AMERICAN FORESTS
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Climate Change and Urban Forests:
Executive Summary

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Executive Summary

Increasing levels of atmospheric carbon dioxide and other "greenhouse" gases (e.g., methane, chlorofluorocarbons, nitrous oxide) are contributing to an increase in atmospheric temperatures by the trapping of certain wavelengths of heat in the atmosphere. The projected changes in climate will affect human health and well-being through generally warmer temperatures, but also changes in precipitation patterns, rising sea levels and increased storm intensities and frequencies. As over 80% of the Unites States population resides in urban areas and many greenhouse gas emissions emanate from urban areas, managing urban areas to mitigate emissions and create resilient cities, given these projected changes, is of paramount importance.

One important attribute in urban areas that can both affect emissions and climate change impacts are urban forests. In 2010, U.S. urban areas occupied 27.4 million hectares (ha) — or 3.6% of land area of the conterminous U.S. — and are projected to increase to 66.0 million ha (8.6%) by 2060. Given that, on average, trees cover 39.4% of urban areas in the U.S., current urban tree cover equates to 10.8 million ha and will increase substantially in the coming years. These trees sequester carbon, but also alter building energy use, which consequently affects emissions from power plants. In addition, these trees alter air temperature and reduce storm water runoff, which can mitigate some of the projected impacts from climate change.

The purpose of this report is to aid in understanding the future impacts of urban forests on climate change mitigation at the county level across the conterminous U.S. This report combines projected changes (2010 to 2060) in urbanization and associated urban tree cover to better understand urban forest impacts related to climate changes.

The report estimates projected changes in urban forests related to carbon storage, building energy use and power plant emissions. Two types of projections were developed: Part 1 addresses projected changes in these effects given projected urban growth; Part 2 projects changes only within existing urban areas (no urban expansion).

Projected Changes to Urban Forest Services Given Projected Urban Expansion

As urban forests and urban populations expand across the nation, urban forests will become increasingly valuable. Between 2010 and 2060, urban land in the conterminous U.S. is projected to grow by 38.5 million ha, with urban tree cover increasing by 10.8 million ha, doubling total urban tree cover to 21.6 million ha. While the amount of urban tree cover will increase as urban land expands, the average percent tree cover in urban is projected to decline from 39.4% in 2010 to 32.8% in 2060. This decline in percent tree cover is largely attributed to tree cover changes in areas of urban expansion and the recent trend in loss of urban tree cover and increase in impervious cover, which is projected to continue into the future.

Overall, total urban forest carbon storage value is projected to increase by $175 billion; energy conservation by $3.3 billion/year; and avoided pollutant emissions by $1 billion/year (Table 1).

Table 1. Summary of projected changes in urban area and forest values due to projected urban expansion. Results by county and state are detailed in Part 1 of the report.

Urban Attribute	2010	2060	Change
Land area (ha)	27.5 million	66.0 million	+38.5 million
Tree cover (ha)	10.8 million	21.6 million	+10.8 million
Tree cover (%)	39.4	32.8	-6.6
Carbon storage (tonnes)	852 million	1.78 billion	+931 million
Carbon storage ($)	160 billion	335 billion	+175 billion
Energy conservation ($)	4.1 billion	7.4 billion	+3.3 billion
Avoided carbon emissions (t)	6.1 million	10.3 million	+4.2 million
Avoided total emissions ($)	1.4 billion	2.5 billion	+1.0 billion

While urban forest carbon storage values will increase substantially, much of this increased value is due to conversion from rural forest storage. Thus, overall carbon storage in rural forests will decrease as urban areas expand, with urban forests gaining some carbon storage from the previously rural land. In addition, while savings from energy use and associated emissions will increase due to increased urban tree cover, overall energy use and emissions will increase as urban areas expand.

