV of benefits and costs of irrigated open spaces management scenarios (2018-2070)

	BAU	50% more IOS
Planting & establishment cost	$0	$53,870,616
Maintenance cost	$432,157,863	$493,664,118
Externality cost	$0	$0
Total cost	$432,157,863	$547,534,735
Total benefit	$1,142,719,352	$1,339,261,284
BCR (Total benefit/Total cost)	2.64	2.45

It is important to emphasise that, there is a lack of research on the valuation of the ecosystem services provided by irrigated open spaces (e.g. species diversity, wildlife habitat, and human health and well-being). Without such information, all the costs to establish and maintain irrigated open spaces are known and accounted for, while only a small portion of the ecosystem services benefits can be represented in monetary terms.

Conclusion and recommendations

The ACT's green infrastructure has a significant capital asset value and provides important direct and indirect benefits to the city. The framework implemented in this analysis allows the comparison of the social benefits of investments in green infrastructure with the returns of investments in other areas. This information could help increase the overall flow of benefits, manage risks generated from asset deterioration, and target the provision of sustainable levels of green infrastructure ecosystem services.

In summary, the findings from this analysis suggest that out of the set of assessed tree management scenarios, the tree management scenario that aims to expand tree canopy cover has the highest benefit-cost ratio. Sensitivity analyses suggest that this benefit-cost ratio is robust to uncertainty in the magnitude of the cost and benefit estimates used in the analysis. In other words, the benefits outweigh the costs despite any changes in the model assumptions. The two modelled scenarios for irrigated open spaces provide evidence of the net social benefits of this type of asset.

In light of these findings, the ACT government could consider prioritising the expansion of tree canopy cover up to 30% by 2045, over continuing on with the current tree planting and maintenance regime. However, further study and research would assist in developing a robust and comprehensive benefit cost ratio. As for the case of IOSs, more research is required to understand the suite of ES benefits that these types of spaces could provide if more were to be established in the ACT.

A number of lessons were learned from this analysis of the whole-of-life benefits and costs of urban forests and irrigated open spaces. Firstly, there is a severe lack of appropriate biophysical, socioeconomic, tourism and health data in the ACT to accurately model the costs and benefits of both public urban trees and irrigated open spaces. Updated spatially explicit information on the number, location, and condition of publicly managed trees is urgently needed to improve the estimation of costs and benefits, and facilitate the long-term management of the urban forest. Secondly, research is needed to estimate the value to ACT residents and visitors of non-modelled ecosystem services (including mental health and well-being, tourism, educational and cultural values, species diversity, habitat and habitat corridors, and noise reduction). Empirical analysis of the benefits of urban living infrastructure by ecosystem service type (i.e. provisioning, regulating, cultural, and supporting) or by type of green infrastructure (e.g. urban forests, irrigated open spaces) is required to support long-term city planning and investments. Since covering the identified data and research deficiencies would be resource intensive, an assessment of the trade-offs and benefits of data acquisition and valuation studies should be made to prioritise the generation of information that supports improved city asset management, liveability and adaptation to climate, demographic, and economic pressures.

The scope of this study was limited to whole-of-life costs being borne by the Government and does not include consideration of innovative business and financing models to assist in cost sharing, thereby reducing the cost burden to Government. There are a number of examples whereby this is already occurring in the ACT and elsewhere. Future work could be undertaken to investigate suitable models to pilot and or implement in the ACT to assist in cost effective growth and maintenance of the ACT urban forest.

1 Introduction

1.1 Green living infrastructure in the ACT

A living infrastructure is a natural asset that has become part of the design and operational plan of a city (ACT Government, 2018). Living infrastructure generally comprises 'green infrastructure' (which focuses on vegetation, such as parks, garden beds, lawn, trees, green roofs/ walls, swales, rain gardens) and 'blue infrastructure' (which focuses on water bodies, such as wetlands, lakes, waterways, bays) situated in urban landscapes (Kazmierczak, 2010). Living infrastructures require natural and designed components to efficiently deliver benefits for city dwellers (ACT Government, 2018). By considering living infrastructure as part of a city's built infrastructure, more comprehensive planning, design, maintenance and renewal of the urban environment can be pursued (ACT Government, 2018).

Green living infrastructure provides multiple socioeconomic, cultural, and environmental benefits. Parks and trees have positive effects on real estate values that benefit not only property owners but also local communities through the additional tax revenue resulting from higher property values (Wolf, 2004). The relevant role in mitigating the effects of climate change, such as ameliorating heat island effects, reducing air and noise pollution, and controlling stormwater runoff have also been documented (Meyers, et al., 2017; Bao, et al., 2016; Marinoni, Battaglia, & Beaty, 2017). Green assets in urban environments also contribute to the physical and psychological well-being of city dwellers (Wang, et al., 2016) which could reduce pressure on strained public health services.

The analysis of this report focuses on the valuation of benefits and costs provided by publicly owned trees and irrigated open spaces (IOSs) in the ACT metropolitan area (Figure 1-1). Although approximately half of the trees in Canberra are privately owned (front and back yard trees), these trees will not be part of this analysis because they are not under government control and may be removed through urban change and redevelopment. Note also that IOSs considered in this report focuses on irrigated areas that are managed by TCCS.

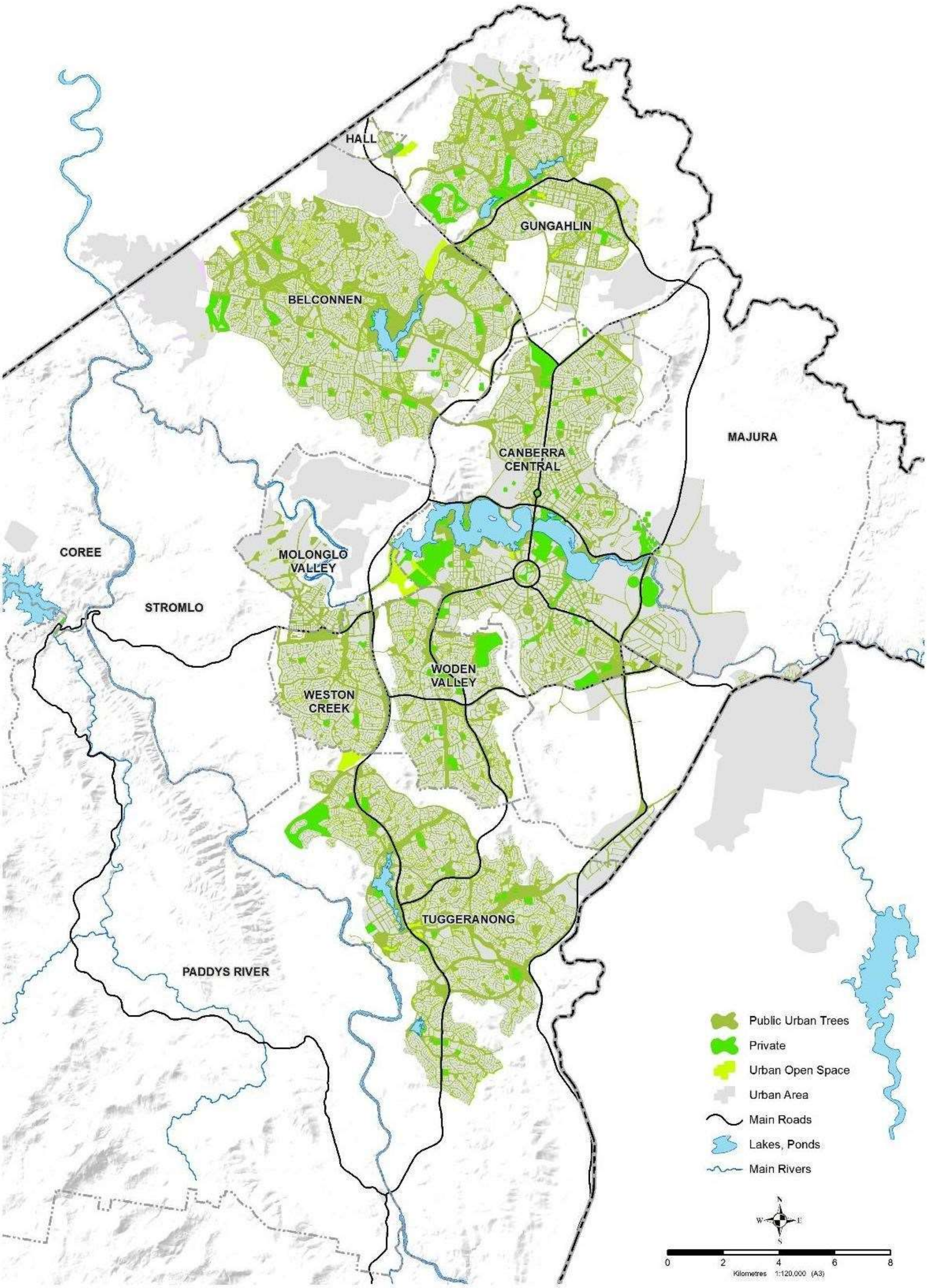

Figure 1-1 Map of public urban trees and urban open spaces in the ACT

1.2 Objective and activities of the research project

Limited budget for maintaining existing green infrastructure and establishing new ones is a major driving force for the rapid reduction in these assets across the ACT (TCCS pers. comm.). However, it is difficult to argue for additional funding without being able to demonstrate the benefits accrued from increased investment in these green assets. For this reason, CSIRO was contracted to complete a pilot study to:

- Evaluate the whole-of-life net benefit of publicly owned trees and IOSs to the ACT (e.g. cooling benefits of trees).
- Estimate the net social benefit to the ACT per additional unit of living infrastructure (e.g. per additional ha of urban forest or IOS).
- Assess the monetised benefit to society for every dollar invested in establishing and maintaining living infrastructure in the ACT.

As part of this research project the CSIRO has:

- Clarified the scope, focus, and extent of the analysis, as well as engaged with project partners and key stakeholders who will be the end-user of the research project output.
- Liaised with stakeholders that held the data sets necessary for analysis.
- Consolidated research evidence and data from a desktop review of the literature and databases, and from project stakeholders.
- Integrated all data sets into a homogeneous modelling environment, performed data quality tests, assessed gaps between available and required data, and identified and implemented strategies to cover identified gaps.
- Performed a benefit-cost analysis (BCA) in @Risk and i-Tree, to arrive at the net present value (NPV) of expanding, retaining, or decreasing the number of urban public trees, and IOSs.

The main objective of this report is to estimate the extent and value of ecosystem services (ES) provided by urban forests and IOSs and to assess the net benefits of different green assets management scenarios. This report also provides a set of recommendations of actions going forward to conduct a more detailed analysis of all living infrastructure in the ACT. Findings from this research will help guide future decisions, and budget allocations, in terms of prioritising public funds to establish and maintain publicly owned trees and IOSs.

The scope of this study was limited to whole-of-life costs being borne by the Government and does not include consideration of innovative business and financing models to assist in cost sharing, thereby reducing the cost burden to Government. There are a number of examples whereby this is already occurring in the ACT and elsewhere. Future work could be undertaken to investigate suitable models to pilot and or implement in the ACT to assist in cost effective growth and maintenance of the ACT urban forest.

2 A review of ecosystem services and the benefits of urban living infrastructure

The objective of a desktop review of the literature is threefold: first, to collate the ES of urban trees and IOSs; second, to identify the methods used to estimate the benefits (or costs) of the ES (or disservices) of trees and irrigated opens spaces; and third, to collect data for the estimation of such ES.

We conducted a systematic review of the international literature from the last decade of studies that place a value on similar green assets. The following keywords were used: public trees, IOS, parks, lawn, sports oval, golf courses, public green space, parks and ES, benefits, values. Priority was given to studies in the ACT, followed by studies in New South Wales, then other parts of Australia, and last in other countries. A review of abstracts was first conducted to eliminate papers that were only marginally related to the objectives of this report. While a comprehensive review effort was undertaken, we acknowledge that the list of relevant research is not exhaustive. Lin et al. (2018) provide an excellent summary of the ES benefits of urban green infrastructure from their review of the international literature. However, there is still a gap in the literature on the ES benefits of green infrastructure that are specific to Australia. Appendix 1 provides a summary table of the ES benefits of trees and lawn (irrigated and non-irrigated) from our review of the Australian literature.

2.1 Urban public tree benefits

There are two types of ES benefits derived from trees – market benefits and non-market benefits. Market benefits generally include food and timber that can be harvested from orchards or commercial forest. The provision of food and timber is not the role of urban forests in the ACT. Hence, we can assume that there are no market benefits from urban forests to the ACT. Having said that, public trees may be planted in the future that could provide fruit to people living nearby.

There are many non-market benefits that public trees provide. From the review of the literature, we gather that trees provide the following ES (see Table 2-1).

Table 2-1 A summary of ecosystem services benefits of urban trees

Provisioning	Food Shade Oxygen
Supporting	Habitat connectivity/corridors Habitat for wildlife Species diversity/Biodiversity
Regulating	Climate regulation/amelioration (cooling) Carbon sequestration Air quality Noise reduction Flood control/Stormwater run-off Water pollution reduction Erosion control
Cultural	Recreational value Property price premium Cultural heritage Symbolic/Spiritual values Mental/Physical health benefits Educational Aesthetic enjoyment Reduce socio-economic inequalities

During the 1970 and 1980s, a number of methods were introduced to place monetary values on the benefits of trees. These include: the 1992 Australian Draft Standard, the 1999 Australian/New Zealand Draft Standard, the 1998 Australian Burnley Method, the 1991 British Helliwell Method, the 1996 Australian Thyer Method, and the USA 1991 Trunk Formula Method (Garner, 1999).

What these methods have in common is that the economic value of trees is based on tree characteristics such as height, trunk volume, crown size, form and vigour, life expectancy, etc. The variation among these methods is that some also include the historical significance value of the tree, visual impact, location in the landscape, etc. Conversion of the physical characteristics of a tree into monetary value is done through a 'conversion factor'. The conversion is based on nursery prices of the tree and the value of the land (Garner, 1999). Differences in assumptions across tree valuation methods can result in significant value differences for the same tree. For instance, using the Helliwell method, Garner (1999) estimated the value of one single *Eucalyptus melliodora* (Yellow Box) tree located on the Australian National University Campus to be around $407,000. However, valuing the same tree using the Burnley method resulted in an estimate of around $40,700. These estimated values did not include the value of the ES from such tree.

From their review of the international literature, Lin et al. (2018) provides an extensive summary of the ES benefits of trees, and the monetary benefits associated with some of the ES. However, Lin and colleagues pointed out that the monetary value of some ES, such as habitat and species diversity, are difficult to quantify. Unlike other types of ES of trees, such as stormwater management, where a correlation between tree size and stormwater run-off prevention has been quantified.

The conclusion found by Lin and colleagues is also echoed by Brouwer et al. (2013) who stated in their review of published literature on ES valuation that "there does not exist one single, standard 'TEEB[2]' method or approach. Most efforts focus on the mapping of ES. Hardly any initiative has (yet) been able to integrate ES assessment and mapping into valuation and accounting."

2.1.1 Property price premium

A potential proxy for deriving the social well-being benefits of trees is the value that buyers place on trees that are planted within the vicinity of a residential building. It is theorised that the value of trees is capitalised in the property sales price, just like the value of other attributes of the home, such as bedrooms and bathrooms (Freeman, 1979). In other words, assuming that there are two homes that are exactly identical in every way, except that one home has a tree and the other one does not, a hedonic property price approach can be used to estimate the premium that a tree adds to property sales price. This method was implemented by Pandit et al. (2013) to estimate the value of street trees in Perth, Western Australia. Pandit and colleagues estimated that street trees add a premium of around $16,000 to an average property in Perth based on a median house price of $395,000 (or approximately 4% of median sales price).

2.1.2 Tourism, recreation, cultural and symbolic

Trees and open spaces, which form many significant parks in the ACT provide significant tourism, recreation, cultural and symbolic values to residents and visitors of the ACT. The changing colours of deciduous trees in the courtyards of Parliament House and the National Arboretum provide beautiful sites and recreational values to locals and visitors of the ACT (Sibthorpe, 2017). The ACT also registers trees that demonstrate natural or cultural heritage value, landscape and aesthetic value, and scientific value (Transport Canberra and City Services (TCCS), 2016).

Tourism statistics from Tourism Research Australia (2018) and VisitCanberra (2017) indicated that for the year ending September 2017, the ACT received 2.71 million domestic overnight stays, 228,038 international visitors, and 2.05 million domestic day trippers, earning a total revenue (equivalent to tourism expenditure) of $2.47 billion. Events such as Floriade and nationally significant tourism sites such as the National Arboretum attract tourists at least partly due to their living infrastructure. Despite the large number of tourists, the ACT did not rank very high compared to other cities as a destination for outdoor adventures and activities. The report by Tourism Research Australia (2014) elaborated that "Canberra was not perceived as a competitor for genuine 'adventure' experiences, particularly among younger age groups", however, "Canberra's outdoors did hold some appeal, particularly with older age groups who were keen to experience the region's parks and gardens." In any case, these statistics are only partially informative, as they do not capture how tourists perceive public trees and IOSs in the urban areas of Canberra, which supports the 'Bush Capital' image of Australia.

[2] TEEB – The Economics of Ecosystem and Biodiversity

2.1.3 Noise reduction

Different types of tree variety, size, planting density and distance to buildings have been shown to reduce street noise in buildings. Marquez et al. (2005) summarised that dense shrubbery at least 5 m wide can reduce noise levels by 2 dB(A). Meanwhile, a 50 m wide plantation can lower noise levels by 3–6 dB(A), and 100 m of dense vegetation can decrease noise by 1–2 dB(A). Greater width and height of trees provides a larger surface area which produces greater absorption and diffusion of sound (Fang & Ling, 2003). However, due to the sparse foliage nature of trees, the most optimal sound absorption strategy is to plant shrubs underneath the trees, as shrubs have denser foliage which is better at absorbing and diffusing noise (Fang & Ling, 2003).

2.1.4 Health

In the ACT, green space and areas covered with trees are shown to have lower mean land surface temperatures than areas covered with urban infrastructure such as buildings and housing e.g. 31°C for forests and 37 °C for urban residential surfaces on a summer day (Meyers et al., 2017). Cooling benefits of trees can have significant health benefits. Hondula & Barnett (2014) examined a time series of geographically referenced hospital admissions data and daily temperatures during 2007–2011, in Brisbane, and found a significant correlation between maximum daily temperature and the number of emergency department (ED) admissions the following day. They used morbidity data with the daily totals of emergency non-accidental hospital admissions (non-accidental hospital admissions exclude transport accidents, intentional self-harm, assault, medical complications, legal interventions, and hospital-related adverse events) to avoid biasing the ED admission rate with nonheat-related illnesses. On average, they found that a 10 °C increase in daily maximum temperature (from the baseline of 29 °C during the summer was associated with a 7.2% increase in hospital admissions (95% CI: 4.7, 9.8%) on the following day. This information can be used to assess the health-related impacts of changes in tree cover under changing climate conditions.

2.1.5 Public educational benefits Investment in public trees, open spaces and constructed wetlands not only provides educational opportunities for parents and schools to introduce children and youth to how ecosystems work, it can also help improve educational performance in some cases. A lack of contact with the natural world has been found to increase the incidence of attention deficit hyperactivity disorder (ADHD). Research suggests that playing among trees, shrubs and grass can reduce ADHD. (Taylor, et al, 2001).

2.1.5 Climate regulation and amelioration (cooling)

Trees provide shade and act as a cooling measure, which in a warming climate can help to reduce the effects of urban heat. As a result, the value of public trees and other types of nature are likely to increase over time. Climate projections indicate that there will be increased risks of extreme events such as flood and drought, increased temperatures and more extreme heatwaves (Office of Environment and Heritage, 2014). This is likely to lead to increased demand for cooling (e.g. air conditioning) and increase in peak demands for such cooling measures.

2.2 Irrigated open spaces (IOSs)

There are a handful of studies that evaluated the ES of urban IOSs that lawns or sports ground provide. These include: recreation, rainfall run-off prevention, cultural, health, aesthetic, noise reduction, and carbon sequestration, to name a few. The recreational benefits of sports grounds in the ACT, as represented by government revenue generated from sports ground hire, is around $4,623/ha/year (TCCS pers. comm.). This is the only market benefit that is accrued from IOSs. Other non-market benefits are summarised in Table 2-2 and the discussion below.

2.2.1 Property price premium

Following the same theory on the capitalised value of street trees to property sales price, proximity to IOSs, which include sports ovals and playgrounds, is also theorised to add a premium to property sales price. In other words, given two exactly identical homes, the one closer to an IOS will have a higher value than the one further away. That is because there is an element of social well-being improvement when one is in close proximity to IOSs. A hedonic property price approach was used to estimate the premium that IOSs add to property sales price in Adelaide, South Australia (Hatton MacDonald et al., 2010). It was estimated that moving 1 metre closer to an irrigated sports oval or an irrigated playground will increase sales price, on average, by around 0.11%. This study also estimated the average distances for these premiums as 0.7 km for sportsground and 1.8 km for playgrounds.

Table 2-2 A summary of ecosystem service benefits of IOSs

Provisioning	Recreational value Sporting value (user fee) Oxygen
Supporting	Habitat connectivity/corridors
Regulating	Climate regulation/amelioration (cooling) Carbon sequestration Noise reduction Flood control/Stormwater run-off Water pollution reduction Erosion control
Cultural	Recreational value Property price premium Cultural heritage Symbolic/Spiritual values Mental/Physical health benefits Aesthetic enjoyment Reduce socio-economic inequalities

2.2.2 Health

Green space is aesthetically pleasing and can result in improved mental health and well-being. Several health studies have empirically shown that interaction with green space (or even the view of green space) can improve mental and physical health.