Efforts to sustain percent tree cover in urban areas at current levels (39.4%) as urban areas expand are projected to require an annual planting of 25 million trees per year in urban areas, or about one new tree planted annually for every 2.0 ha (4.9 acres) of urban land. Sustaining current percent urban tree cover would retain 353 million tonnes of carbon storage, avoid the emission of an additional 3.3 million tonnes of carbon per year, save an additional $1.9 billion in energy costs per year, and avoid pollutant emissions with an associated value of $729 million per year in the year 2060. Sustaining tree cover through time sustains multi-billion dollars in benefits annually that are otherwise projected to be lost by 2060 in urban areas as urban land expands. These values are conservative as numerous other benefits are not considered (e.g., air pollution removal, air temperature reduction, human health benefits). However, many rural forest values (e.g., carbon storage, timber production, wildlife habitat) will be lost due to urban expansion. Thus, the expansion of urban forests is likely not a net gain in overall forest values for the nation, but rather just a conversion of forests and other land from rural to urban as population expands. This conversion will likely lead to net loss in total forest values as overall forest cover will likely decline; in addition, emissions from urban areas will increase. More research is needed regarding the locally specific drivers and outcomes of changes in tree cover among rural and urban areas as urban areas expand. The information can be used to help develop specific management and policy actions to sustain tree cover and ecosystem services at desired levels.

Projected Changes to Urban Forest Services in Existing Urban Areas

Given recent losses in urban tree cover in many areas, tree cover within existing urban areas is projected to decline in the coming years. Loss of urban trees is due to many reasons, including urban development (removal of healthy trees), storms, insects and diseases and old age (attrition). A net loss in tree cover indicates that the loss of existing tree canopies is greater than new canopy cover generated through tree growth, natural regeneration and tree planting. Between 2010 and 2060, urban tree cover in existing urban areas (2010) is projected to decrease 39.4% in 2010 to 31.0% in 2060. Overall, total urban forest carbon storage value is projected to decrease by $34 billion; energy conservation by $855 million/year; and avoided pollutant emissions by $318 million/year (Table 2).

Table 2. Summary of projected changes in urban area and forest values within existing urban areas. Results by county and state are detailed in Part 2 of the report.

Urban Attribute	2010	2060	Change
Tree cover (ha)	10.8 million	8.5 million	-2.3 million
Tree cover (%)	39.4	31.1	-8.3
Carbon storage (tonnes)	852 million	671 million	-180 million
Carbon storage ($)	160 billion	126 billion	-34 billion
Energy conservation ($)	4.1 billion	3.3 billion	- 855 million
Avoided carbon emissions (t)	6.1 million	4.7 million	-1.4 million
Avoided total emissions ($)	1.4 billion	1.1 billion	-318 million

To sustain urban tree cover through 2060, on average, 23 million trees would need to be planted annually. On average, this planting equates to a national rate of one new tree annually for every 1.2 ha (3.0 acres) of urban land. Planting 23 million trees per year also equates to each urban resident planting one tree every 11.5 years, or about seven trees during their lifetime, to sustain tree cover in existing urban areas. By reducing projected tree losses (i.e., enhancing preservation of existing canopy), fewer trees would need to be planted to sustain tree cover. Canopy preservation is often a better option to sustain tree cover than planting as existing trees are already established and larger than planted trees. Sustaining current percent tree cover will prevent these losses by sustaining an additional 180 million tonnes of carbon storage and avoiding the emission of an additional 1.4 million tonnes of carbon (Table 2). Additional urban forest values (e.g., air pollution removal, air temperature reduction, human health benefits) would also be sustained.

Projection Limitations

The projected changes in urban forest ecosystem services are uncertain, with uncertainty increasing as one projects farther into the future. As these projections are often based on current trends, numerous factors in the future could change these projections (e.g., environmental changes, economic changes, urban forest management and urban development policies and patterns). However, the projections illustrate potential changes in urban forest cover and associated ecosystem services given current patterns of change.

As projections are based on recent trends, some estimates are likely overestimates (e.g., loss of urban tree cover in Central Plains states). All estimates will be subject to fluctuations due to numerous factors. As the environment changes so will the forces that affect urban forest health and productivity. Some factors will enhance, and others will decrease health and productivity. In context with the limitations, projected changes can be used as a starting point for discussion on where to direct policies and management to protect future urban forests and populations. Human decisions related to implementing policies and management actions will ultimately guide urban forest change in the coming years.