For example, Ulrich et al. (1991) studied the recovery rate of patients in a hospital and found that patients with rooms facing a park had 10% faster recovery and needed 50% less strong pain-relieving medication compared to patients in rooms facing a building wall. However, Ulrich et al. (1991) did not specifically attribute those benefits to IOSs.

2.2.3 Biodiversity and species migration

Mexia et al. (2018), mapped six vegetation units in Lisbon, Portugal (including irrigated lawns, and non-irrigated grasslands) and estimated the value of multiple ES including: carbon sequestration, seed dispersal, erosion prevention, water purification, air purification and habitat quality. Mexia and colleagues found that lawns provide seed dispersal potential services, better than other types of vegetation, as evidenced by the abundance of birds on lawns. Nutrient retention of lawns is also high – in fact, nutrient loss in lawns is close to zero. Although small city parks and urban forests are often too small to sustain a varied flora and fauna in themselves, through the migration of organisms from larger core areas outside the city, the diversity in urban ecosystems can still be maintained.

2.2.4 Tourism, recreation, cultural and symbolic

Although we cannot confirm how much tourism benefits IOSs provide, findings from the Canberra Destination Playgrounds Study (Hope et al., 2018) strongly supports the point that there are recreational, cultural, and symbolic benefits associated with public parks and IOSs. People visit parks and open spaces because they enjoy the natural environment setting, they spend time interacting with family and friends, they use the public facilities such as picnic areas and playgrounds, and they get a chance to relax and recharge (Hope et al., 2018).

2.2.5 Climate regulation/amelioration (cooling)

A review of the international literature suggests that close proximity to lawn-covered surfaces can provide a cooling effect, which could then reduce energy use in homes and therefore reduce demand on electricity infrastructure and subsequently reducing infrastructure supply (Energeia, 2019), COAG Energy Council (2018). Yaghoobian et al. (2009) studied the cooling benefits of grass relative to other ground surface materials such as concrete, timber, and asphalt. They found that grass offers cooling benefits during a typical summer day in coastal Southern California, where parts of it share a similar climate to the ACT. Overall, the highest temperature of all urban surfaces in the experiment was the roof at 50.6˚C. The maximum temperature for grass was 31.3˚C. Over the course of 24 hours, the maximum ground temperature increases relative to grass by 21.28˚C for asphalt and 16.2 ˚C for concrete. The temperature reduction function of ground surfaces mainly comes from two aspects: water content evaporation and reduction in net radiative heat flux between ground and building walls. Grass transfers the least longwave radiative flux to buildings, as compared to concrete and asphalt. Thus, the reduction of heat transfer from ground reflection as well as the reduction of domestic cooling energy consumption increases in the same order.

Wang et al. (2016) measured the heat reduction function by introducing parameters of lawn coverage ratio (fv) and normalized tree crown radius (rt). They report that a ground area with 60% coverage of lawn could be around 1 ˚C cooler during the hottest part of a day than bare ground, and a mixed ground with 0.06 rt and 60% coverage of lawn could reduce the heat by nearly 8 ˚C during the same time period. For the hottest time during a day after normalization by month, the temperature was 46˚C for bare ground, around 45˚C for ground with 60% of lawn coverage and 38˚C for the mixed tree and lawn landscape. Ground with 60% of lawn coverage, could save on average, 10kWh per square meter of building floor area per month, while properties with the maximum rt of 0.1 could save nearly 40 kWh per square metre monthly during summer. Maximum savings were US\$1.82/m^2 (US\$12.83 kW/h) with 100% lawn coverage, and \$5.50/m^2 with maximum tree crown size (rt = 0.1). Note that study by Wang et al. (2016) is based on Arizona, which is a desert state, unlike the ACT.

In the ACT, Meyers et al. (2017) mapped spatial patterns of urban heat by developing maps of land surface temperatures from satellite imagery for summer 2016–17 and winter 2017. Myers and colleagues reported that unirrigated grass and pasture has a mean land surface temperature over 38 °C, almost 5 °C hotter than irrigated golf courses, which benefit from cooling through evaporation and evapotranspiration.

2.2.6 Rainfall run-off/drainage

According to The Lawn Institute (2018), a dense healthy lawn absorbs rainfall six times more effectively than a wheat field and four times better than a hay field. The exact volume of runoff reduced by lawn infiltration depends on various indicators such as soil fraction, slope, soil depth, grass root systems and so on. Many researchers report the relative percentage of runoff reduction in specific case studies. Research in Beijing by Zhang et al. (2012) revealed that the reduction of stormwater runoff depends on the soil infiltration rate and rainwater runoff coefficient, which are highly variable across cities. Their estimated total volume of rainwater runoff reduced by Beijing's urban green spaces was to be 154 m^3 and the amount of reduced runoff per ha green space was 2494 m^3. To our knowledge the avoided runoff benefits of IOSs in Australia have not been documented.

2.2.7 Carbon sequestration

Although lawns may have positive effects on the environment, e.g. through carbon sequestration in soil (Qian et al, 2010), the total effect on the environment may be offset by the frequent use of mowers powered by fossil fuels. This is particularly relevant to IOSs, as irrigated lawns grow faster and require more frequent mowing and maintenance than natural grassland. An example from the USA supports the argument above. For the purposes of this pilot study, it was assumed that government operations would be carbon neutral by 2020.

Townsend-Small & Czimczik (2010) measured organic carbon sequestration rates and emission of N_2O in Southern California, USA, and estimated CO_2 emissions generated by fuel combustion, fertilizer production, and irrigation. They concluded that "irrigation and fertilisation enhance CO_2 sequestration in managed turfgrass ecosystems but can also increase emissions of CO_2 and other greenhouse gases.

Turf emits significant quantities of N_2O (0.1–0.3 g N m^2 per year) associated with frequent fertilization. In ornamental lawns this is offset by organic carbon sequestration (140 g C per m^2 per year), while in athletic fields, there is no organic carbon sequestration because of frequent surface restoration. Large indirect emissions of CO_2 associated with turfgrass management make it clear that OC sequestration by turfgrass cannot mitigate GHG emissions in cities".

2.2.8 Negative externalities

We found two main types of negative externalities (or ecosystem disservice) of turf areas; biodiversity impact and human impact. Lawns have been found to cause problems with invasive species in the USA and New Zealand because most lawn grasses originate from Europe (Ignatieva et al., 2015). Getting rid of an established invasive species usually result in significant economic costs. As for human impacts, a review of the literature suggests that living in close proximity to sports oval could present nearby residents with negative externalities, including traffic congestion, and excessive noise pollution (Bolitzer & Netusil, 2000). However, the study did not go into estimating the economic costs.

2.3 Summary

From our synthesis of the exiting published literature, we are able to conclude that:

- There are substantially more studies published on the ES benefits of urban trees than IOSs.
- Many studies evaluated the ES benefits of urban 'green space' without making a distinction between trees and lawn/turf, making it difficult to separate the ES benefits for each of these two assets.
- Many studies claim that IOSs such as turf, lawn, and golf course have ES, but do not go further to elaborate on how those ES are measured.
- Without a robust measurement of ES, such as, how many cubic metres per ha lawns can prevent stormwater run-off, it is impossible to monetise those benefits.
- To our knowledge, there has not been a study that estimated the ES of IOSs or trees in the ACT, using values that are specific to the ACT. Some studies estimate the value of ES for other Australian cities.
- One study (Brack, 2002) estimated the ES of trees in the ACT, however, the monetary benefits of ES (e.g. the value of carbon for every unit of carbon sequestered by trees in the ACT) are based on values from other countries.

3 Methods and data collection

A synthesis of the literature reviewed allowed us to construct a framework for evaluating ES values for public trees and IOSs, as well as the costs associated with establishing, maintaining and removing these assets, as shown in Figure 3-1 and Figure 3-2.

3.1 Methods

We first discuss the System of Environmental-Economic Accounting (SEEA) framework that is the main framework guiding the analysis in this report. Subsequently, we present the economic framework and methods that are used to place monetary values on ES of environmental goods and services. The first is a framework called the non-market valuation framework. It is often used to help decide which method is most suitable for valuing different types of ES. The second, is a method called benefit transfer, which is used for transferring economic value from one site to another.

3.1.1 System of Environmental-Economic Accounting (SEEA)

Standard approaches to measuring economic growth through market activities, such as gross domestic product (GDP), fail to capture the vital and multi-directional relationship between the economy and the environment. The System of Environmental-Economic Accounting (SEEA) is a statistical framework for organising biophysical data, and measuring the corresponding ES in a way that is compatible with the System of National Accounts. The SEEA establishes baseline values and tracks changes in ecosystem assets (through changes in ecosystem stocks and flows), and links all this information to economic and other human activity (OECD, 2013). The SEEA framework uses concepts, definitions and classifications consistent with the System of National Accounts (SNA), which is the internationally agreed standard set of recommendations on how to compile measures of economic activity (United Nations Statistics Division, 2009). The SEEA framework was adopted by the UN Statistical Commission in 2012 as the first international standard for environmental economic accounting (Brouwer et al., 2013).

The SEEA framework considers a natural asset to have two types of values: 1) the value of the *stock* of the asset, and 2) the value of the *flow* of ES the asset provides. The stock is measured by assessing the asset's extent and condition, and the flow captures the ES that the asset provides yearly, such as pollution removal.

The SEEA framework allows estimation of the economic benefits and costs obtained from natural resources in the form of ES. By valuing ES in monetary terms, it is possible to better recognize their important contribution to human well-being and economic growth. Such valuation could also inform stakeholder' decisions on how to manage the living infrastructure in a way that improves environmental conditions and enhances community benefits (DoEE, 2018).

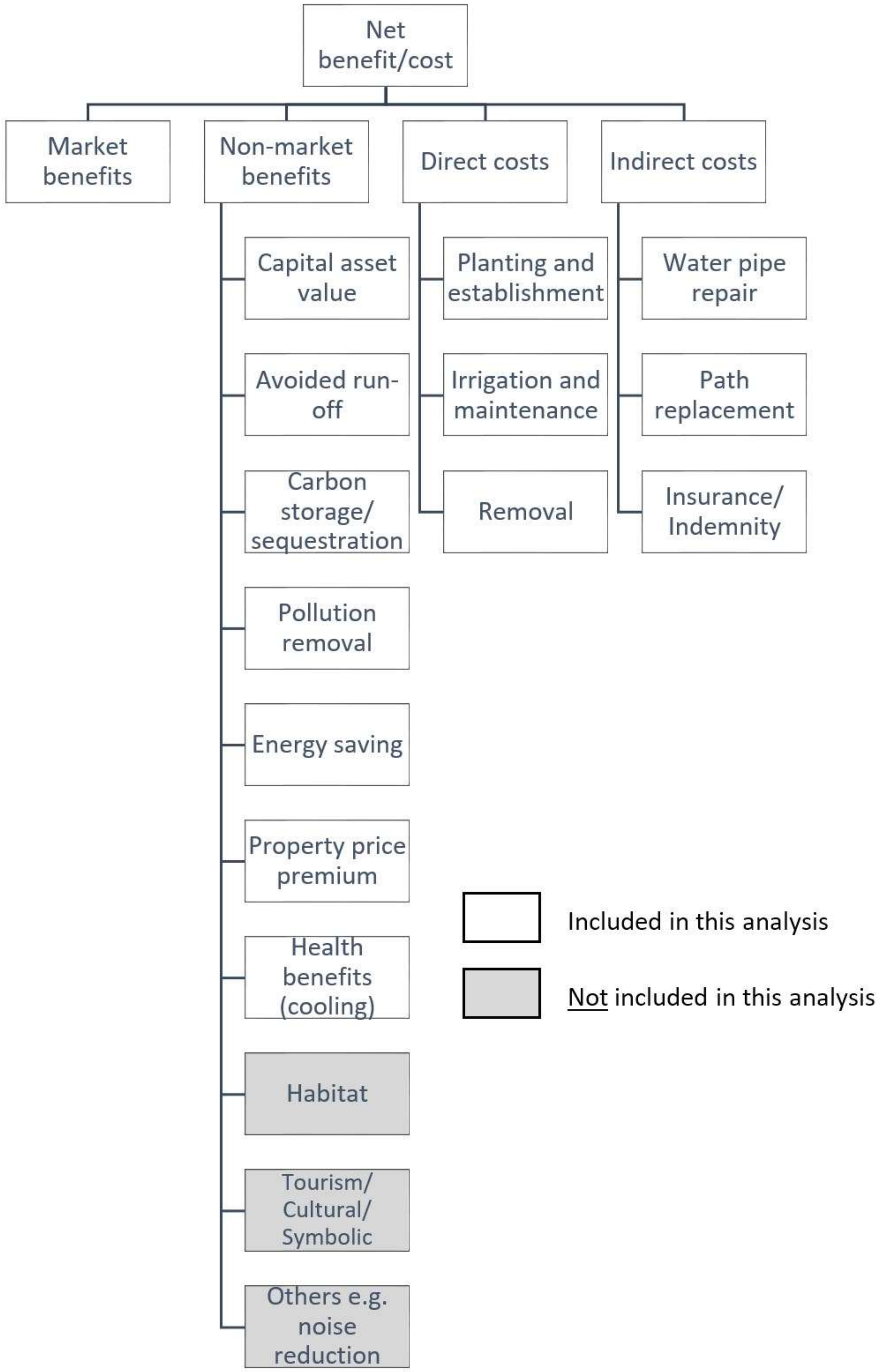

Figure 3-1 Benefit and cost items of publicly managed trees

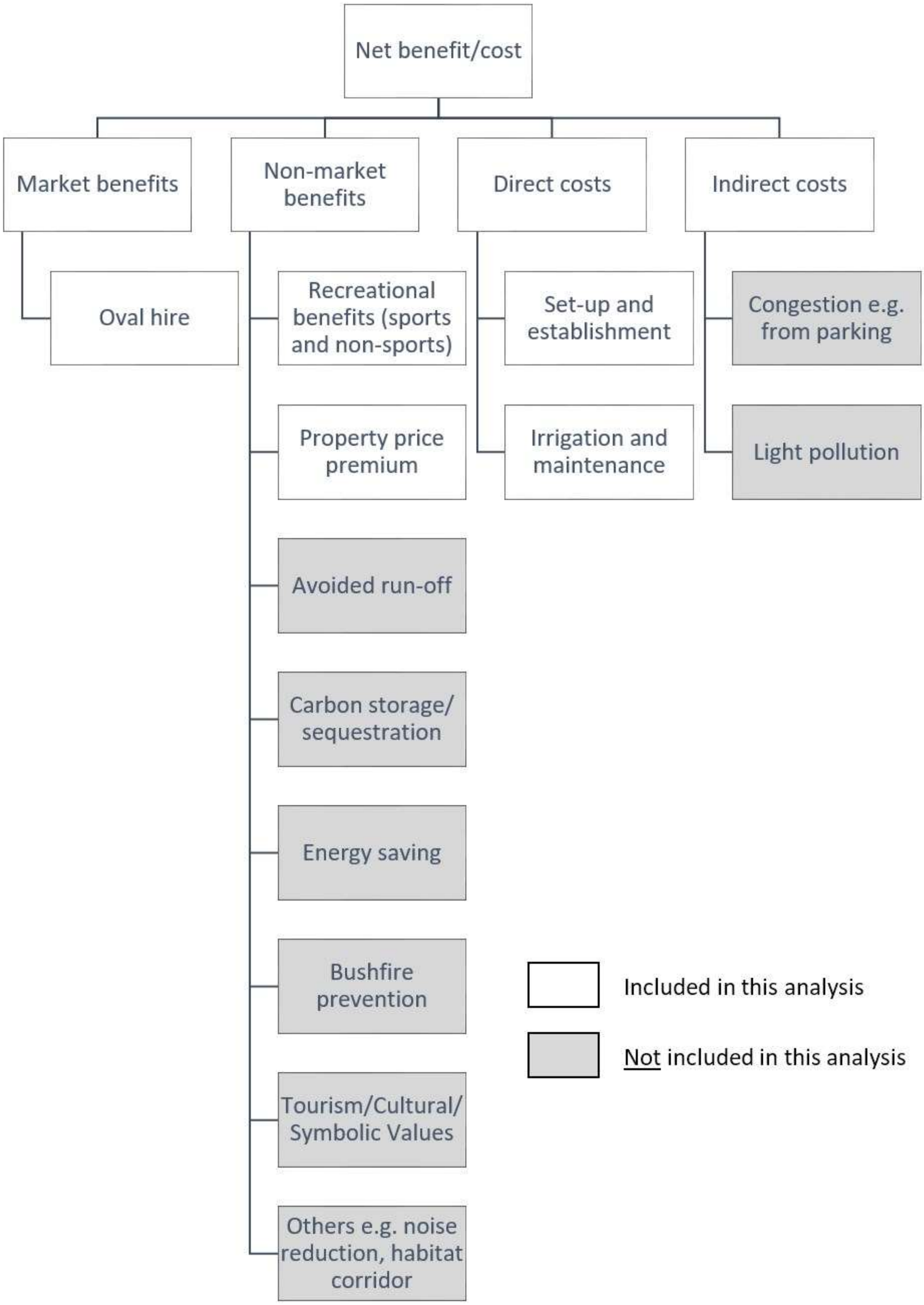

Figure 3-2 Benefit and cost items of publicly managed irrigated open spaces

The frameworks presented in Figure 3-1 and Figure 3-2 guide the data collection process for estimating the ES benefits of public trees and IOSs. The grey boxes are values that are not estimated due to the lack of data specific to Australia. However, the methods and the data required for estimating these values will be discussed.

3.1.2 Non-market valuation framework

Estimating the monetary value of the ES of environmental goods, such as trees and IOSs, is not a straightforward task because ES do not often have market value, unlike cars, homes, and groceries that have a price, and thus, a market value. However, there are well-established methods in economics to help evaluate the monetary values of these non-market environmental goods. We applied non-market valuation methods, to monetise the ES benefits of trees and IOSs (Figure 3-3). Non-market valuation techniques are broadly classified into two categories, namely revealed preference and stated preference. Revealed preference infers the value of the ES of an environmental good from observing people's behaviour in a simulated or proxy market. For example, the value of a national park should be at least equivalent to the amount of money someone spends to get there. Stated preference methods elicit ES values directly from people by using survey techniques, such as willingness-to-pay (WTP) surveys.

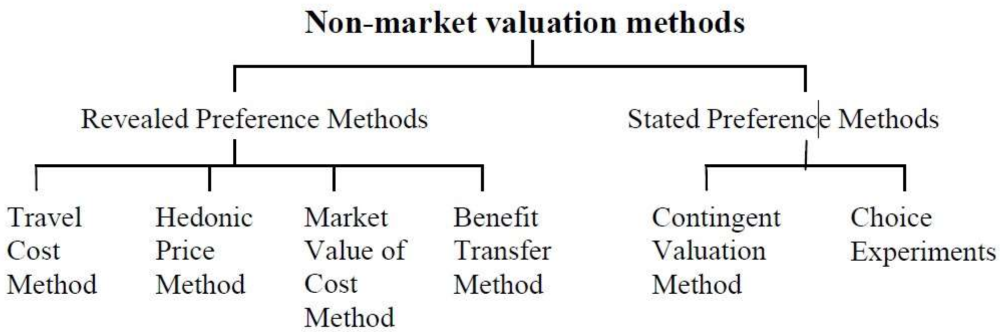

Figure 3-3 Non-market valuation framework

The following section describes in more details which valuation methods are being used to estimate ES values given the existing information that is available for Canberra and Australia. When there is insufficient information to estimate the ES of urban public trees and IOSs for the ACT, the benefit transfer method is applied.

3.1.3 Benefit transfer method

The benefit transfer (BT) method allows the valuation of ES for a region by relying on valuation of a similar good or service generated in a different region (Asafu-Adjaye, 2000). To estimate the value of ES, this method could be used to transfer mean value estimates from one or more regions to the study area, or to adapt a model developed for a different region(s) with the information and parameters that are specific to the location of interest (Bateman et al., 2002). Asafu-Adjaye (2000) argued that the BT method is useful when there are time and budget constraints that prevent original studies from being conducted.

3.2 Estimating non-market benefits of ecosystem services

This analysis relies on a combination of revealed preferences and benefit transfer methods to estimate the ES value of public trees and IOSs. This approach will be used to estimate other benefits provided by public forests not covered by the i-Tree model (e.g. aesthetic values, property price impacts). The following sections describe in more detail the methods, assumptions and parameter values used.

3.2.1 Property price premium of public trees

A hedonic property price study by Pandit et al. (2013) in Perth, Western Australia, estimated that verge trees add around 4% premium to property sales price. Using this information, we can approximate the monetary benefit of public trees that are on street verges in front of homes. Each year, the ACT Government collects rates from homeowners as a source of revenue. In the ACT, rates are calculated based on property type (residential, commercial, or rural) and the unimproved value (UV) of the land (ACT Revenue Office, 2017a). The UV of land is "the value of a block of land before any improvements are made to it - before any buildings, fences, driveways or anything else is added to it." (Mo'r Mortgage Option, 2017). The UVs are determined by qualified, independent valuers (ACT Revenue Office, 2017b). The method for estimating UVs are based on an analysis of individual property sales information from the most recently sold properties from each suburb in the ACT, excluding the sales of units and townhouses (Mo'r Mortgage Option, 2017). The approach assumes that there is a correlation between property sales price and its UV.