Climate Change and Urban Forests:
Part 1: Urban Forest Projections with Urban Expansion

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1. Introduction

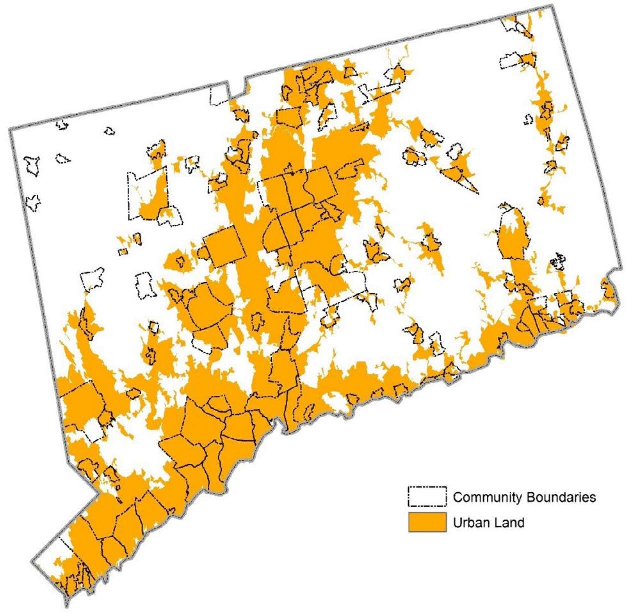
This report is Part 1 of a two-part report. Part 1 is designed to aid in understanding the future impacts of urban forests on climate change mitigation given projected future urban expansion. This part only addresses the impacts within urban areas as they expand and does not address the concomitant changes that will occur in rural land as rural lands decrease in area. Part 2 is designed to aid in understanding the future impacts of urban forests on climate change mitigation with no urban expansion. Results are projected at the county level across the conterminous United States for the years 2010, 2030 and 2060. This report does not investigate the impact of climate change on urban forests, rather it investigates how projected urban development will affect future urban tree cover and urban forest impacts on greenhouse gases (Part 1), as well as how projected changes in tree cover in existing urban areas will affect greenhouse gases (Part 2).

Urban forests are defined as all trees within urban areas, from individual trees (e.g., on front lawns) to trees embedded in natural forest stands. The term urban tree cover refers to the canopy cover produced by urban forests.

Urban land is delimited based on U.S. Census Bureau definitions (U.S. Census Bureau 2020). Urban areas (Figure 1) represent densely developed territory and encompass residential, commercial and other non-residential urban land uses. For the 2010 Census, an urban area is composed of a densely settled core of census tracts and/or census blocks that meet minimum population density requirements, along with adjacent territory containing non-residential urban land uses, as well as territory with low population density included to link outlying densely settled territory with the densely settled core. To qualify as an urban area, the territory identified according to criteria must encompass at least 2,500 people, at least 1,500 of which reside outside institutional group quarters. The Census Bureau identifies two types of urban areas:

- Urbanized Areas (UAs) of 50,000 or more people;
- Urban Clusters (UCs) of at least 2,500 and less than 50,000 people.

Figure 1. Urban land and community boundaries in Connecticut.



This report projects urban development and tree cover change in urban areas through 2060, and its associated impacts on carbon storage, building energy use and associated carbon emissions from building energy use. Changes (2010-2030; 2010-2060) within urban areas are assessed for each county. Three future scenarios are assessed:

1. *Current Trend* – tree cover change based on projected urban growth.
2. *Conserve Canopy* – similar to current trend projections, but percent urban tree cover held to a minimum of the 2010 percent tree cover value.
3. *Enhance Canopy* – similar to conserve canopy projections, but also includes a 10% relative increase in tree cover.

Results in the report are presented within tables and maps. Methods for each projection will be discussed first, followed by resulting tables and maps illustrating variations in these themes across the conterminous U.S.

2. Methods

2.1. Projected Urban Development and Tree and Impervious Cover

Urban expansion in the U.S. was projected for 2010-2060, based on the average growth within county urbanization classes between 1990 and 2010. Methods and results of these methods are given in Nowak and Greenfield (2018b). For each decade, the amount of urban land at the start of the decade, and new urban land added during the decade, was calculated for each county. The 2010 starting percent urban tree cover was estimated using NLCD tree cover maps (MRLC 2020) for: a) urban land (2000) remaining urban land (2010); and b) rural land (2000) converting to urban land (2010).

As NLCD tree cover is known to underestimate actual tree cover (Nowak and Greenfield 2010), photo-interpretation was conducted to help determine actual tree cover values. State urban tree cover values were determined through photo-interpretation of 1,000 points per state using c. 2014 aerial photos (Nowak and Greenfield 2018a). Urban tree cover estimates for 2010 were adjusted based on ratio of the state average urban tree cover to the estimated urban tree cover based on photo-interpretation:

County Urban Tree Cover = county urban tree cover (NLCD 2011) x state urban photo-interpreted tree cover c. 2014 (%) / state urban NLCD tree cover (%)

It is important to note that just because rural land converts to urban land, not all the land cover will change (e.g., to developed land cover). Urban conversion indicates an increase in population density and development but does not necessarily lead to a complete land cover conversion to developed land. For example, on average, about 20% of forest land remains as forest when rural land converts to urban land (Nowak and Walton 2005).