Given this information, we assume that a portion of the revenue collected from rates can be attributed to a premium generated by trees, at a rate of approximately 4% of property value (i.e. in this case the unimproved land value). Therefore, we specify the property price premium of trees as:

$$\begin{aligned} &Property\ price\ premium_k\ (\$) \\ &\quad = Average\ unimproved\ value_k(\$/sqm) \times Average\ land\ size_k(sqm) \\ &\quad \times Premium\ from\ trees\ (4\%\ of\ sales\ price) \\ &\quad \times Historical\ rate\ of\ increase\ of\ detached\ homes\ for\ ACT \times \\ &\quad No.\ of\ detached\ homes_k \end{aligned}$$

where k is a vector of suburbs of Canberra. The total premium of trees is the property price premium sum across all ks. We assumed that the number of detached homes increases every year, at a rate that is based on the average number of approved detached homes in Canberra during the period of 2000-2018 (Australian Bureau of Statistics, 2018).

Note that we only use the number of detached homes to estimate property price premium of trees, hence, we expect this to be a lower-bound estimation of the property price premium for all trees in Canberra. We also assumed in this calculation that there is one tree on the verge of each detached home.

3.2.2 Avoided cost of heat-related morbidity from planting more trees

Assuming an evenly spread population distribution, population density in the ACT is estimated at 5.19 persons per ha (based on a current population of 419,192 and an area of 80,760 ha). Data from the ABS 2016 Census of Population and Housing reveals that around 19% of the population at this time is considered vulnerable (around 79,646), and are potentially more susceptible to temperature changes. In this analysis, we used two main factors to determine vulnerability – age and income. Age groups that are considered vulnerable are children who are younger than 5 years old, and adults who are older than 65 years of age[3]. In Australia, there is a strong correlation between income and age. As such, those who are in the older age bracket also tend to have the lowest income. Given the fact that we did not have the spatial distribution of vulnerable population per hectare for this analysis, we assumed an even spatial spread of vulnerable population across the ACT. We approximated that there is one vulnerable person per hectare. We then assumed that out of the total vulnerable population in the ACT, 7.2% (based on estimates by Hondula & Barnett (2014) for the Brisbane heat-related morbidity study), will need to go to the ED due to heat-related health illness on a hot day (a day above 35 °C). Currently, Canberra experiences less than 10 hot days per year (Office of Environment and Heritage, 2014). In this analysis a climate change impact of an additional five hot days per year was considered[4]. The expected number of hot days per year is included in the analysis as a stochastic variable where the expected number of hot days could be between 2 to 14 days per year.

Given this information, and using information on the average number of ED presentations per day (Australian Institute of Health and Welfare, 2011:2017) and the average cost per ED presentation (Independent Hospital Pricing Authority, 2018) in the ACT, we can estimate the avoided cost of heatrelated morbidity from trees using the following specification:

$$\begin{aligned}
&\mathit{Avoided\ cost\ of\ heat\ related\ morbidity}\ (\$) \\
&\qquad = \mathit{Average\ no\ of\ ED\ presentations\ in\ CBR}\ (\mathit{person/day}) \\
&\qquad \times \mathit{Average\ cost\ per\ ED\ presentation}\ (\$/\mathit{person}) \\
&\qquad \times \mathit{Expected\ number\ of\ hot\ days\ per\ year} \\
&\qquad \times 7.2\%\ \mathit{increase\ in\ ED\ presentations\ from\ heatwaves} \\
&\qquad \times \mathit{Vulnerable\ population}\ (\mathit{person/ha}) \times \mathit{change\ in\ tree\ cover}(\mathit{ha})
\end{aligned}$$

3.2.3 Property price premium of public irrigated open space

To estimate the property price premium of houses that are in close proximity to IOSs, we used estimates from a study by Hatton MacDonald et al. (2010) that was implemented in Adelaide. The reported estimates suggested that moving 1 metre closer to IOSs will increase sales price, on average, by 0.11%. This study also estimated the average distances for these premiums as 0.7km, and 1.8km, for sports ovals and non-sports ovals (e.g. playgrounds) respectively.

[3] "As climate change progresses heat exposure stands to cause additional heat-related illness and death, especially for the most vulnerable groups such as older people, young children, people with chronic disease and those living in built-up areas in cities." (Loughnan, 2013)

[4] Canberra is projected have an additional 1-5 hot days in the near future expanding to over 10–20 more hot days by 2070 (Office of Environment and Heritage, 2014).

The same set of assumptions used to estimate the property price premium of trees, where a portion of revenue collected from rates can be attributed to premium generated by proximity to IOSs, is used to estimate property price premium of public IOSs.

We applied a uniform property price premium method applied by Polyakov et al. (2017) to estimate the aggregated property price premium of being in close proximity to these three types of IOSs in the ACT using the following specification:

$$
\begin{aligned}
&Property\ price\ premium_{ks}\ (\$) \\
&\qquad = Average\ unimproved\ value_{k}(\$/sqm) \\
&\qquad \times Average\ land\ size_{k}(sqm)P \\
&\qquad \times Premium\ from\ proximity\ to\ irrigated\ open\ space_{s}\ (\%\ of\ sales\ price) \\
&\qquad \times Historical\ rate\ of\ increase\ of\ detached\ homesfor\ ACT \times No.\ of\ detached\ homes_{ds}
\end{aligned}
$$

where k is suburbs of Canberra, s is an IOS of interest, and d is the average premium distance for each type of IOS s. The total premium of trees is the property price premium sum across all ks, for each type of s.

In a situation where a property is in close proximity to both types of IOSs, the property price premium will be the sum of both premiums. This is also the case for properties that have a tree in front of the property. In other words, if the property has a tree in front, and is in close proximity to one or both types of IOSs, we assumed that the property will accrue all three types of values in its premium.

3.2.4 Recreation benefits of public irrigated open spaces

The recreational benefits of public parks have been extensively estimated using methods such as travel cost (Shaw, 1988). The economic value of a park is assumed to be based on the amount of time someone spends to travel to and stay at the park. Since most people's time has value and that value can be monetised based on their income, the value of a park could also be monetised based on how much time people spend to travel and stay there as a proxy. Given this assumption, the recreation benefits of IOSs is specified as:

$$
\begin{aligned}
&Recreational\ benefits\ _{j}(\$) \\
&\qquad = \%\ of\ CBR\ people\ who\ visit\ IOS_{j} \times Frequency\ of\ visit\ (visits/person/year) \\
&\qquad \times CBR\ working\ age\ population \times (1 - CBR\ unemployment\ rate) \\
&\qquad \times Average\ hours\ spent\ at\ IOS_{j}/person \times Cost\ of\ recreational\ time\ \$/hr/person
\end{aligned}
$$

where IOS_j is IOS type j (football/soccer and playgrounds), and the

$$
\begin{aligned}
&Cost\ of\ recreational\ time\ (\$/hr/per) \\
&\qquad = f\{Average\ income, Value\ of\ recreational\ time\ (\%\ of\ income)\}
\end{aligned}
$$

The value of recreational time is estimated to be around 30% of a person's gross income (see e.g. Englin & Shonkwiler, 1995; Lockwood & Tracy, 1995). Average income levels in the ACT, along with working-age population, and unemployment rate are extracted from the 2016 Census of Population and Housing (ABS, 2017b).

We focused on estimating the benefit of two types of IOSs in this analysis, namely, public green space around playgrounds, and football/soccer ovals, as they were the only two types of IOS where there was information specific to the ACT.

A survey by Hope et al. (2018) which was commissioned by the City Renewal Authority, ACT Government, concluded that out of the 1,370 respondents surveyed, all have visited a Canberra playground at least once in the past year, but only 4% said the reason for visiting the playground was for the use of open space/green space. From the same survey, it was estimated that on average Canberra residents spend 1.3 hours at playgrounds, and around 55% visit playgrounds weekly. However, not all the time spent would be attributed to green space, hence we conservatively assumed that only 4% of the time spent is attributed to greenspace (same percentage as a reason for visit). Given these assumptions, we estimated the value of recreational time spent on green space at playgrounds to be $38 per person per year.

With regards to football/soccer ovals, a survey conducted by AusPlay (2016) concluded that 7.4% of Canberra residents play football/soccer, and spend around 161 hours/person/year playing sports. This works out to be approximately 3 hours per person per week. Given these figures, we estimated the value of recreational time for football/soccer to be $7.5 per person per month. This figure is relatively low compared to CommBank (2018) figures, which reported that "Australians spend $712 million a month on health and fitness products, equating to a $38 monthly spend for the average Australian".

3.3 i-Tree valuation of ecosystem services of urban forest

The monetary benefits of public urban forests in the ACT were assessed through the peer-reviewed i-Tree Eco model (USDA Forest Service, 2018). The i-Tree eco model estimates the value of the 'stock' and the 'flow' of ES benefits that trees provide. The value of the 'stock' of a tree is approximately equal to the cost of replacing that tree if it were to be destroyed, for example in a bushfire, with a similar tree of the same age, species, and condition i.e. like-for-like replacement. The value of the flow of ES of a tree is derived from the benefits that trees provide from avoided stormwater runoff, carbon storage, air pollution reduction and energy consumption impact due to tree shading.

i-Tree Eco has been customised for Australian cities (e.g. population, pollution, energy costs) and Australia 202020 Vision have chosen this tool as Australia's standard measure tool for tree canopy cover. There are some limitations to this tool including some services not being valued, e.g. property price premiums and heat related morbidity. Despite such limitations, i-Tree Eco is an international benchmark model for the valuation of urban forests' ecosystem services. This model has been developed through decades of research on urban forests' ecosystem services stocks and flows and the value of such services to city dwellers. Results from i-Tree Eco facilitate comparison of benefits from urban forests with respect to studies in other cities around the world.

3.3.1 Replacement cost of trees

The replacement cost of a standing tree at a particular point in time (without considering the value of its future ES) is a function of its age, species, health condition, and location. As trees grow, such cost is expected to increase up to a certain age and then decrease as trees approach the end of their useful life. Changes in the value of trees cannot be estimated in the same way as the depreciation of a built asset, such as a water treatment plant. However, the change in the value of trees (and urban forests) need to be approximated to inform long-term management decisions (Hollis, 2009).

Tree replacement cost in this analysis is based on four tree-specific parameters: trunk area (cross-sectional area at DBH), species, condition, and location (Nowak et al., 2008). Those parameters are used in i-Tree to estimate the replacement cost of the urban forest following the approach of the U.S. Council of Tree and Landscape Appraisers (Nowak et al., 2008). Trunk area and species are used to estimate an initial replacement cost estimate. Such cost is then adjusted according to the condition (% crown dieback) and location within urban land uses (e.g. residential, industrial, parks) of each tree to determine a final cost. Our analysis relies on Australian tree species information but average replacement costs, transplantable size and replacement prices are the default i-Tree values collected from the International Society of Arboriculture publications.

3.3.2 Avoided stormwater runoff

Stormwater runoff in urban areas is a major source of water pollution. Trees protect water quality by substantially reducing runoff during small rainfall events, which are responsible for most pollutant wash-off. Trees also reduce the onset of peak flows. However, the overall benefits of reducing catastrophic flooding are minimal (urban trees may only delay flooding by minutes while their biomass gets saturated) (Mcpherson et al., 2000).

In i-Tree, the annual avoided stormwater runoff attributable to trees is calculated by comparing hourly precipitation (ACT rainfall observed in 2010, the only year that also included the pollution data needed for the valuation of other ES) and total annual surface runoff volume with and without trees (Mcpherson et al., 2000). For this analysis, we obtained avoided runoff costs from proposed projects to build stormwater wetlands or retention ponds in the ACT (Environment Division, Environment Planning and Sustainable Development, 2018). Hence, we can use the market value of a proposed alternative to infer the value of avoided stormwater runoff benefits of trees. The value of avoided stormwater runoff in this analysis is approximated by the average treatment cost per m^3 of stormwater in the ACT (see Table 3-1). The average benefit of avoided runoff is \$1.25/m^3 for the ACT. As a reference, the benefit of avoided runoff is estimated to be \$2.26/m^3 in the U.S.

Table 3-1 Levelised cost ($/kL) of stormwater infrastructure

Item	Wetland Design I	Wetland Design II	Bio retention Design I	Bio retention Design I	Pond Design I	Pond Design II
Area (m^2)	5,640	8,730	5,270	2,315	3,200	4,666
Capital cost ($)	3,085,562	4,287,054	2,378,251	2,737,784	2,965,323	2,987,606
Design cost ($)	308,556	428,705	237,825	273,778	296,532	298,760
O&M ($/yr)	180,000	210,000	230,000	170,000	80,000	150,000
Life span (yr)	50	50	50	50	50	50
Treatment vol (ML/yr)	694	567	543	163	208	311
NPV (capital + design + O&M, $)	5,878,252	7,613,916	5,790,247	5,357,689	4,365,915	5,356,478
NPV of water (ML)	9,577	7,825	7,499	2,242	2,866	4,292
Levelised cost ($/$m^3$)	0.61	0.97	0.77	2.39	1.52	1.25
Source: Environment Division, Environment Planning and Sustainable Development, ACT Government, 2018						

3.3.3 Carbon storage

The amount of carbon stored in above and below ground tree biomass was estimated using carbon yield formulas that account for tree health and growth conditions and species type. Based on recommendations of the ACT's Climate Change Council the value of the carbon stored in standing urban forests is approximated by the social cost of carbon ($SCCO_2$) emissions. The $SCCO_2$ is a monetary estimate of the climate change impact to multiple economic sectors (e.g. agriculture, real estate, energy consumption) due to additional carbon emissions. The $SCCO_2$ used in this analysis is $65 per tonne of CO_2 (Revesz et al., 2017), which is the figure endorsed by the ACT Government's independent panel of experts, the Climate Council.

For the purposes of this pilot study, it was assumed that government operations would be carbon neutral by 2020 and that there is no value from urban forest carbon sequestration benefits beyond 2045 given the ACT Government's target of net zero emissions set to be achieved by 2045. It was also assumed that the carbon sequestration potential of public trees used in this study only considered carbon sequestration that could help the ACT Government achieve its ACT Government net zero emissions 2045 target and assumes there is no value from urban forest carbon sequestration benefits beyond 2045.

3.3.4 Pollution removal

Pollution and weather data for the year 2010 (the most recent dataset available in the i-Tree database for the ACT) was used to estimate the removal of ozone, nitrogen dioxide, particulate matter less than 2.5 microns (PM2.5), sulphur dioxide and carbon monoxide. The pollution data is suitable for this analysis based on comparison with current pollution levels supplied by the Health Protection Service of the ACT Health Directorate. i-Tree relies on leaf area index and multi-layer canopy deposition models to estimate the flow of this service.

The value of pollution removal is $22 per metric tonne for carbon monoxide, $4,300 per metric tonne of ozone, $641 per metric tonne of nitrogen dioxide, $234 per metric tonne of sulphur dioxide, and $149,365 per metric tonne of (PM2.5). These values are based on international estimates of the health impacts of urban pollution adjusted by the 2018 urban population in the ACT estimated at 419,192 people.

3.3.5 Building energy savings and avoided energy emissions

Trees reduce energy consumption during the summer and the effect during winter months depends on the location of trees around buildings. Estimates of the seasonal effect of trees on building energy use in I-Tree are based on the distance and direction from each tree to the nearest building within a 20 m radius. Energy effects are estimated using United States models for a region with similar climate, building types and landscape geography as the ACT. The net value of energy savings is based on a price of $2.98 per therm for heating, 2.831 cents per MJ cost of the second tier of residential gas use from ActewAGL for the period 2017-2018 (ActewAGL, 2017), and $0.25 per kWh of average residential electricity use (ICRC, 2018).

By reducing energy consumption trees contribute to emission reductions from the energy sector. The emissions generated by fossil-fuel based power plants for the estimated energy savings are multiplied by the $SCCO_2$ to estimate the value of this service. For the scenario assessment, the value of avoided emissions gradually moves towards zero to approximate the impact of carbon-neutral energy policy in the ACT.

3.4 Benefit-cost analysis

The benefit-cost analysis (BCA) evaluates alternative management scenarios for trees and IOSs where there is an increase of both of these assets. BCA is widely applied for evaluating both private and public investments because it allows ranking of multiple options with disparate timing and scale of costs and benefits with a single summary metric (Khan, 1998). The benefit-cost ratio (BCR), which is the ratio of the NPV of the total benefit over the NPV of the total cost, is used for comparing the outcomes across multiple scenarios. A BCR greater than one indicates that the benefits outweigh the costs, the greater the BCR the larger the net benefits of an investment.

Non-market benefits and costs of public trees and IOS that could be assessed through robust valuation methodologies were included in the BCA of the living infrastructure. Without such information, the BCA becomes a standard asset performance analysis. However, since these living assets can be accessible by the general public, the commercial benefits of these goods would be very low. Hence, to truly reflect the value of these two assets, we must include the non-market benefits of the ES as well.

3.4.1 Discount rate

A 3% discount rate based on recommendations by the National Academies of Sciences and the U.S. Council of Economic Advisers was used as baseline in this report. Such rate better captures the intergenerational effects of environmental decisions and natural assets than the standard 7% rate based on private capital returns (Revesz et al., 2017). A sensitivity analysis was implemented to test the impact of varying discount rates.

3.4.2 Time horizon

The time horizon for the benefit-cost analysis is from 2018 to 2125. For consistency with long-term management of public forests in the ACT, we assume tree planting until 2045 and management of the simulated tree stock during all the period of analysis. This approach allows to examine the longterm benefits and costs of planting strategies aimed at specific urban forest targets by 2045.

3.4.3 Sensitivity analysis

A discount rate recommended by the New South Wales Treasury in 2007 of 7% was also applied to the future costs and benefits, for sensitivity testing. A further 10% discount rate was also applied to examine whether the BCR results are robust to assumption changes on the discount rate.

Sensitivity analysis on other uncertain variables including the UV of land, the number of detached houses approved each year, and the value of recreational time was dealt with using a stochastic BCA model. A stochastic BCA model applies a Monte Carlo simulation across the possible ranges of all uncertain parameters and performs a systematic sensitivity analysis on the BCR. The process includes calculating the values of the BCR over 1000 random selections of values from the probability distributions, and each of the uncertain parameters is given as a range. For the parameters with a large enough number of observations, the @Risk software was used to determine their probability distribution and estimate their impact on the value of ES estimates. However, for the recreational value of time, we used a beta distribution, a continuous probability distribution function typically used for uncertain parameters as we only have data on the median and the range.

3.4.4 Levelised benefits

The annual ES benefits of trees, for current and projected tree stock, is estimated in i-Tree and incorporated into the BCA. To estimate the average ES benefit for each tree, we applied the levelised benefit method, commonly used for evaluating the benefit of water from every kilolitre of water produced. The levelised approach allows us to discount the future benefits of the tree stock, and estimate the NPV per tree for each of the ES a tree provides. The calculation of the levelised benefit follows the method applied by (Marsden Jacob Associates, 2013), where the levelised cost or benefit of an environmental good or services is expressed as follows:

$$Levelised\ benefit\ of\ trees\ (\$/tree) = \frac{NPV[ES\ benefit\ (\text{or cost})\ of\ trees]}{NPV[number\ of\ trees]}$$

3.5 Data collection

Data collected for this analysis consists of spatial data and economic data. The following sections describe the type of data collected, and the sources of where the data came from.

3.5.1 Data for cost-benefit analysis

There are two main types of data that were collected for the BCA. The first type consists of data that is collected from the desktop review of the literature and used for the estimation of monetary benefits of ES of urban public trees and IOSs. The second type consists of cost data which includes the establishment, removal, maintenance cost, and some externality costs.

Parameters for estimating ecosystem services benefits

Table 3-2 presents the parameter values used in the BCA. Some parameter values are taken directly from the source, while some are estimated based on a series of information from different sources. Note that the majority of parameter values are derived from the ACT, and a few others from other parts of Australia, in order to reduce any errors through the benefit transfer process. Only one parameter was derived from the international literature, which was the value of recreational time (i.e. value of recreational time is approximately equal to 30% of a person's income).

Direct and indirect costs of urban public trees

Given that our analysis follows the SEEA framework, the cost component consists of the cost of planting and establishment, maintenance, and the removal of public trees. Indicative whole-of-life costs for public trees is presented in

Table 3-3. The direct cost has three components: the cost of planting and establishing a new tree, the cost of removing an old tree, and the cost of maintaining the existing stock of trees. The cost of planting, establishment, and removal are one-off costs when planting or removal occurs. Maintenance cost occurs on a yearly basis.

The indirect cost component presented in

Table 3-3 accounts for the negative externalities that trees create, such as cracked pavers and pipes. There is also insurance and indemnity payments for publicly own trees. In the case of the ACT, insurance cost consists of: 1) insurance claim payments, which varies from year to year depending on the number of claims, and 2) insurance policy excess. In this analysis we use the average insurance payout cost per tree per year.

Table 3-2 Parameter values used for the BCA and their sources

Parameter value	Unit	Mean	Min	Max	Source/data correspondence
Tree stock as of 2018	trees	767,636			TCCS
% of native trees as of 2018	%	41.5			TCCS
% of exotic trees as of 2018	%	58.5			TCCS
Area of IOS managed by TCCS					
Categorised as for sport	ha	380			TCCS
Categorised as not for sport	ha	104			TCCS
Property price premium calculations					
Estimated average rate charge for detached house	$/house	2,958			ACT
Estimated number of detached houses with 1 tree in front	trees	105,518			ACT
Number of new detached houses approved	House/yr		40	277	ACT
Tree premium as (%) of rate charged	%	4			Perth
Sports oval premium (%) of rate charged	%	0.11			Adelaide
Non-sport ground premium (%) rate charged	%	0.11			Adelaide
Premium distance to sports oval	km	0.74			Adelaide
Premiums distance to non-sport ground	km	1.8			Adelaide
Recreational benefits calculations					
Percentage of people who visit playground for green space	%	4			ACT
Estimated average time spent at playground	hr/per/yr	4.84			ACT
Estimated average playground visits	trips/per/yr	96.73			ACT
The value of recreational time as (%) of income	%		29	33	International
ACT median weekly incomes people aged 15 years +	$/wk	998			ACT
ACT population	persons	419,192			ACT
ACT % of working-age population	%	68%			ACT
ACT unemployment rate	%	4%			ACT
Total area of urban playground in ACT	ha	16.93			ACT
Estimated value of time spent at playground	$/ha/yr	12,6323			ACT
Estimated time spent playing sport	hr/wk/per	3			ACT
% of ACT population who play football/soccer	%	7.4			
Estimate value of time spent on sports oval	$/ha/yr	73,363			ACT
Heat-related morbidity calculations					
Canberra emergency department (ED) presentations	person/yr	135,379			ACT
Average cost per ED presentation	$/person	839			ACT
% increase in ED presentation from 10°C increase in daily max temp	%	7.2	4.7	9.8	Brisbane
% of vulnerable population in ACT	%	19			ACT
Area of Canberra	ha	80,760			ACT
Estimated ACT population density	per/ha	5.19			ACT
Bushfire cost					ACT

Average cost of bushfire damage (2003 bushfire)	$/ha	1819			ACT
Value of statistical life	$M/person		1.4	4.2	Australia
Deaths (from 2003 bushfire)		4			ACT

Table 3-3 Breakdown of the whole-of-life cost of trees by native and exotic species

Cost item	Native (2018 $)	Exotic (2018 $)
Cost to plant and establish (one-off cost $/tree)		
• Tree purchase (native)	40	90
• Planting	130	160
• Consolidation	80	80
• Watering	180	300
• Formative pruning	75	75
Total (planting and establishment)	**505**	**705**
Cost to maintain (average annual $ per tree)		
• Maintenance	35.83	71.66
• Street sweeping cost	2.12	4.25
Total (cost of maintenance)	**37.95**	**75.91**
Cost to remove a tree (one-off cost $/tree)	**1,210**	**1,210**
Externality cost (average annual $ per tree)		
• Stormwater pipe maintenance	1.35	3.83
• Path replacement, grinding, patching	1.38	3.90
• Shopping centre precinct – pavers	0.18	0.52
• Tree claim payments	0.13	0.13
• Insurance excess payments	0.03	0.03
Total (annual spend on externality cost per tree)	**3.07**	**8.41**

Direct costs of irrigated open space

The cost component for IOSs consists of the cost of planting and establishing IOSs, and the cost of maintaining such spaces. We split the cost of IOSs into two categories based on use: 1) IOSs used for sports, and 2) IOSs not used for sport, recognising that the cost for establishing and maintaining these two types of spaces are going to be very different.

The cost of setting up a sports oval is based on the cost estimates for bringing Higgins Neighbourhood Oval back online as a sports oval. The estimated budget for this project is $1.2M. This budget includes an irrigation system and metre pit upgrades, surface levelling, turfing, goal posts, floodlight provision, line marking and establishment (pers. comm. TCCS, 2018). Given that Higgins Oval is approximately 2 ha in size, the cost for establishing a sports oval is around $600,000/ha. The average annual cost to maintain a sports oval was also provided by TCCS.

The cost of setting up an IOS not used for sport, on the other hand, is estimated based on indicative costs for Logan City Council, Queensland (2015) due to the lack of data available from the TCCS. These costs include the cost of turf supply and installation and top soil purchase.

The maintenance cost of IOS not used for sport is based on cost estimates for maintaining IOS for sport that was provided by TCCS, however, certain cost items were removed. The removed cost items are the cost of waste hoppers, cleaning southside, and management staff field/office/bookings. A summary of the cost items used in this analysis is presented in Table 3-4.

Note that land purchase cost is not included in the NPV analysis of irrigated open space expansion. The assumption is that all land designated for expansion already belongs to the ACT. There may be indirect costs, such as insurance claim payouts, or insurance excess related to the management of IOS, however, the information was not available when this analysis was conducted.

Table 3-4 Break-down of the cost of irrigated open spaces by type of use (sports and non-sports)

	Sports (2018 $)	Non-sports (2018 $)
Cost to plant and establish (one-off cost $/ha)		
Set up turf, irrigation, drainage, sports infrastructure	600,000	
Turf – supply & install		13,399*
Topsoil		80,000*
Irrigation system (incl pumps and bores)		30,000*
Total establishment	**600,000**	**123,399***
Maintenance cost (annual per ha)		
Irrigating	13,418	5,600
Mowing	9,480	189
Waste Hoppers	789	
Cleaning	718	
Fertiliser and amendments, including soil testing	925	925
Pest and disease control - materials	740	740
Aeration	1,700	1,700
Dethatching	750	750
Annual renovation-top soil/ seed/ (spring and autumn)	1,850	1,850
Irrigation repairs-materials	1,171	1,171
Repairs and maintenance – buildings and floodlights	925	
Management staff field/office/bookings	5,859	
Total maintenance (annual)	**38,325**	**12,925**
*Estimates based on Logan City Council figures (all other costs figures are provided by TCCS)		

3.5.2 Spatial data

Spatially explicit information on the current number, location, and conditions of the publicly managed forests in the ACT is not available. However, from 2000 to 2015 three major tree audits were implemented: the Decision Information System for Managing Urban Trees (DISMUT) (Brack, 2002), the 2010-12 Canopy Audit (Tree Logic Pty. Ltd, 2012), and the 2015 Canopy Audit (Brack, 2015). We combined canopy audit information and new plantings data to estimate height, Diameter at Breast Height (DBH), and species distribution of the urban forest standing in 2018.

To estimate the condition and extent of the urban forests under the existing data limitations we applied this process:

1. Identify the regions in the tree canopy percentage data provided by TCCS (Figure 3-4a) that contained tree information data from the 2010-12 tree canopy audit (Figure 3-4b). A sample set of 232,056 locations were identified.
2. Update tree age and expected useful life distribution in the sample data to account for temporal changes from 2010 to 2018.
3. DBH formulas estimated with 2015 canopy audit data were used to estimate DBH as a function of tree height. DBH formulas for the ten most prevalent tree species were applied. The overall goodness of fit (R-squared) of the DBH formulas in the calibration data (i.e. the 2015 tree canopy audit data) was around 90%.
4. Estimate the distance and direction to the three nearest buildings from the centroid of the sample tree polygon data to model energy savings effects (Figure 3-4c, d).
5. Run i-Tree with the sample data and estimate the results for the total number of trees reported by TCCS (767,636 trees in 2018).

Spatially explicit data of heat island effects (land surface temperature) in the ACT, vulnerability index, information map of bushfire prone areas, and location of playgrounds are presented in Figure 3-5.

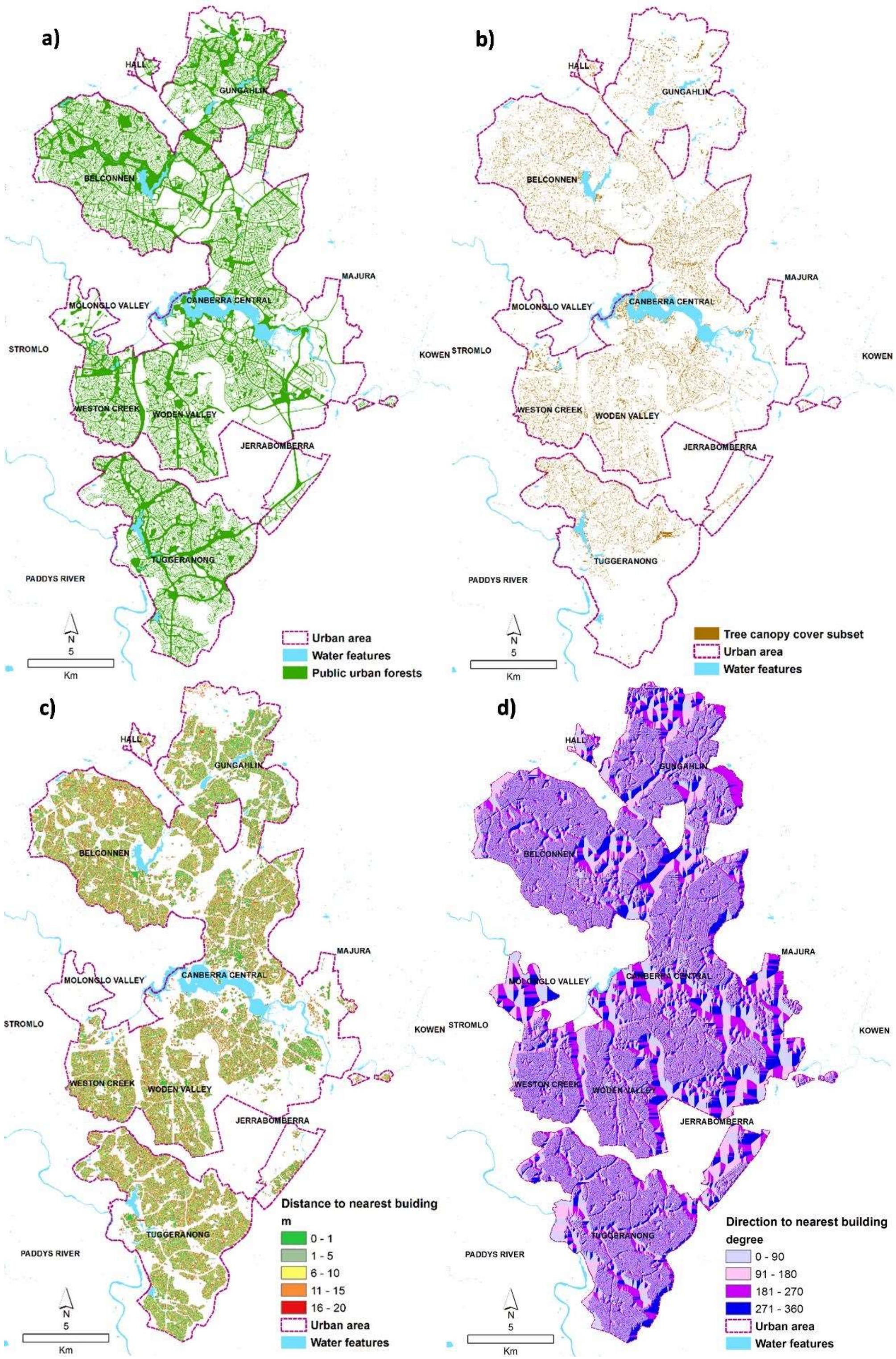

Figure 3-4 Spatial data used to inform the estimation of public urban forests benefits. a) ACT urban forest area. b) Sites with tree condition information data (sample data). c) Distance from each sample point to the nearest building (similar maps were generated for the 2nd and 3rd nearest buildings). d) Direction from each sample point to the nearest building (similar maps were generated for the 2nd and 3rd nearest buildings).

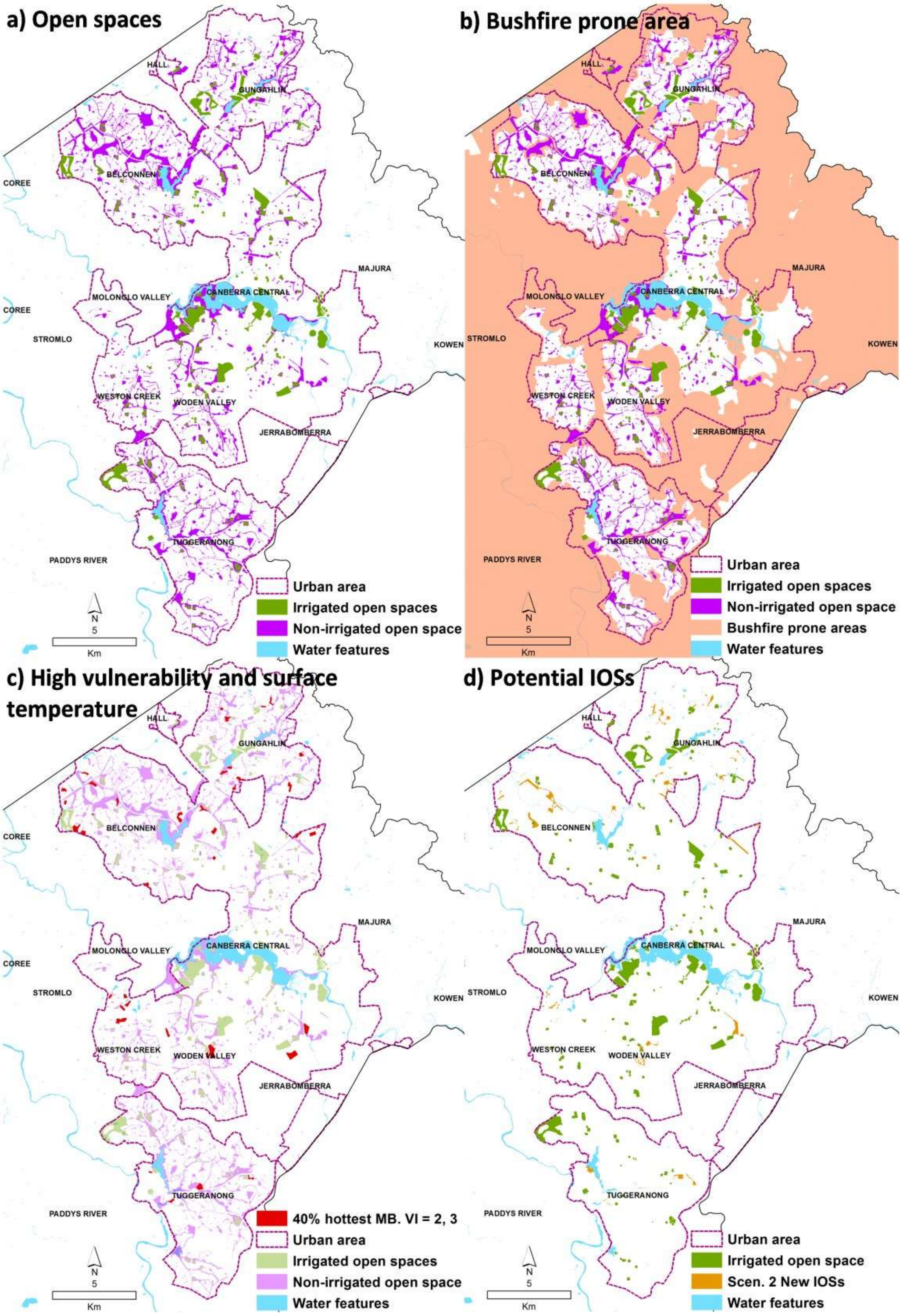

Figure 3-5 Spatial data to estimate the effects of expanding irrigated open spaces area. a) Irrigated and non-irrigated open spaces. b) Bushfire prone areas. c) Mesh blocks with the hottest 40% average summer surface temperature and with high socioeconomic and demographic vulnerability (based on Meyers et al., 2017). d) Non-irrigated open spaces within a 100 m radius of the hottest and highly vulnerable mesh blocks and bushfire prone area

3.6 Scenario analysis

The objective of scenario analysis is to examine how the whole-of-life costs and benefits change from 2018 to 2125 for urban forests, and from 2018 to 2070 for IOSs, given different management decisions affecting those assets under projected socioeconomic and climate change trend trajectories.

3.6.1 Public urban forests

For public urban forests, three scenarios of different removal and replanting strategies were assessed under projected climate change for the ACT. These scenarios include continuation of existing trends as usual, maintaining current tree numbers, and increasing tree canopy cover. We expect that under all the modelled scenarios tree plantings will aim at increasing the flow of ES, reducing management costs and externalities, and increasing tree canopy in socioeconomically vulnerable areas. However, due to uncertainties associated with technological development, climate change impacts on urban vegetation, and spatially explicit data on available space for new plantings, we use historical data and tree-growth models to estimate future costs and benefits of the reconfigured urban forest.

Scenario 1. Business as usual (BAU)

The three major tree canopy audits in the ACT implemented between 2000 and 2015 concluded that the proportion of trees at the end of their useful life expectancy (ULE) is gradually reaching critical levels (Brack, 2015). Consequently, the extent and flow of services from public forests is expected to decrease. In addition, a large number of dead trees could require increasingly frequent and expensive management.

From 2013 to 2017 around 1700 trees were removed and 1300 trees were planted annually (pers. comm. TCCS, 2018). The removal of dead trees is based on reducing risks to people and people's assets, and replanting does not necessarily occur when and where trees are removed. Such net loss of 400 trees per year is modelled from 2018 to 2045 with tree removals continuing at 1700 per year from 2045 to 2125. Under these assumptions the proportion of standing trees that have reached the end of the ULE is gradually increasing.

Scenario 2. Maintaining the current extent of the urban forests

The health of public urban forests in the ACT is declining and significant levels of tree removal and replanting are required to maintain their flow of ES (Brack, 2015). The distribution and composition of the urban forest are proactively managed to improve its resilience to climate pressures and to enhance their flow of ES. To maintain the overall condition and flow of services of the ACT's urban forest observed in 2018, trees at the end of their useful life are removed and similar numbers of trees are planted, i.e. the objective is to maintain the tree stock observed in 2018. An underlying (non-modelled) assumption is that tree species selection under this scenario aims at achieving a more efficient configuration of the urban forest and that replanting prioritises a spatially balanced distribution of the urban forest.

Scenario 3. Expanding canopy cover to 30%

The distribution and composition of the urban forest are proactively managed to gradually increase tree canopy cover from 21% to 30% of publicly managed land (excluding nature reserves).

Improvements in the extent and health of the asset increase its resilience to climate change impacts and enhance the provision of ecosystem services. Replanting and removals (based on useful life expectancy) target the development of a balanced distribution of trees age, size, and species composition.

Table 3-5 contains the parameterisation of the modelled public urban forest scenarios. For scenario analysis, we assume that all standing trees reported by TCCS only in 2018 provide some ES. This assumption is not expected to have a significant impact in the analysis unless the proportion of death trees that have not been removed is larger than 3% of the urban forest.

Table 3-5 Summary of key parameters for the modelled public urban forests scenarios

General:			
Interest rate	3%, 7% and 10%		
Climate change	Local warming of 2 °C by 2070		
Time horizon	2018-2125 (tree plantings only from 2018 to 2045)		
Scenario specific:	BAU	Maintaining the current extent	30% canopy cover by 2045
Tree replacement p.a.	1700 trees removed 1300 trees planted	Based on ULE	Based on ULE
Balanced tree distribution across suburbs	No	Yes	Yes

3.6.2 Irrigated open spaces

For IOSs, we assessed the impact of maintaining or improving the current configuration of IOSs under changing climate and demographic conditions. Table 3-6 contains the parameterisation of the IOSs scenarios described below.

Scenario 1. Business as usual (BAU)

This scenario assumes that the current distribution and extent of IOSs does not change from 2018 to 2070. Benefits are modelled based on property price premium and recreational benefits.

Scenario 2. 50% more IOS

The population of the ACT is estimated to reach 614,633 by 2045 (Chief Minister, Treasury and Economic Development Directorate, 2019). To accommodate for the increasing population, the ACT Government can choose to increase the area of IOSs to maintain the level of service (i.e. access to IOSs) to the increasing population. As such, we assess a future scenario where 50% more IOSs (approximately 240 ha) are established in 2045. The area and location of IOSs are managed to mitigate heat island effects and reduce risks of wildfire spread to enhance amenity values and to promote active recreation. However, due to limited information specific to the ACT, only the benefits of promoting more recreational activities are modelled (i.e. no surface reduction or asset deterioration are modelled).

Table 3-6 Summary of key parameters for the modelled IOSs scenarios

General:		
Interest rate	3%, 7%, and 10%	
Climate change	Local warming of 2 degrees C by 2070	
Time horizon	2018-2070	
Population growth by 2040	Around 50% more than 2018	
OIS composition	79% for sport, 21% for non-sports	
Scenario specific:	**BAU**	**More spaces**
Expansion of IOSs cover within the study area	No	50% more
Water availability	Not constrained	Not constrained

4 Results

The SEEA framework comprises the 'measurement' and 'valuation' of natural assets. The 'measurement' component involves the classification and measurement of the extent of the natural asset, and the health condition of the natural asset. The 'valuation' component involves the measurement of the flow of ES from the natural asset to its beneficiaries, and measurement of the values (or benefits) people receive from the flow of services that the natural asset provides. The first part of the results section describes the measurement of the current living infrastructure asset in the ACT. The second part discusses the flow of ES as estimated by i-Tree, and the third part presents the valuation of public urban trees and IOS, and the benefit and cost assessment following the BCA framework.

4.1 Asset extent, characteristics, and condition

4.1.1 Urban forests

TCCS estimates indicate that in 2018 the urban forest is integrated by around 767,636 trees covering around 3,535 ha. The flow of ES provided by this living asset depends significantly on the species composition and the total canopy cover of each species. Those factors were used to rank the relative importance of the ten most common tree species in the ACT. *Eucalyptus mannifera, Casuarina cunninghamiana, Eucalyptus melliodora* and *Eucalyptus polyanthemos* account for nearly 50% of the tree population and leaf area (Table 4-1 and Figure 4-1) and therefore their importance value is higher than other species in the ACT urban forest due to their numbers. However, such assessment is relative because the species composition and relative importance differ across suburbs. For instance, *Pinus radiata* is the most frequent species in the public forests of Braddon and Macarthur.

Table 4-1 Dominant tree species

Species	% Population	% Leaf Area	Importance Value
Eucalyptus mannifera	25.00	27.05	52.05
Casuarina cunninghamiana	4.55	4.55	9.09
Eucalyptus melliodora	3.48	3.86	7.35
Eucalyptus polyanthemos	4.02	2.27	6.29
Eucalyptus cinerea	2.27	3.94	6.21
Eucalyptus blakelyi	1.89	3.48	5.38
Quercus palustris	2.35	2.12	4.47
Eucalyptus sideroxylon	2.12	2.27	4.39
Eucalyptus nicholii	2.12	2.20	4.32
Fraxinus oxycarpa	2.05	1.82	3.86

Most tree species in the study area are Australian (42%) and around 18% and 14% are originally from North America and Asia, respectively (Figure 4-2). The most frequent tree species in the urban forests of the ACT are from the genus *Eucalyptus*.

Figure 4-1 Species distribution in public forests over all the study regions and for some suburbs. Labels for tree species or genus with a small percentage of the total population are omitted to improve readability of the charts

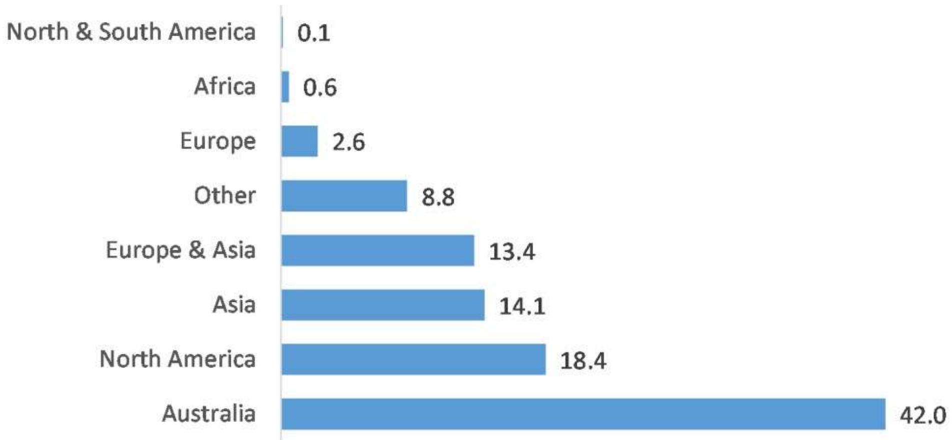

Figure 4-2 Percent tree distribution by place of origin

The proportion of publicly managed land in the ACT covered by canopy is larger in long-established suburbs where trees have reached or almost reached a mature size (Figure 4-3). Areas with low tree canopy cover correspond to new residential regions such as Gungahlin. Young trees in those areas are expected to increase their provision of ES gradually. However, total potential tree canopy cover in suburbs with higher construction density and narrower verges may be smaller than the cover in old suburbs. An issue to further investigate is the presence of areas with little canopy cover within old suburbs. Such a result may indicate that there are unused spaces for plantings, that young trees are growing in those areas or that removals are greater than replacement.

If the current urban forest was to be damaged or destroyed (e.g. in a bushfire) the cost of replacing the entire forest like-for-like with trees of the same species, age composition, and condition would be equal to its capital asset value. The ACT's urban forest is estimated to have a current capital asset value of $3.4 billion. Increasing the number, condition and life-expectancy of trees through more replanting and better maintenance is expected to increase the capital asset value of the ACT's urban forest. Table 4-2 provides the estimated current and future asset value of the ACT's urban forest under three different tree management scenarios.

Table 4-2 Change in capital asset value of trees over time for different scenarios (2018 $)

	BAU ($)	Maintain ($)	30% Canopy Cover ($)
Capital asset value (2018)	3,407,216,706	3,407,216,706	3,407,216,706
Capital asset value (2045)	3,698,574,731	4,056,626,314	4,497,278,880
Change in capital asset value (NPV over 2018-2045)	245,849,804	419,802,396	689,258,782

All three scenarios start with the same capital asset value of $3.4 billion. By 2045, which is the end of any planned replanting, the capital asset value for increasing tree canopy cover to 30% scenario increases by $689 million. This is $443 million greater than the gains under the BAU scenario and $269 million greater than the capital asset gains of the maintaining the current extent of the forest scenario. Despite net tree loss in the BAU scenario, a proportion of the forest continues to grow. This results in increases in capital asset value. Such increase reaches a maximum around 2043 and then gradually declines as a significantly large proportion of the urban forest reaches the end of their ULE.

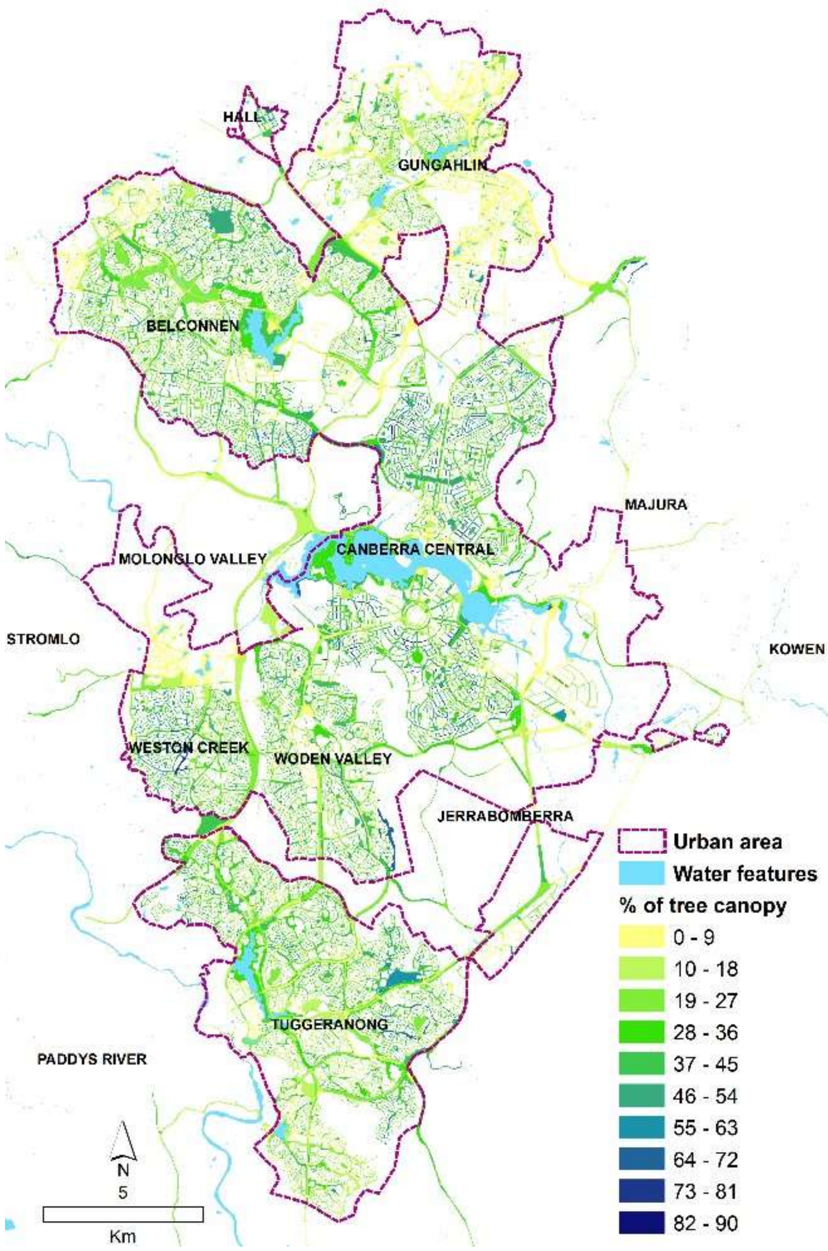

Figure 4-3 Distribution of public urban forests in the ACT.

4.1.2 Irrigated open spaces

In the study area 213 irrigated spaces covering 1,335 ha were identified (Figure 4-4). Given that there is no information available on the conditions of those IOSs, our assessment assumes that all are in fair condition and are able to deliver a sustained flow of use and non-use services. Note however, that the area of IOS managed by the TCCS is only 484 ha, which is composed of 380 ha of IOS for sporting activities, and 104 ha of IOS not designated for sports. The rest corresponds to privately managed irrigated spaces such as golf courses.

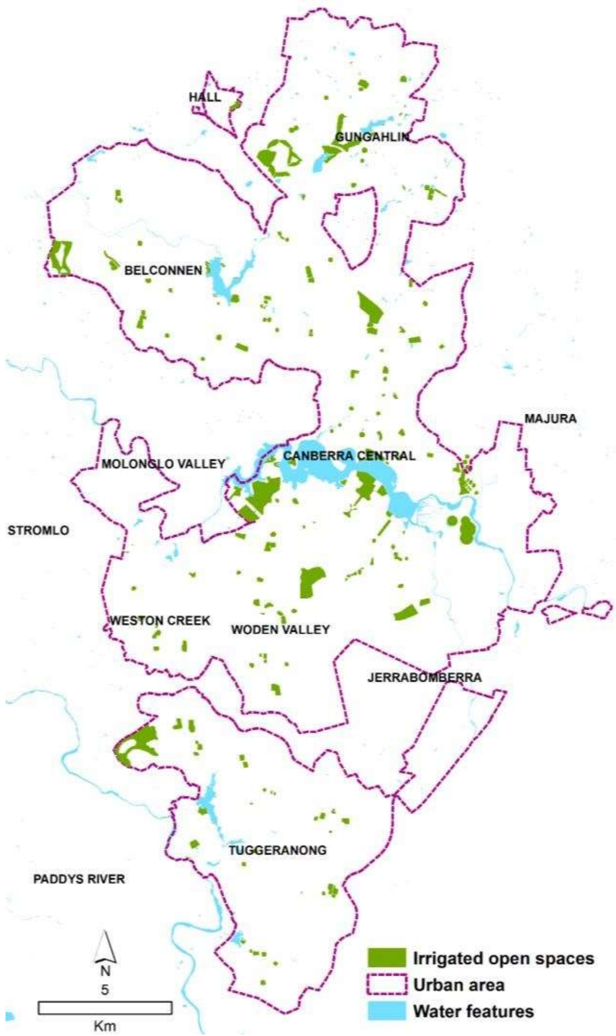

Figure 4-4 Distribution of irrigated open spaces. This map includes golf courses and turf farms that were not included in the valuation due to focus on public infrastructure.

4.2 Current flow and value of benefits from the urban forests

Around 236,355 m^3 of stormwater runoff were intercepted by urban forests in 2018 at a value of \$295,402. The benefits of removing around 154 tonnes of pollutants per year (ozone, carbon monoxide, nitrogen dioxide, particulate matter less than 2.5 microns) in that year represented savings on health expenditures in the order of \$863,382. The climate of Canberra generates a higher energy demand for heating than for cooling. Tree shade helps reduce ambient temperature and provide wind protection for buildings. The combined effect of those services was estimated to reduce energy consumption around 120,369 MWh in 2018, which represented savings in energy bills of around \$9.1 million. The avoided energy emissions (33,319 tonnes of CO_2) had a social benefit of \$514,392. This value could decrease given the transition to carbon-neutral electricity and gas in the ACT. Carbon sequestration in tree biomass (around 39,068 tonnes of CO_2) during 2018 provided a benefit of \$2.15 million. Average tree benefits are provided in Table 4-3.

The value of the carbon accumulated during the lifespan of trees standing in the ACT's urban forest in 2018 was estimated at \$56.55 million (around 1.03 million tonnes of CO_2). This represents an average of 29 Kg of CO_2 per m^2 of tree cover which is consistent with studies from 28 U.S. cities that report an average of 21 Kg of CO_2 (Nowak et al., 2013).

IOSs provide a flow of benefits to the city via higher land rates of properties that are in close proximity to sports ovals and IOSs. We estimated that around 97,000 homes are within the premium distance (740 metres) to a sports ground, and around 62,500 homes are within the premium distance (1.8 kilometre) to an IOS. There are also high recreational benefits derived from using sports ground and other IOSs. Hope et al. (2018) found that Canberra residents spend 1.3 hours at playgrounds, and around 55% visit playgrounds weekly. Meanwhile, AusPlay (2016) found that 7.4% of Canberra residents play football/soccer, and spend around 161 hours/person/year playing sports. Without IOSs, this level of recreational values could not be achieved.

Table 4-3 Estimated ecosystem services of ACT public forests in 2018.

Benefits	Biophysical flows	Total value (2018 $)	Per tree basis (2018 $)
Carbon sequestration[1]	39,068 tonnes of CO_2	2,145,011	2.79
Avoided stormwater runoff[2]	236,355 m^3	295,402	0.38
Pollution removal[3]	154 tonnes	863,382	1.12
Building energy savings[4]	120,369 MWh	9,096,938	11.85
Avoided energy emissions[5]	33,319 tonnes of CO_2	514,392	0.67
Land rate premium[6]	105,518 houses	14,191,296	18.98
Cooling effect (avoided heat-related morbidity)[7]	Assumed 3 hot days	12,644	0.01

Description of benefits and data sources

1. The annual CO2 sequestered in tree biomass was valued using the social cost of carbon estimate recommended by the ACT's Climate Change Council.
2. Stormwater intercepted in tree biomass valued using the average cost per m3 of water treatment in the ACT (pers.comm. ACT Environment, Planning and Sustainable Development Directorate, 2018).
3. Ozone, carbon monoxide, nitrogen dioxide, particulate matter less than 2.5 microns removed by trees estimated using ACT pollution and climate data for 2010 (latest dataset available in i-Tree). These values are based on international estimates of the health impacts of urban pollution adjusted by the 2018 urban population in the ACT (ABS, 2017).
4. Building energy savings from micro-climate effects generated by trees within a 20 m radius of buildings. Energy savings were valued using average residential prices of gas and electricity.
5. CO_2 emissions avoided in the energy sector due to energy savings valued using the social cost of carbon.
6. Land rate premium on detached homes with verge trees estimates are based on tree premium estimates in Perth, and land value data in the ACT
7. Health benefits (from avoided hospital visits due to heat-related morbidity) from increase canopy cover to create cooling effects are based on hospital admission data from Brisbane, and hospital costs in the ACT

4.3 Cost-benefit analysis of management scenarios

We conducted a series of BCAs to assess how the outcomes of each scenario compare. The main output of interest is the BCR.

4.3.1 Scenario-specific urban forests and ecosystem services provision change

Planting and removal decisions under the BAU scenario are unrelated to the ULE of the trees in the urban forest. From 2018 to 2045 a net loss of 400 trees is assumed (Figure 4-5a) with annual removal of 1,700 trees continuing from 2046 to 2125. The net change in tree numbers of both the current extent and increasing tree canopy cover to 30% scenarios are driven by the number of trees reaching the end of their ULE.

From 2018 and 2071 tree removals are the same for both scenarios. Afterwards, tree removal is larger for the former scenario due to replanted trees from 2018 to 2045 gradually reaching the end of their ULE.

Planting of around 246,000 new trees would be needed to reach the target 30% canopy cover by 2045 (Figure 4-5b). This represents an increase of around one-third of the number of standing trees in 2018. Under the Maintaining the current extent of the urban forest scenario the removal of dead trees and new plantings could result in a gradual increase in tree canopy cover of around half the change in the Increasing tree canopy cover scenario (Figure 4-5c). The BAU scenario indicates increasing tree canopy cover until around 2025, while leaf biomass increases until around 2040(Figure 4-5d). Such increases are due to the growth of trees that have not reached the end of their ULE.

A significant difference across the modelled scenarios is that all standing trees in the Maintaining the current extent and Increasing canopy cover scenarios have positive ULE. However, under the BAU scenario not all dead trees are replaced. This generates a reduction in the number of trees able to provide ES of around one-half of the 2018 tree stock. In addition, the growing number of dead trees increases risks to people and property, and gradually increases the investment needed for them to be replaced.

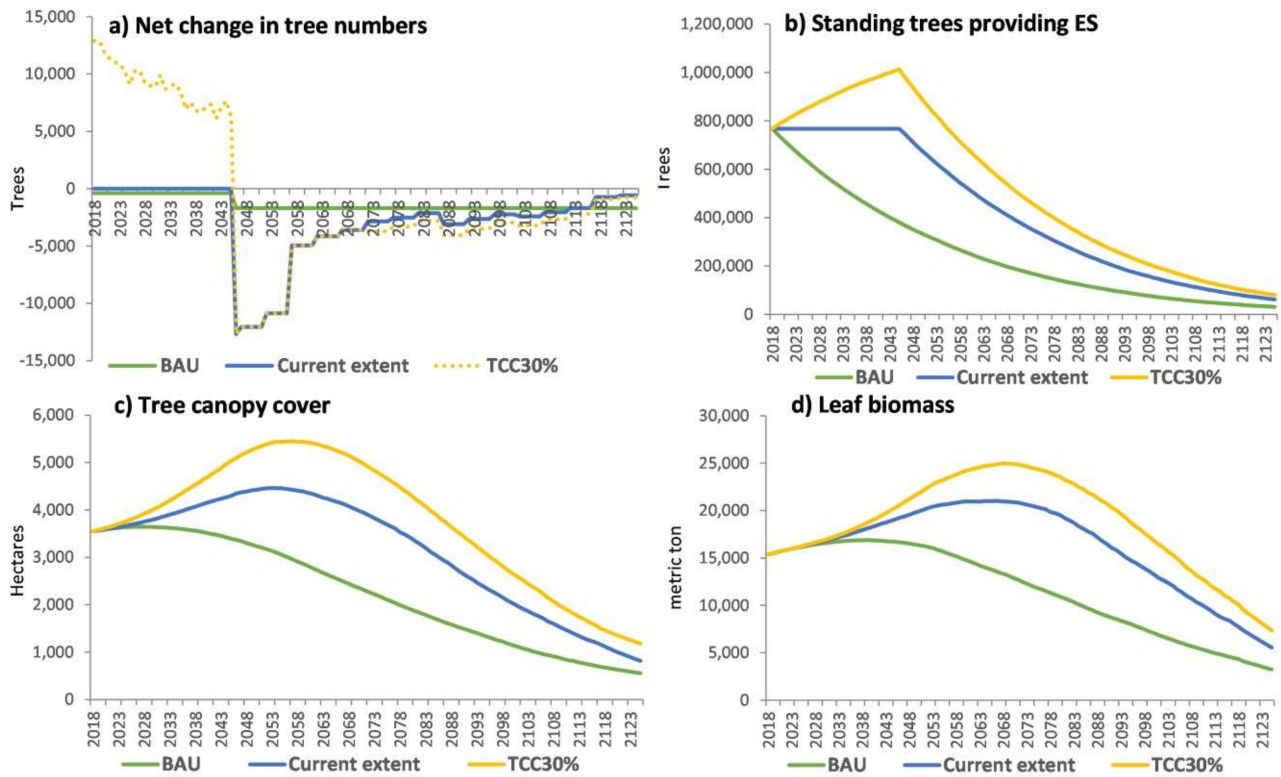

Figure 4-5 Annual net change in tree stock, standing forests, tree canopy and leaf biomass. a) Net change in tree number per year, b) standing trees with useful life expectancy, c) tree canopy cover, and d) leaf biomass

The forecasting component of i-Tree Eco provides estimates of changes in tree stock, canopy cover, biomass, leaf area, and other indicators of urban forest vegetation. Such software directly estimates changes in the value of pollution removal (Figure 4-6a) and carbon sequestration (Figure 4-6c).

Annual changes in leaf area from 2018 to 2125 were used to estimate annual changes in the baseline 2018 value of avoided stormwater runoff and energy savings (Figure 4-6b, e), since those services are mostly influenced by non-woody tree biomass. A similar approach was applied to model changes in the value of avoided energy emissions but considering a gradual transition towards energy neutrality from 2018 to 2045 (Figure 4-6d). Changes in the capital value of the urban forest from 2018 to 2125 were approximated using estimates of change in tree-biomass (Figure 4-6f).

From 2018 to 2045, under BAU the value of pollution removal decreases around 5%, and 26% for avoided stormwater runoff and energy savings. The value of carbon sequestration increases around 65%, despite a reduction in tree biomass growth, due to the increasing social cost of additional carbon emissions under global warming. The value estimates of the Maintaining the current forest extent scenario indicate a 21% increase for pollution removal services, 76% for energy savings and stormwater reduction, and 82% for carbon sequestration. The Increasing tree canopy scenario, generates the largest value gains with a 40% increase for pollution removal, 142% for energy savings and avoided stormwater runoff, and 102% for carbon sequestration. Under all scenarios the value of avoided energy emissions is zero after 2045.

Due to the growth of young trees, the capital value of urban forests increases around 9% for the BAU scenario. For the Maintaining the current extent, and Increasing tree canopy cover scenarios the increase is around 16% and 32%, respectively. Long-term tree growth dynamics generate increases in ES provision and capital asset value even under the assumption of no replanting after 2045 for the two scenarios that gradually replace or increase tree stocks.

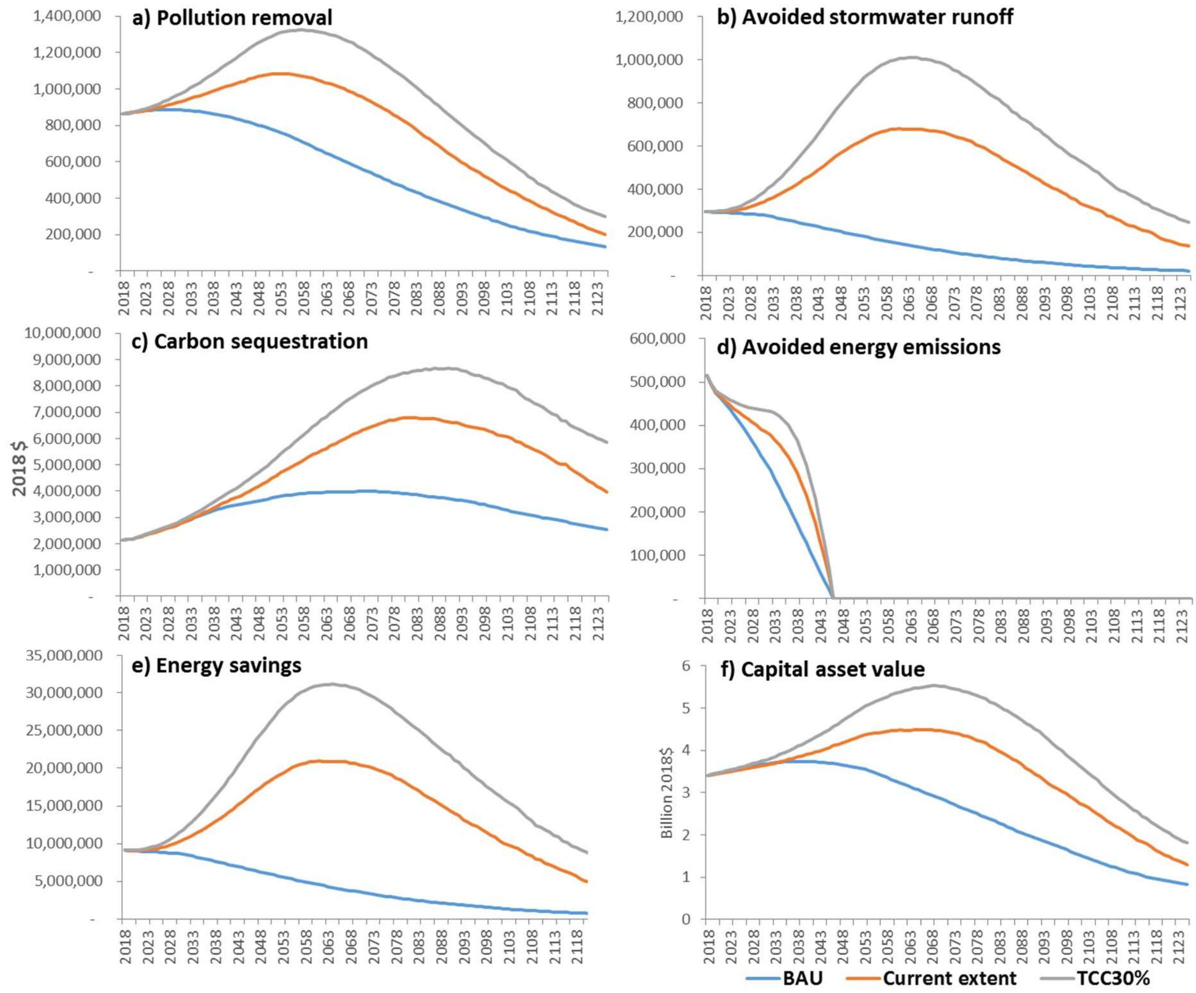

Figure 4-6 Ecosystem services and capital asset value under modelled urban forest management scenarios (20182125). Plantings are assumed to stop under all management scenarios by 2045.

4.3.2 Benefits and costs of modelled urban forest management scenarios

The first set of results, presented in Table 4-4, provides a detailed breakdown of the benefit and cost items that go into the BCA for native versus exotic trees in order to demonstrate the different costs accrued and benefits derived from each type of species. The net benefit (=total benefit – total cost) of exotic trees are greater than native trees only because the current species composition is 42% native trees and 58% exotic trees, and we assume the same species composition until the end of the study time horizon (2125). However, we are aware that the cost to maintain exotic trees is significantly higher than native trees, as demonstrated in Table 4-4. Meanwhile, the benefits are assumed to be the same across both species as there is not sufficient information at this point to distinguish ES benefits between the two species.

Table 4-4 Itemised benefits and costs of managing natives and exotic trees for the BAU scenario (3% discount rate)

		Native trees		Exotic trees	
Items	**Units**	**$/unit**	**NPV ($) all trees**	**$/unit**	**NPV ($) all trees**
Cost to plant and establish					
Tree purchase	$/tree	40	592,953	90	927,118
Planting	$/tree	130	1,927,098	160	1,648,209
Consolidation	$/tree	80	1,185,907	80	824,105
Watering	$/tree	180	2,668,290	300	3,090,392
Formative pruning	$/tree	75	1,111,787	75	772,598
Total cost to plant and establish			**7,486,036**		**7,262,422**
Cost to remove a tree	**$/tree**	**1,210**	**28,104,956**	**1,210**	**39,617,829**
Maintenance cost (annual)					
Tree maintenance cost	$/yr/tree	35.83	149,642,635	71.66	421,675,082
Street sweeping cost	$/yr/tree	2.12	8,854,100	4.25	25,008,639
Total maintenance cost (annual)	**$/yr/tree**	**37.95**	**158,496,734**	**75.91**	**446,683,721**
Externality cost (annual)					
Stormwater pipe maintenance	$/yr/tree	1.35	7,861,431	3.83	31,439,411
Path replacement, grinding, patching	$/yr/tree	1.38	8,036,130	3.9	32,014,022
Shopping centre precinct - pavers	$/yr/tree	0.18	1,048,191	0.52	4,268,536
Tree claims payment	$/yr/tree	0.13	757,027	0.13	1,067,134
Insurance excess payments	$/yr/tree	0.03	174,698	0.03	246,262
Total externality cost (annual)	**$/yr/tree**	**3.07**	**17,877,477**	**8.41**	**69,035,364**
Total cost			**211,965,203**		**562,599,337**
Capital asset value change	**$/yr/tree**	**-17.00**	**-96,410,669**	**-17.00**	**-135,904,196**
Benefits of ES flows from trees (annually)					
Pollution removal	$/yr/tree	1.75	10,218,926	1.75	14,404,992
Avoided runoff	$/yr/tree	0.50	2,898,549	0.50	4,085,907
Building energy savings	$/yr/tree	15.33	89,261,035	15.33	125,825,796
Avoided energy emissions	$/yr/tree	0.00	0.00	0.00	0.00
Carbon storage change	$/yr/tree	0.44	2,578,886	0.44	3,635,298
Land rate premium	$/yr/tree	35.30	200,141,953	35.30	282,127,814
Avoided heat-related morbidity	$/yr/tree	-0.02	-93,673	-0.02	-130,560
Total benefits of ES flows from trees			**305,005,677**		**429,949,247**
Total benefit (ES flows+Capital asset value change)			**208,595,008**		**294,045,051**
Net benefit (Total benefit-Total cost)			**-3,370,195**		**-268,554,286**

Note that unit costs per tree were provided directly by TCCS and that these cost estimates do not include project management resource costs. The unit benefits were estimated within the model. For example, the average capital asset value per tree is $-17. It is estimated based on the levelised benefit (or cost) estimate. Recall the levelised benefits (or costs) is the discounted NPV of the benefits over the period 2018-2125 divided by the discounted number of trees over the same period, giving a per tree benefit (or cost) that has been adjusted by the discount rate.

The following set of results consists of a summary of benefits and costs for the three scenarios for urban public tree management – BAU, Maintaining the current extent of the forest, and Increasing tree canopy cover to 30% (see Table 4-5). The BCR for the BAU scenario is the lowest as expected (BCR=0.65). Although the cost to establish, maintain and remove trees is the lowest in this scenario, the benefits are also the lowest ($503 million). The low costs are a result of very few trees being planted to replace dying ones. However, the declining tree stock has also resulted in a substantial loss in capital asset value of $232 million, and low ES benefits of $735 million. The scenario where more trees are planted to achieve 30% canopy cover by 2045 is the scenario with the highest BCR (=1.19). The benefits of expanding the urban forest by planting more trees from 2018 to 2045 results in an increase in capital asset value of the ACT's tree stock, and an increase in the overall level of ES to the people of Canberra. In between the BAU and Increasing tree canopy cover to 30% scenario is the Maintaining the current extent of the forest scenario with a BCR of 1.02.

Table 4-5 Benefits and costs compared for the three public tree management scenarios (NPV 2018-2125)

		BAU		Maintain		30% Canopy
Cost to plant and establish		$14,748,458		$74,864,659		$181,959,038
-Native	$7,486,036		$37,999,872		$92,358,936	
-Exotic	$7,262,422		$36,864,786		$89,600,102	
Cost to remove a tree		$67,722,785		$248,969,999		253,885,010
-Native	$28,104,956		$103,322,549		$105,362,279	
-Exotic	$39,617,829		$145,647,449		$148,522,731	
Maintenance cost (annual)		$605,180,455		$890,759,926		$1,070,458,707
-Native	$158,496,734		$233,498,867		$280,965,594	
-Exotic	$446,683,721		$657,261,060		$789,493,113	
Externality cost (annual)		$86,912,841		$127,734,593		$153,171,615
-Native	$17,877,477		$26,274,279		$31,506,530	
-Exotic	$69,035,364		$101,460,314		$121,665,085	
Total Cost		$**774,564,540**		$**1,342,329,177**		$**1,659,474,370**
Capital asset value change		$-232,314,866		$268,076,877		$698,411,172
-Native	$-96,410,669		$111,251,904		$289,840,636	
-Exotic	$-135,904,196		$156,824,973		$408,570,535	
Benefits of ES flows from trees (annually)		$734,954,924		$1,107,671,430		$1,278,695,644
-Native	$305,005,677		$459,683,643		$530,658,692	
-Exotic	$429,949,247		$647,987,786		$748,036,952	
Total benefit (ES + Capital asset value change)		$**502,640,059**		$**1,375,748,307**		$**1,977,106,816**
Net benefit (Total benefit-Total cost)		$-**271,924,481**		$**33,419,130**		$**317,632,446**
Benefit-cost ratio		0.65		1.02		1.19

The ES benefits presented in Table 4-5 are only a part of a whole suite of ES benefits provided by trees. A number of ES benefits including species diversity, habitat, and habitat corridors; mental health and well-being benefits; tourism, cultural and symbolic values; and noise reduction have not been included in this study due to data limitations or lack of accepted valuation methodologies.

Table 4-6 provides a summary of the levelised benefit per tree for pollution removal, avoided stormwater runoff, energy savings, avoided emissions, and carbon storage over the period of 20182125.

The number of trees with ULE under the BAU scenario reduces significantly by the end of the time horizon, while the number of trees in the other two scenarios remains constant or increases to 2045 and then decreases. Ecosystem services benefits from replanting take some time to reach meaningful levels, and the combined effects of increasing tree numbers and slow growth in tree benefits generates an outcome where the levelised benefit for pollution removal is highest in the BAU scenario and lowest in the increasing tree canopy cover scenario. A similar explanation applies to the cases where the levelised benefit per tree is larger for the maintain scenario relative to the increasing canopy scenario

Table 4-6 Estimated levelised ES benefit per tree (over the period of 2018-2125)

Levelised ES benefit ($/tree)	BAU	Maintain	30% Canopy Cover
Pollution removal	$1.75	$1.46	$1.37
Avoided runoff	$0.50	$0.70	$0.77
Building energy savings	$15.33	$21.57	$23.74
Avoided energy emissions	$0.00	$0.35	$0.32
Carbon sequestration	$0.44	$6.25	$6.00

In comparison, we present Table 4-7, which is an extract from Lin et al. (2018) summarising the ES benefits of trees from the international literature. We see large differences in the pollution removal estimates and avoided runoff estimates between what we estimated for the ACT, and what has been estimated internationally. This raises a point of caution in that using the BT approach, where values are transferred from studies overseas to Australia may provide inaccurate estimates.

Table 4-7 Estimated ES benefits of trees from the international literature (Source: Lin et al. 2018)

Ecosystem Service	ES value (per tree per year)	Source
Avoided runoff	$1.6	USA
	$12 to $113	Canada
	$47.80	Portugal
Pollution removal/Air quality	$5.40	Portugal
Climate and energy savings	$6.20	Portugal
	$36	Toronto
	$250	Netherlands
Carbon Sequestration	$0.33	Portugal
	$1.50	USA South Carolina

4.3.3 Sensitivity analysis of tree management scenarios

The main advantage of @Risk is that it allows the BCA to account for uncertainties in the parameter values. In the case of public trees, there are uncertainties around the UV of land, and the number of detached houses approved each year, which have an impact on the estimation of the property price premium of trees. Given this uncertainty, @Risk can report the BCR in the form of a distribution of possible outcomes, instead of one fixed value.

Table 4-8 presents the BCR for the three urban forest management scenarios at different discount rates. Note for example that the BCR for BAU scenario, assuming 3% discount rate, is on average 0.65.

However, depending on the discount rate chosen, the average BCR for the BAU scenario is between 0.65 and 1.13. Figure 4-7, Figure 4-8, and Figure 4-9 present the probability distribution of the BCR for each of the three tree management scenarios.

Table 4-8 Results from the sensitivity analysis on the discount rate for the BAU and alternative scenarios for public trees (NPV $ 2018-2125)

	Discount rate	Total cost ($M)	Total benefit ($M)	BCR		
				Min	Mean	Max
BAU	3%	$774.56	$502.64	0.56	0.65	0.74
	7%	$464.12	$490.22	0.96	1.05	1.13
	10%	$361.69	$414.84	1.06	1.13	1.26
Maintain	3%	$1,342.33	$1,375.75	0.98	1.02	1.07
	7%	$707.39	$720.84	1.00	1.02	1.11
	10%	$511.37	$515.73	0.99	1.01	1.09
30% Canopy cover	3%	$1,659.47	$1,977.11	1.15	1.19	1.25
	7%	$867.46	$1,000.19	1.11	1.15	1.19
	10%	$624.50	$669.63	1.05	1.07	1.14

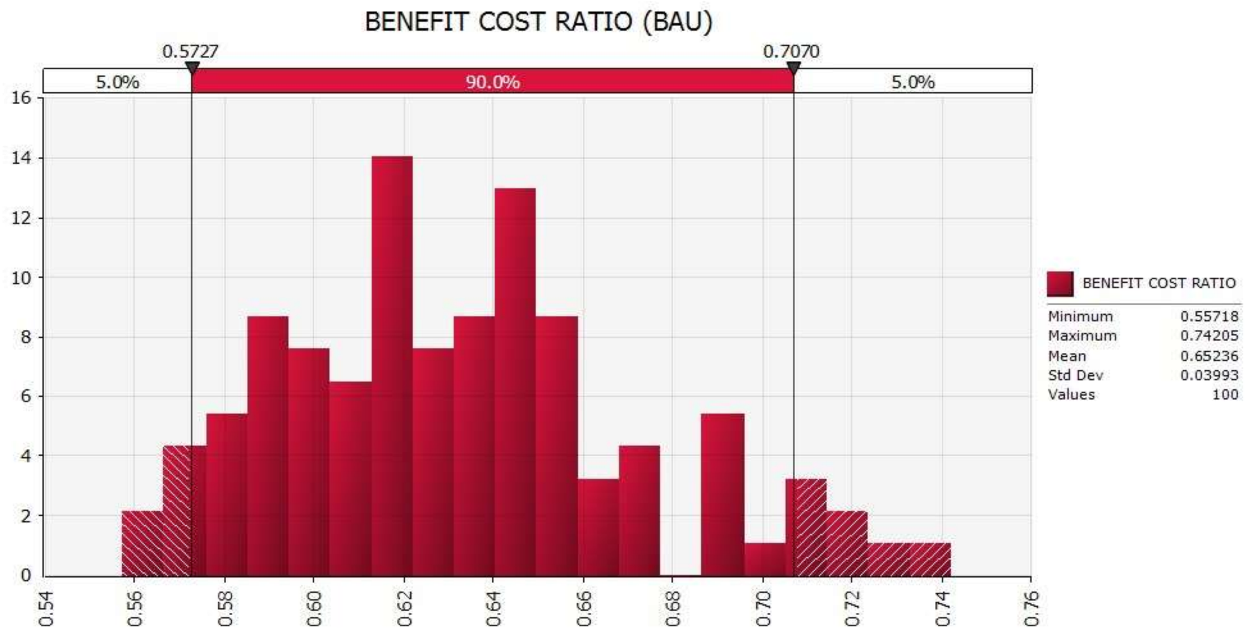

Figure 4-7 Probability distribution of possible BCRs for the BAU scenario of public tree management (2018-2125)

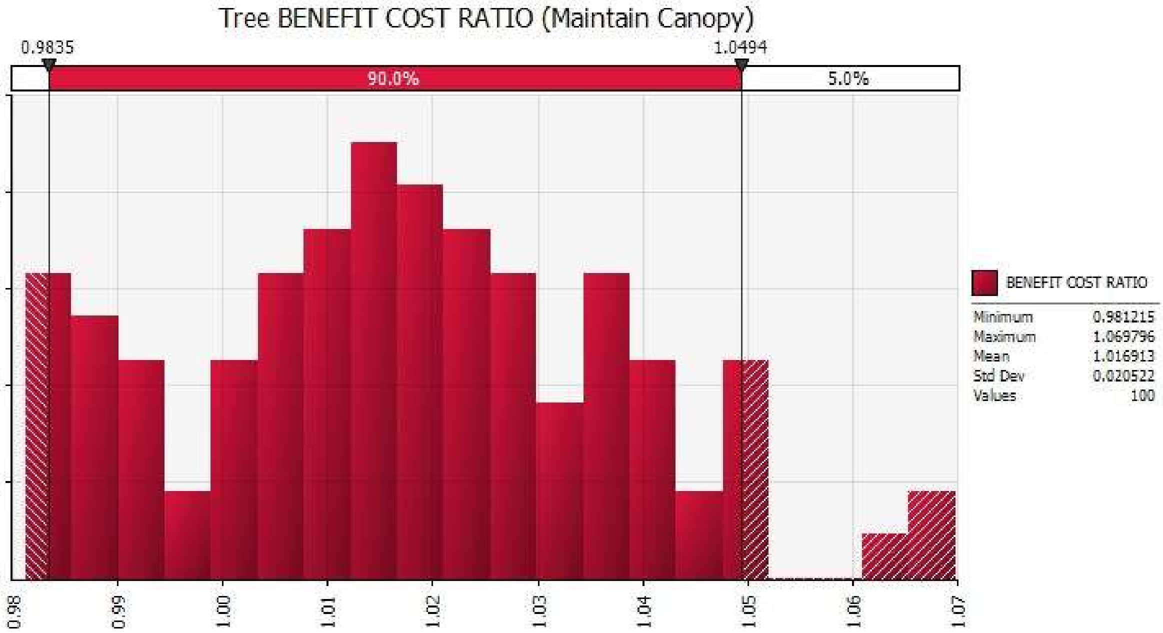

Figure 4-8 Probability distribution of possible BCRs for the scenario where 2018 canopy cover is maintained (20182125)

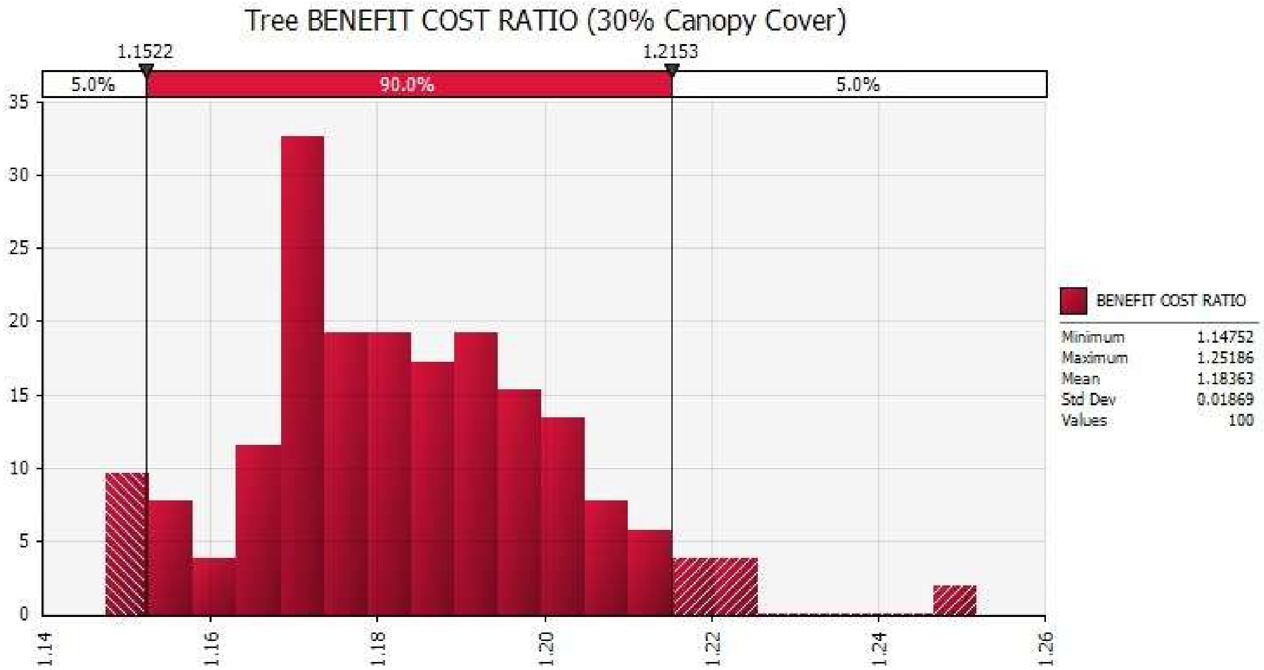

Figure 4-9 Probability distribution of possible BCRs for the scenario where canopy is 30% (2018-2125)

4.3.4 Benefits and costs of irrigated open spaces

The BCA for IOSs examines the benefits and costs of maintaining existing spaces (in the case of the BAU), and expanding the area of IOSs to cope with the increasing demand from a growing population (in the alternative scenario).

The first set of results presents the benefits and costs breakdown of the BAU scenario for the two types of IOSs – sports and non-sports for the 2018-2070 time horizon (see Table 4-9).

Note that total establishment cost is reported but not included in the BAU scenario as it was assumed that there were no new IOSs established. For both types of assets, the net benefit is positive, but the benefits accrued from sportsgrounds is higher because there are more hectares of sports ground (380 ha of sportsgrounds versus 104 ha of non-sports grounds), and the recreational benefit per hectare from sports grounds is higher.

Table 4-9 Itemised benefits and costs of managing sports and non-sport IOSs for the BAU scenario (3% discount rate)

BAU 3%		**Sports**		**Non-sports**	
	Unit	**Unit value**	**NPV $ (20182070)**	**Unit value**	**NPV $ (20182070)**
Direct benefits					
Sports ground hire	$/ha/yr	4,624	47,731,763		
Benefits of ES flows from trees					
Value of time playing sport	$/ha/yr	75,905	995,882,074	23,995	83,654,196
Council rate premium	$/house/yr	3.4	9,428,818	3.4	6,022,501
Total benefit			**1,053,042,655**		**89,676,697**
Cost to plant and establish					
Sports oval - Set up turf, irrigation, drainage, sports infrastructure	$/ha	600,000	0		
Turf - supply & install			0	13,399	0
Top soil			0	80,000	0
Irrigation system + pumps and bores			0	30,000	0
Pumps and bores (1 unit)			0	0	0
Total establishment cost	$/ha	600,000	0	123,399	0
Maintenance cost (annual)					
Irrigating	$/ha/year	13,418	138,521,120	5,600	15,821,618
Mowing	$/ha/year	9,480	97,862,632	190	535,669
Waste Hoppers	$/ha/year	789	8,144,982		
Cleaning southside	$/ha/year	718	7,412,037		
Fertiliser and amendments, including soil testing	$/ha/year	925	9,548,933	925	2,613,392
Pest and disease control-materials	$/ha/year	740	7,639,147	740	2,090,714
Aeration	$/ha/year	1,700	17,549,391	1,700	4,802,991
Dethatching	$/ha/year	750	7,742,378	750	2,118,967
Annual renovation-top soil/ seed/ (spring and autumn)	$/ha/year	1,850	19,097,867	1,850	5,226,785
Irrigation repairs-materials	$/ha/year	1,171	12,088,433	1,171	3,308,413
Repairs and maintenance - buildings and floodlights	$/ha/year	925	9,548,933		
Management staff field/office/bookings	$/ha/year	5,859	60,483,460		
Total maintenance cost (annual)	$/ha/yr	38,325	395,639,313	12,926	36,518,549
Total cost			**395,639,313**		**36,518,549**
Net Benefit (Total benefit-Total cost)			**657,403,341**		**53,158,147**

The following set of results (see Table 4-10) compare the costs and benefits of the BAU scenario versus a scenario where 50% more IOSs are established by 2045. Note that the main difference between these two scenarios is that the BAU still has zero cost for planting and establishment, while the alternative scenario captures the costs associated with expanding the areas of IOSs. The BCR for the alternative scenario (2.45) is lower than the BCR of the BAU scenario (2.64). In any case, these BCR ratios are considered high. They indicate that the benefits will outweigh the costs by a ratio of more than 2 to 1.

Table 4-10 Benefits and costs compared for the two IOS management scenarios (NPV $ 2018-2070)

		BAU		50% more IOS
Planting & establishment cost		**$0**		**$53,870,616**
- Sport	$0		$51,640,286	
- Non-sport	$0		$2,230,330	
Maintenance cost		**$432,157,863**		**$493,664,118**
- Sport	$395,639,313		$453,077,535	
- Non-sport	$36,518,549		$40,586,584	
Externality cost		**$0**		**$0**
- Sport	$0		$0	
- Non-sport	$0		$0	
Total cost		**$432,157,863**		**$547,534,735**
- Sport	$395,639,313		$504,717,821	
- Non-sport	$36,518,549		$42,816,914	
Total benefit		**$1,142,719,352**		**$1,339,261,284**
- Sport	$1,053,042,655		$1,238,667,570	
- Non-sport	$89,676,697		$100,593,715	
BCR		**2.64**		**2.45**

4.3.5 Sensitivity analysis of irrigated open spaces management scenarios

Regardless of which discount rate is used, the BCR of the two management scenarios both show a ratio of greater than 2 (see Table 4-11). Hence, the findings are very robust to any discount rate assumption proposed in this analysis.

Table 4-11 Results from the sensitivity analysis on the discount rate for the BAU and alternative scenarios for IOSs

	Discount rate	Total cost ($M)	Total benefit ($M)	BCR		
				Min	Mean	Max
BAU	3%	$432.16	$1,142.72	2.51	2.64	2.77
	7%	$236.43	$579.81	2.32	2.45	2.58
	10%	$173.87	$411.07	2.25	2.36	2.48
50% more IOS	3%	$547.53	$1,339.26	2.32	2.44	2.56
	7%	$270.40	$625.91	2.19	2.31	2.44
	10%	$188.43	$427.87	2.14	2.27	2.38

Figure 4-10 and Figure 4-11 present the distribution of the BCR for the two management scenarios for IOSs, applying a discount rate of 3%. Both distributions present the range of the expected BCR for each scenario, the probability that a particular BCR will occur.

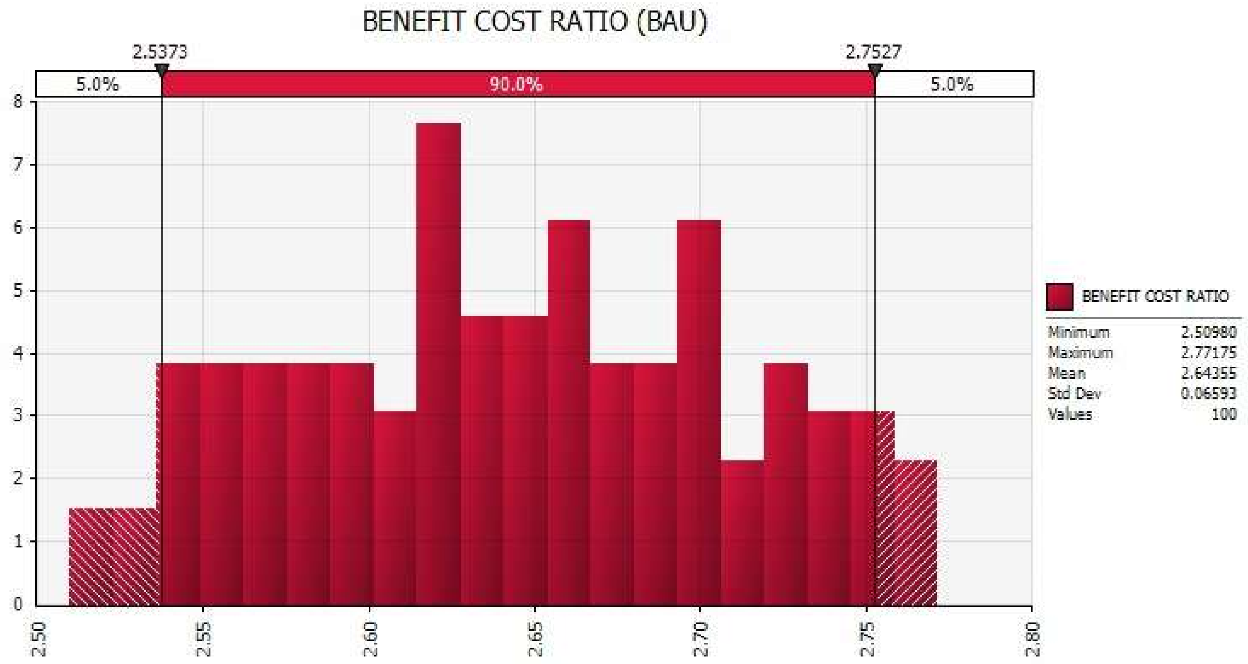

Figure 4-10 Probability distribution of possible BCRs for the BAU scenario of IOS management

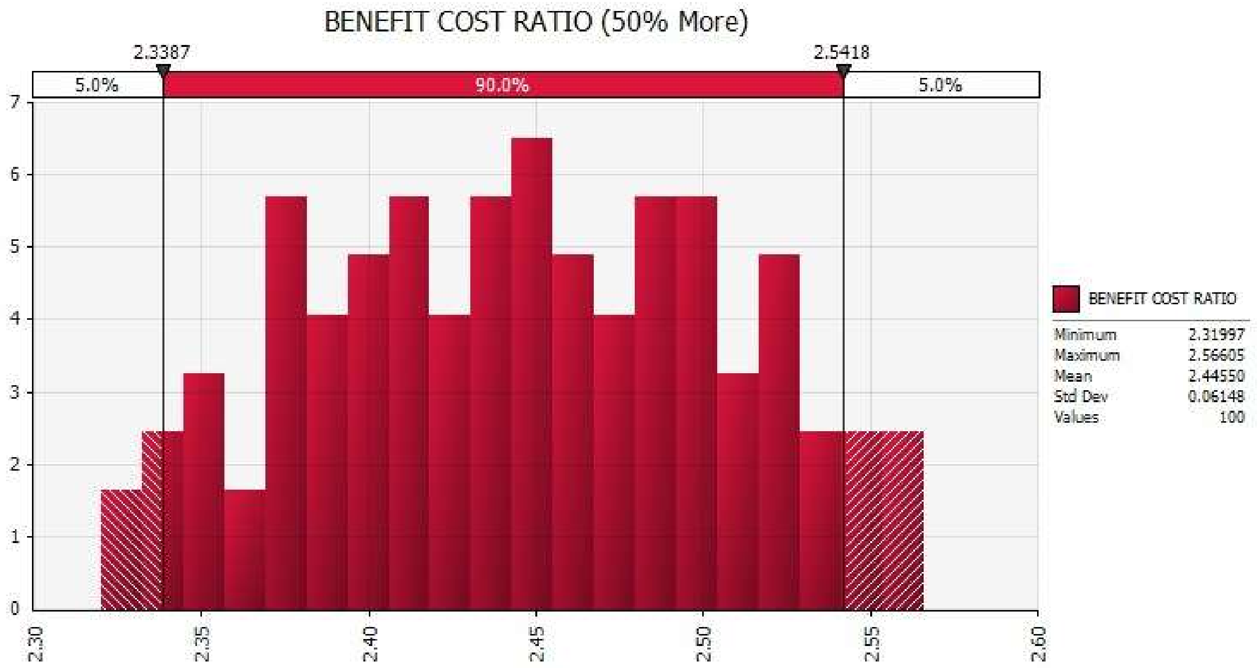

Figure 4-11 Probability distribution of possible BCRs for the scenario where 50% more IOSs are established by 2040

4.4 Average net cost per person

To examine how much these costs and benefits translate to cost per person, we examined the cost per person per week for each of the three tree management scenarios for the 2018-2045 time horizon. This is the time horizon of interest as all planting and establishment costs are assumed to occur during this time period, and varies greatly between each of the three scenarios. Note that this cost figure is the net cost. In other words, it is the total costs minus the benefits accrued for each tree management scenario. The current population in the ACT is 420,321 and is estimated to reach 614,633 by 2045 (Chief Minister, Treasury and Economic Development Directorate, 2019).

4.4.1 Urban forests

Table 4-12 presents the number of trees in 2018 and 2045 for the three tree management scenarios. Trees per person decline under all scenarios during 2018-45, as does the cost per person per week (in 2018 $). Under the BAU scenario, the net cost to taxpayers is negligible (effectively $0), as the cost under the BAU scenario is low. However, the decline in the number of trees is substantial. A net loss of 387,946 trees is expected by 2045 under the BAU scenario, resulting in an average number of trees per person of 0.62 by 2045 (a drop from 1.83 trees per person in 2018). This situation can be avoided at a cost of $0.71 per person per week in 2018, in real dollar terms, (declining to $0.51 by 2045) under the Maintaining the current extent of the forest scenario. At $1.05 per person per week in 2018 (declining to $0.70 by 2045) the taxpayer funds a net increase of 245,984 trees under the Increasing tree canopy cover to 30% scenario, which is 633,930 trees more than BAU in 2045.

Table 4-12 Net cost per person for each tree management scenario (2018 $)

	No. of trees providing ecosystem services		Net cost/person/YEAR		Net cost/person/WEEK	
	2018	**2045**	**2018**	**2045**	**2018**	**2045**
BAU	767,636	379,690	$37.33	$0.85	$0.72	$0.02
Maintain	767,636	767,636	$36.75	$26.40	$0.71	$0.51
30% Canopy cover	767,636	1,013,620	$54.79	$36.22	$1.05	$0.70

4.4.2 Irrigated open spaces

Currently, the average area of IOS per person that is managed by TCCS is around 11.52 m^2 per person (see Table 4-13). With the population of the ACT expected to reach over 614,633 by 2045 (Chief Minister, Treasury and Economic Development Directorate, 2019), the average area per person will drop to 7.87 m^2. However, at an additional cost of $0.13 per week ($1.29-$1.16) in 2018, dropping down to $0.09 ($0.88-$0.79) per person per week in 2045, the area of IOSs could be increased by 50%. This could increase the average area of IOS per person to 11.81 square meters in 2045.

Table 4-13 Cost per person for each of the two IOSs management scenarios

	m^2 per person		Cost per person		Cost/person/week	
	2018	2045	2018	2045	2018	2045
BAU	11.52	7.87	60.38	41.29	1.16	0.79
50% more IOS	11.52	11.81	67.27	46.00	1.29	0.88

5 Conclusion

The CSIRO was commissioned by the Climate Change and Sustainability Division, Environment Planning and Sustainable Development Directorate, ACT Government to estimate the whole-of-life net social benefit of publicly owned trees and IOSs to the ACT. The objectives of this research were to determine:

- The whole-of-life net social benefit of publicly owned trees and IOSs to the ACT (e.g. cooling benefits of trees).
- The net social benefit to the ACT per additional unit of living infrastructure (e.g. per additional ha of urban forest or IOSs).
- The monetized benefit to society for every dollar invested in establishing and maintaining living infrastructure in the ACT.

5.1 Summary of findings and management implications

In summary, the findings from this analysis suggest that:

- Under BAU tree management conditions indicates a negative long-term return for the ACT, with a benefit-cost ratio of between 0.56 and 0.74 (mean of 0.65)
- Under Maintaining the current extent of the forest indicate a near positive long-term return for the ACT, with a benefit-cost ratio of between 0.98 and 1.07 (mean of 1.02)
- Under Increasing tree canopy cover to 30% of the public land indicate a positive long-term return for the ACT, with a benefit-cost ratio of between 1.15 and 1.25 (mean of 1.19)
- The current capital asset value of the ACT's urban forest is $3.4 billion. Tree cover increase generated by young trees in the 2018 urban forest could increase such capital asset value to $3.7 billion by 2045. A significant decline in such value is observed afterward.
- The estimated capital asset value for the Increasing tree canopy cover to 30% scenario reaches nearly $4.5 billion by 2045.
- Under BAU IOS management conditions indicates a positive long-term return for the ACT, with a benefit-cost ratio of between 2.51 and 2.77 (mean of 2.64)
- Under 50% increase in the area of IOSs conditions indicates a positive long-term return for the ACT, with a benefit-cost ratio of between 2.32 and 2.56 (mean of 2.44)

Recall that a BCR greater than one indicates a management scenario where the whole-of-life benefit outweighs the cost. Note that we provide the mean benefit-cost ratio, along with its lower and upper bound values to account for variations in the assumptions. Out of the set of assessed tree management scenarios, the tree management scenario that aims to expand tree canopy cover has the highest benefit-cost ratio.

Sensitivity analyses suggest that this benefit-cost ratio is robust to uncertainty in the magnitude of the cost and benefit estimates used in the analysis. In other words, the benefits outweigh the costs despite any changes in the model assumptions.

The ACT's green infrastructure has significant capital asset value and provides important direct and indirect benefits to the city. Our analysis shows that increasing the number, condition and lifeexpectancy of trees through more replanting and better maintenance is expected to increase the capital asset value of the ACT's urban forest.

As for IOSs, although the proposed expansion of IOS by 50% presents a lower BCR than the BAU, the overall BCR suggests that investment in expanding the number of IOSs is worthwhile, given that the benefit outweighs the cost by a factor of more than 2 to 1. To our knowledge, this project is the first attempt at valuing the recreational benefits of IOSs in the ACT. We would like to emphasise that our benefit figure is potentially a lower-bound estimate, as the benefit of sports ovals was only estimated based on people who play football/soccer. We have not included the recreational benefits of people who play cricket, track and field and other sports on irrigated sports spaces. Also, our report estimated that the recreational benefits of sports ovals is around $7.8 per person per month. Meanwhile, the Commonwealth Bank reported that "Australians spend $712 million a month on health and fitness products, equating to a $38 monthly spend for the average Australian" (CommBank, 2018). This figure is nearly 5 times higher than our estimate. More people could switch from going to the gym to use sports ovals in the ACT if more high-quality spaces were made available and accessible. This would significantly enhance the social and recreational benefits that IOSs provide.

5.2 Limitations and recommendation for future research

There were a number of benefit and cost items where estimates could be improved if more ACT specific information was available. The issue with getting accurate costs by species, or by type of IOSs is discussed further below. Additionally, many ES benefits of public trees and IOSs were difficult to value due to insufficient data or lack of accepted methodologies. Specifically, the omitted benefits include: species diversity, habitat, and habitat corridors; avoided stormwater runoff (for IOSs); avoided electricity supply infrastructure costs from building energy savings; physical and mental health and well-being benefits; educational, tourism, cultural and symbolic values; and noise reduction. The assumptions regarding the carbon storage of public trees used in this study are very conservative. In addition, the study does not factor in climate change over the coming decades. This also is likely to lead to an underestimate of the benefits of public trees and living infrastructure. We discuss the limitations in more detail below, along with recommendations on how future research should proceed.

5.2.1 Tourism/ Cultural/ Symbolic Values

The ACT is known as the Bush Capital of Australia. It is therefore certain that public trees and IOSs support these ES. In this analysis, we were at least able to estimate the recreational benefits of IOSs, because there are recreational use data specific to the ACT.

Tourism, cultural and symbolic values were not estimated in this analysis due to lack of data.[5] Future research could be done to better understand why visitors come to Canberra and visit sites such as the Arboretum and Floriade to better quantify the value of urban forest ecosystem services to ACT's tourism sector. An economic analysis of the WTP for those services could help to incorporate them in the valuation of the urban forest services.

5.2.2 Recreational, educational and public health value

The recreation values of IOSs from sports activities and playground visits are lower-bound estimates of recreational values. The reason is three-fold. Firstly, the value of recreational time includes time spent on site and time spent travelling to and from the site. In our analysis, we do not have information on how much time people spend travelling to IOS, we therefore only estimated the recreational benefits based on time spent on site. Future surveys of recreational use of IOSs should include questions around how long people take to travel from home to the IOS and what vehicle was used for travelling. Secondly, consumer surplus for recreational use of irrigated open spaces has not been accounted for. In the cost benefit analysis literature, it is common to assume that the community would be willing to pay 50% higher than current payments using the consumer surplus '*rule of one-half principle'* (Winkler, 2015; NASEM, 2017). Thirdly, overtime, with an aging population, risks rising obesity, and diseases of physical activity making up a significant percentage of public health budgets, the public health benefits of ACT citizens doing physical exercise at playgrounds and irrigated open spaces with trees providing shade, will increase. How these benefits from shaded playgrounds and irrigated sports ovals increase overtime has not been factored into this study.

As outlined in the report, there are various educational benefits associated with urban forests and open spaces, which have not been valued as part of this research. Further work could be undertaken to monetising the value of these public educational benefits.

5.2.3 Wildlife habitat and species diversity

Trees and open spaces create wildlife habitat in urban areas and enhance species diversity. However, quantifying the improvement in wildlife and species diversity has rarely been done, or done to the point where the findings can be used to place monetary values on these ES benefits. An alternative solution is to conduct a stated preference study to ascertain how much people are willing to pay for more wildlife habitat and species diversity in urban areas. A WTP study will give some indication of the monetary benefits people place on public trees and IOSs as a source of wildlife habitat and species diversity.

5.2.4 Climate regulation and amelioration (cooling)

A review of the literature has revealed very little information on the cooling potential of IOSs and the impact on energy bills. Without quantitative information on cooling benefits, it was not possible to estimate avoided heat-related morbidity, energy savings and avoided electricity supply infrastructure spend, avoided energy emissions from such type of living assets.

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[5] https://www.cmtedd.act.gov.au/open_government/inform/act_government_media_releases/barr/2019/tourism-jobs-and-contribution-at-record-level

These savings could be significant. As the COAG Energy Council's 2018 "*Report for Achieving Low Energy Homes*" showed, "*Almost $1,000 in electricity system infrastructure could be saved for each household that cuts their peak demand by one kilowatt – the power used to run an air-conditioner in one room. This could reduce electricity prices for everyone. In the short term, reducing peak demand reduces consumption when wholesale electricity prices are high, the savings of which can flow through to consumers*" (COAG Energy Council, 2018).

One important finding to point out is that most IOSs are bordered or include trees. In the analysis the impacts of trees and irrigated grass areas are modelled separately.

5.2.5 Implications of future climate change

The value of public trees and living infrastructure benefits is likely to increase overtime, due to climate change as trees and other forms of nature can act as effective cooling measures in warming climates. This is currently not factored into the modelling. Future research and modelling could be done to better value these ecosystem services from urban forests in a changing climate for the ACT.

5.2.6 Establishment and maintenance cost

There are some limitations around the establishment and maintenance cost of public trees and IOSs as follows:

- It is likely that investment to achieve a 30% urban tree canopy target will create economies of scale that could reduce the cost of establishment and maintenance. These have not been factored into this study due to lack of data on how economies of scale effect costings.
- Uncertainty around cost differences between native and exotic trees. We obtained from TCCS the ideal costs for establishing and maintaining native and exotic trees, however, these costs and are not reflective of actual expenditures for native and exotic species. This resulted in some assumptions that impact the analysis. For instance, pruning costs per tree were assumed to be the same for both native and exotic trees, due to lack of information about how much is exactly spent each year on these two tree types.
- The establishment cost of IOSs that are not used for sport, specifically for the cost of purchase and installation of turf and the cost of top soil, was based on estimates from Logan City Council, Queensland (Logan City Council, 2015). Information specific to the ACT is needed to improve the accuracy of those two cost items.
- The maintenance cost of IOSs that are not used for sports was estimated based on the maintenance cost of IOSs for sport.

Improvements in the tracking of expenditures related to living assets could improve the accuracy of cost-benefit analysis and facilitate the identification of where the resources are being dispensed.

5.2.7 Consideration of alternative funding models for the establishment and maintenance of urban forests.

The scope of this study was limited to whole-of-life costs being borne by the Government and does not include consideration of innovative financing models whereby costs are shared thereby reducing the cost burden to Government. For example, Friends of the Urban Forest, a not-for-profit organisation, work with the City and Country of San Francisco and the community to plant trees and vegetation on public nature strips[6]. There appear to be a number of other examples already in the ACT including:

- ACT businesses investing in accredited carbon offset schemes which fund tree planting projects as part of their social responsibility goals to reduce their carbon footprint.
- Approximately 35 ACT urban "Parkcare" volunteer groups that help to plant and maintain trees and expand and maintain ACT living infrastructure assets via the "Adopt a Park" program[7].
- The ACT Government is partnering with ACT Greening Australia, the community, and citizen scientists to plant and maintain 300,000 tree seedlings with help of 15,000 volunteers in the Lower Cotter Catchment[8].
- A number of ACT public and private schools have invested in large scale on campus living infrastructure projects entirely funded by the school community.

Further research could be undertaken to investigate and develop alternative funding models, including analysis of the above examples, to better inform future cost benefit modelling.

5.2.8 Externality costs

The literature suggests that living in close proximity to sports oval could present nearby residents with negative externalities, including traffic congestion and noise (Bolitzer & Netusil, 2000). Unlike trees, costs of negative externalities of IOSs were not included in the analysis. Evidence from other regions indicates that IOSs could harbour invasive species, and anecdotal information suggests that light pollution and traffic congestions around those assets can generate disservices to residents. The inclusion of negative externalities and other benefits could change the magnitude of the BCR. ACT specific analysis of the externalities of these types of assets could improve the assessment.

5.2.9 Bushfire effect

There was limited information on spatially explicit bushfire risk across the study area. There are many factors that contribute to bushfire risk, including topography, wind, temperature, humidity, and fuel condition (Nogrady, 2015). Examining the relationship between these environmental characteristics and bushfire risk is beyond the scope of this analysis. Consequently, it was not possible to run a scenario analysis where a change in management of public trees and IOSs would increase or decrease the risk of a bushfire, and to estimate the corresponding benefit-cost estimates.

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[6] https://www.fuf.net/

[7] https://www.environment.act.gov.au/parks-conservation/parks-and-reserves/get-involved/the-ParkCare-initiative

[8] https://www.greeningaustralia.org.au/new-life-rising-ashes/

Information on the economic impact from the 2003 bushfire in Canberra was collected (see Table 3-2). This information contains economic parameters that can be used for future bushfire scenario analysis when information around spatially explicit areas that are at high versus low risk of bushfire become available. Additionally, it is important to consider the economic loss from trees burnt down in bushfires. Results from our analysis indicate that the cost to replace an existing tree in the ACT is on average $4,400. Given this information, we could estimate the cost of a bushfire on tree loss, to add to other damages, such a loss to property, to the cost of a bushfire. The same method can be applied to IOSs in that the loss of IOSs due to bushfire is equal to the cost per ha of replacing that IOS with a new one with the same functionality.

5.2.10 Tree characteristics and land use composition

The analysis assumed that tree type composition i.e. the ratio between native and exotic trees remains the same for newly established trees throughout the time period of the analysis. If more information becomes available, trends in the change in species composition could be included in the BCA of publicly owned trees. However, to improve the accuracy of the analysis it is important that the actual costs of different tree species are available. This could be done through more detailed account keeping of tree management expenditure per year.

To date, estimates of the urban forests condition are based on tree canopy audit data from 201012 and estimates of replanting and removal to 2018. There is not spatially explicit information of the distribution and conditions of the trees in the urban forests which complicates the efficient management of such an asset. An inventory or a more comprehensive tree audit of the characteristics of the urban forest (e.g. species composition, age, diameter at breast height, condition) is required for the whole of Canberra. As an alternative, a randomly selected survey of tree conditions could provide robust data of the overall characteristics and extent of the urban forest. Updated information on tree characteristics and extent of the urban forest could improve significantly the valuation of ES benefits, guide long-term planting decisions under budget constraints, and generate a more spatially uniform distribution of the forest extent as to increase the benefits to urban dwellers and visitors.

Similar to the case of public trees, we assumed that for new IOSs, the ratio of sports and non-sports spaces remains the same. This may not be the case in the future, depending on the needs and demand of Canberra residents. It may be that more non-sport places are required and the ratio between these two land use types change. We recommend conducting a Canberra wide survey of residents to find out how people currently use IOSs now, how they intend to use these spaces for in the future, the perceived benefits and externalities of those assets, and the residents WTP for increased quantities or quality of such IOSs. That information could improve the projections of new IOSs by type.

ACT specific information and research to value omitted benefits of green infrastructure (e.g. biodiversity, noise reduction, health improvement, climate adaptation, tourism) could help to improve city infrastructure decisions.

5.2.11 Opportunities to Improve i-Tree Software

The i-tree ECO model was used in this study because it is a globally respected modelling tool for estimating the value of trees. Future work could include liaising with i-Tree Eco to further develop this tool to provide more robust and comprehensive estimates and expand the benefits that can be modelled with this tool.

5.3 Final notes

The ACT’s green infrastructure has a significant capital asset value and provides important direct and indirect benefits to the city. The framework implemented in this analysis allows the comparison of the social benefits of investments in green infrastructure with the returns of investments in other areas. This information could help increase the overall flow of benefits, manage risks generated from asset deterioration, and target the provision of sustainable levels of green infrastructure ES.

In summary, the findings from this analysis suggest that out of the set of assessed tree management scenarios, the tree management scenario that aims to expand tree canopy cover has the highest benefit-cost ratio. Sensitivity analyses suggest that this benefit-cost ratio is robust to uncertainty in the magnitude of the cost and benefit estimates used in the analysis. The two modelled scenarios for IOSs provide evidence of the net social benefits of this type of asset and the potential benefits of expanding their area.

In light of these findings, the ACT government could consider prioritising the expansion of tree canopy cover up to 30% by 2045, over continuing on with the current tree planting and maintenance regime. As for the case of IOSs, more research is required to understand the suite of ES benefits that these types of spaces could provide if more were to be established in the ACT.

A number of lessons were learned from this analysis of the whole-of-life benefits and costs of urban forests and IOSs. There is still a lack of appropriate biophysical, socioeconomic, and health data in the ACT to accurately model the costs and benefits of both public urban trees and IOSs. While the valuation of ES is rapidly developing, not much of this research truly identifies the benefits by ecosystem service type (i.e. provisioning, regulating, cultural, and supporting) or by type of green infrastructure (e.g. urban forests, IOSs) within a framework that facilitates comparison with other public investments. Updated spatially explicit information on the location and conditions of publicly managed trees is needed to improve the estimation of costs and benefits. More research is needed to provide estimates of the value to ACT residents and visitors of non-modelled ES (e.g. biodiversity). Since covering such deficiencies would be resource intensive, an assessment of the trade-offs and benefits of data acquisition and valuation studies should be made to prioritise the generation of information that supports improved city asset management.

Green infrastructure plays a significant role in adaptation strategies to projected socioeconomic, demographic and climatic pressures. It is important to maintain or increase the provision and flow of services from living assets so that future generations can enjoy at least the same level of benefits. To that end, it is necessary a long-term vision regarding the management of the ACT green infrastructure and avoid postponing investments in such assets. Letting green infrastructure gradually decline in health and/or extent could result in losses of ES, thereby increasing liabilities and potentially increasing the need for large investments to compensate for the lost benefits.

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Appendix

Table A.1 A summary of ES of green infrastructure for Australia

Year	Title	Location	Purpose of study	Ecosystem service of interest	Type of green infrastructure	Economic valuation	Findings
2015	ACT State of the Environment Report	ACT		Fire	Nature reserve	N	Review of the environmental impacts by 2003 Canberra bush fire. 164914 ha of forests were burnt.
2004	BushFIRE Arson Bulletin - The Cost of Bushfires	ACT		Fire	Nature reserve	Y	The fire destroyed over 500 homes and claimed four lives caused over $300 million (AUD$412.78 million in 2018) damage including more than $50 million (AUD$68.8 million in 2018) from the almost total loss of ACT forests.
2013	Landscape Scale Influences of Forest Area and Housing Density on House Loss in the 2009 Victorian Bushfires	VIC		Fire	Nature reserve	N	The 50 m influence of houses is approximately the zone of flame contact or high exposure to radiant heat. The home ignition zone is defined as the area between 30 and 60m around the house that directly influences ignition of the house.
2010	A literature review on the economic, social and environmental impacts of severe bushfires in south-eastern Australia - Fire and adaptive management	South-eastern Australia		Fire	Nature reserve	Y	The loss of retail and commercial income across the four Victorian shires in total Gross Shire Product is estimated $121.1 million (AUD$153.12 million in 2018), with the ongoing disruption, the direct impact on large businesses totalled $235 million (AUD$297.14 million in 2018) and an additional of $265 million (AUD$335.07 million in 2018) from indirect and flow-on costs. The 2006 - 2007 Great Divide Fires resulted in an estimated loss of $200 million (AUD$252.89 million in 2018) in the tourism. For the forest itself, the Victorian government pledged $5 million (AUD$6.32 million in 2018) to regenerate 3500 ha of fire-affected forests after the 2003 Alpine Fires. Many other losses to livestock, horticulture, properties and governments are investigated as well. Value of per fatality in 2007 dollars: 3.5 million (AUD$4.43 million in 2018), per injury: $151,000 (AUD$190,929 in 2018).
2001	Economic costs of natural disasters in Australia	Australia		Natural disasters	General	Y	Value of per fatality - $1.4 million (AUD$2.09 million in 2018), insurance cost is usually 16-33% of total natural disaster cost.
2005	URBAN FREIGHT IN AUSTRALIA: SOCIETAL COSTS AND ACTION PLANS	Australia		Noise cancellation	Freights and roads	N	In Australia, a Noise Depreciation Index of 0.5 percent of property value per dB (A) is typically applied for noise levels in excess of a threshold level of 50dB(A) - 55dB(A) (Nairn et al, 1994).
				Noise cancellation	Shrubs	N	A dense shrubbery, at least 5m wide can reduce noise levels by 2 dB(A).

				Noise cancellation	Plantation	N	A 50-m wide plantation can lower noise levels by 3-6dB(A) (Naturva°rdsverket, 1996).
				Noise cancellation	Vegetation	N	Another source claims that 100 m of dense vegetation is only reported to decrease noise by 1–2 dB(A) (Kommunforbundet, 1998).
2006	BRISBANE: "BEAUTIFUL ONE DAY, PERFECT THE NEXT"- IS THERE ROOM FOR IMPROVEMENT?	Brisbane		Emission absorption	Urban trees	N	in 2000, Brisbane's residential tree cover was estimated to be absorbing the equivalent amount of CO_2 emitted by 30,000 cars per year.
				Additional property value	Urban trees	Y	A Survey by the Real Estate Institute of Queensland in 2004 found that the value of homes in leafy streets were up to 30% higher in the same suburb.
2010	The value of public and private green spaces under water restrictions	Adelaide		Additional property value	Public green spaces	Y	Property price is lower by AU$ 24 (AUD$27.76 in 2018), AU$ 18 (AUD$20.82 in 2018), AU$6 (AUD$6.94 in 2018) for every additional metre a property is away from watercourses, golf courses and sport reserves, respectively. The distance to large hiking reserves is positive and significant with value increasing by AU$ 11 (AUD$12.73 in 2018) for every additional metre a property is from a large reserve.
2016	Experimental Ecosystem Accounts for the Central Highlands of Victoria	Central highlands of VIC, of 735,655 ha	The primary aim of the report is to determine the extent to which the concepts and accounting structures of the System of Environmental-Economic Accounting (SEEA) (UN 2014a, UN 2014b) can be populated with existing data to aid decision-making at a regional level.	Agricultural production	Nature reserve	Y	$119 million (AUD$121.32 in 2018)
				Plantations	Nature reserve	Y	$5 million (AUD$5.1 million in 2018)
				Recreation	Nature reserve	Y	$45 million (AUD$45.88 million in 2018)
				Water provision	Nature reserve	Y	$105 million (AUD$107.05 million in 2018)
				Native timber production	Nature reserve	Y	$19 million (AUD$19.37 million in 2018)
				Carbon sequestration	Nature reserve	Y	$70 million (AUD$71.36 million in 2018)
				Industry value	Nature reserve	Y	around $1 billion (AUD$1.02 billion in 2018)
2018	Innovative Finance for Sustainability – Climate	Melbourne	This Options Paper was commissioned by the Environment,	General	Urban forests	Y	Valued totally at $700 million using i-Tree, about $10,000 per tree.

	Adaptation and Living Infrastructure	ACT	Planning and	General	Urban forests	Y	$8 billion of 800,000 trees.

			Sustainable Development Directorate (the Directorate) to explore the contribution that innovative finance solutions can make to delivering on its targets, and their relevance for particular abatement opportunities and emission activities.	Establishment cost	Shaded walk and bike ways - trees with planted under-storey	Y	$48,000 per km
				Maintenance cost	Shaded walk and bike ways - trees with planted under-storey	Y	$2700 per km p.a.
2014	Urban forest strategy - making a great city greener 2012 -2032	Melbourne	The goal of this strategy is to guide the transition of our landscape to one that is resilient, healthy and diverse, and that meets the needs of the community. Its intended outcomes are to create resilient landscapes, community health and wellbeing and a liveable, sustainable city.	Energy saving	Urban forests	Y	982 trees delivered $6,370 (AUD$6676.26 in 2018) in energy savings in several streets.
				Air purification	Urban forests	Y	982 trees remove 0.5 metric tonnes of air pollution per year at a dollar benefit of $3,820 (AUD$4,003.66 in 2018).
				Carbon sequestration	Urban forests	Y	982 trees store 838 metric tonnes of carbon at a dollar value of $19,100 (AUD$20,018.31 in 2018), additional 24 metric tonnes of carbon each year at a dollar value of $548 (AUD$574.35 in 2018) per year.
				Structural value	Urban forests	Y	982 trees have a structural value (replacement cost) of approximately $10.4 million (AUD$10.9 million in 2018).
2013	Urban forest strategy	Sydney	It is a supporting document to the draft Environmental Action 2016 - 2021 Strategy and Action Plan. It reviews the past and present urban forest situation in Sydney and sets environmental targets and actions for the Plan.	Energy saving	Urban forests	Y	One tree cools like 10 air conditioners running continuously annually.
				Water provision	Urban forests	N	One tree absorbs 3400 litres of stormwater.
				Air purification	Urban forests	N	One tree filters 27 kg of pollutants from the air.

2016	Structure, function and value of street trees in California, USA	Municipal forests in California, applied to ACT	This study examines the structure, function and value of California's current street tree population, to scope the concern	Energy, air pollution, stormwater & GHG emissions benefits	Urban forests	Y	Total US$25 to US$33 (AUD$37.86 to AUD$49.98 in 2018) per tree excluding property values.
			for decline of street tree density and to prioritize management challenges at the state and regional levels.	Maintenance cost	Street tree	Y	US$8.05 (AUD$12.19 in 2018) per tree, BCR of about 3.5 to 1 (excluding property value uplift).
2002	Pollution mitigation and carbon sequestration by an urban forest	ACT	This paper presents a case study of the publicly managed urban forests in Canberra of 425,200 trees and an estimate of the contribution these forests can make towards reducing energy consumption, GHG emissions and other pollutants.	Energy saving	urban forests	Y	$1.57 million (AUD$2.27 million in 2018) per year
				Pollution amelioration	urban forests	Y	$1.05 million (AUD$1.52 million in 2018) per year
				Water provision	urban forests	Y	$1.33 million (AUD$1.92 million in 2018) per year
				Carbon sequestration	urban forests	Y	$0.3 million (AUD$0.43 million in 2018) over 5 years
2014	Urban vegetation for reducing heat-related mortality	Melbourne		Heat reduction	Urban forests	N	Decrease of 0.5 to 2 degrees of temperature will reduce the incidence of heat-related mortality by 5 to 28%.
2018	AusPlay ACT data tables	ACT		Sports	General	N	Close to 93% (more than 305,000 Canberrans) aged 15 or over participated in sport or physical activity in the last 12 months. Over 85% aged 15 yrs visit at least once a week and just over 66% at least 3 times per week.
2016	Participation data for the sport sector - Summary of key national findings October 2015 to September 2016 data	Australia		Sports	General	N	88.5% of total adult population participate in outdoor activities at least once a year. 37.2% of children organised field activities out of school hours.

1995	Nonmarket Economic Valuation of an Urban Recreation Park	Centennial Park, Sydney		Recreation	Park	Y	An average value per visit of $10.56 (AUD$18.06 in 2018).
2006	Safe and sustainable trees for the bush capital - an asset management strategy for Canberra's urban trees	ACT		Pruning cost	Urban trees	Y	Trees taller than 15 metres are projected to make up more than 66 per cent of Canberra's ageing urban forest by 2022, the greater requirement to use travel towers would increase estimated pruning costs by $1.4 million (AUD$1.81 million in 2018) per year.

				Pruning cost	Urban trees	Y	Trees less than 14 metres tall can be pruned at $50 (AUD$64.69 in 2018) per hour with a mini tower. Pruning trees that are more than 15 metres tall requires use of a travel tower at a cost of around $170 (AUD$219.96 in 2018) per hour.
				Maintenance cost	Urban trees	N	After growing taller than 20 metres, the chance of a eucalypt developing deadwood or epicormics in the crown each year is more than 50 per cent. Beyond 25 metres tall, this probability increases rapidly to exceed 70 per cent. The ANU research predicts that the number of trees around 20 metres or taller will increase from 39 187 trees in 2005 to 166 351 trees in 2022. This will inevitably increase maintenance costs.
		Australia average		Maintenance cost	Urban trees	Y	The cost per tree for mainly reactive maintenance (excluding capital works) is currently $47 (AUD$60.81 in 2018) but under a three to five year inspection/maintenance cycle it is estimated to fall to $36 (AUD$46.58 in 2018) per tree.
2014	Environmental Policy Analysis: A Guide to Non-Market Valuation	Murray-Darling regions		General	Nature reserve	Y	Per 1% increase in healthy native vegetation will contribute an extra of $2 - $6 (AUD$2.31 to $6.94 in 2018) value per household.
2012	Public greenspace and life satisfaction in urban Australia	Australia average		Recreation	Urban forests	Y	On average, it is found that a resident has an implicit willingness-to-pay of $1,168 (AUD$1,285.35 in 2018) in annual household income for a one-percent (143m^2) increase in public greenspace.
	Design standards for urban infrastructure	ACT		Recreation	Town parks	N	Town parks are formal parks adjacent to and serving the main town centres serving 50,000 to 100,000 people. The minimum area of a town park is 1 ha with the relationship of 0.05 ha per 1000 people.
				Recreation	District parks	N	District parks are extensive informal parks ranging in size from 4 to 10 ha and serving a catchment area of 25,000 to 50,000 people (0.45 ha/1000 people).

				Recreation	Neighbourhood parks	N	Neighbourhood parks are small, usually 0.25 to 2 ha in area (1 ha/1000 people), and are located in residential areas generally within 400 metres of each dwelling.
2013	The effect of street trees on property value in Perth, Western Australia	Perth		Additional property value	Urban trees	Y	A broad-leaved tree on the street verge increases the median property price by about AU$16,889 (AUD$18141.1 in 2018), suggesting a positive neighbourhood externality of broad-leaved trees. However, neither broadleaved trees on the property or on neighbouring properties nor palm trees irrespective of the locations contributed significantly to sale price.

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