To project urban tree cover for each decade (2020-2060), the percent urban tree cover at the start of the decade in each county was adjusted by the projected average annual relative percent change in urban tree cover from the associated state average (c. 2009-2014) (Nowak and Greenfield 2018a). For example, if state urban tree cover changed from 50% to 49% between 2009 and 2014, that would equate to a 1% drop over 5 years, or -0.2% per year. The -0.2% annual change was converted to a relative change based on the starting tree cover percentage (e.g., -0.2/50 = -0.004% change per relative to existing tree cover). This relative change value was applied to the tree cover from the previous year to project tree cover annually (e.g., tree cover in county in 2010 = 40%; 2011 = (40% x -0.004) + 40% = 39.8%; 2012 = (39.8% x -0.004) + 39.8% = 39.7%, …). The new percent tree cover was applied to urban land remaining urban at the end of the decade to estimate total tree cover in this area.

Total tree cover within urban expansion areas was based on the county-specific percent tree cover from the rural to urban land conversion (2000-2010) multiplied by the land area of urban expansion. The proportion of tree cover in urban expansion areas among NLCD land cover classes was also recorded. Total decadal urban tree cover (2020-2060) was calculated by adding total tree cover in urban land remaining urban and rural land converting to urban land at the end of each decade. For counties with no urban land in 2010, but with urban land in future years, estimates of percent urban tree cover in future years (2030, 2060) were derived from the neighboring county with the closest county geographic center to existing county center. Urban impervious cover was also projected using similar methods as for tree cover. Impervious cover projections are needed to assess future potential plantable spaces.

Urban population data by county for 2010 were derived from U.S. Census Bureau (2020). Urban population estimates for 2030 and 2060 were derived from U.S. Forest Service Resources Planning Act (RPA) socioeconomic projections[1] (Wear and Prestemon 2019; https://www.fs.usda.gov/rds/archive/catalog/RDS-2019-0041). The RPA projected total county population. To estimate urban populations, the percent of the county's population that was urban in 2010 was applied to future total county populations. This process will likely underestimate future urban populations as the percent urban population is likely to increase in the coming years. Various climate change scenarios were projected in the RPA, but this project used a middle of the road projection of the SSP2 scenario (https://www.fs.usda.gov/rds/archive/catalog/RDS-2018-0014).

2.2. Projected Urban Forest Impacts on Reducing Greenhouse Gas Emissions

Urban forests can affect atmospheric carbon dioxide by:

- Sequestering atmospheric carbon as the tree grows
- Emitting carbon as a tree decomposes
- Altering building energy use and consequent carbon and other emissions from power plants

1. Urban population for 2030 and 2060 is based on the RPA projections of total population of CONUS minus two island counties of MA (Nantucket and Dukes) with urban population. For those two counties, the urban population was set to 2010 values for 2030 and 2060.

In addition, trees reduce air temperatures through tree shade and transpiration, and this cooling can offset some of the projected temperature increases in urban areas. While temperature effects are not estimated in this project, tree cover can be used as a proxy for temperature effects (i.e., areas with greater percent tree cover will likely have relatively lower air temperatures). Tree shade and temperature reduction can also have direct effects on building energy use and consequently carbon emissions from energy production. Shade effects from trees will vary depending on tree size and position around a building with tree shade due to leaves and branches often increasing building energy use during heating seasons (Nowak et al. 2014). The effects of tree shade on energy use are relatively greater on smaller residential buildings than larger downtown buildings.

2.2.1. Carbon Storage and Sequestration

Projected decadal urban tree cover (m^2) was converted to total carbon storage and net annual sequestration based on national urban forest carbon storage values (7.69 kgC/m^2 tree cover) and state specific net sequestration values (Nowak et al. 2013). Net sequestration values are based on estimated gross sequestration due to tree growth minus an estimated loss of carbon due to decomposition from tree death and decay. Net sequestration rates vary depending upon land use and tree health. Based on field data assessments from several cities, the average net sequestration rate averages 74% of the gross sequestration rate (Nowak et al. 2013).

2.2.2. Building Energy Use and Altered Power Plant Emissions

Projected decadal urban tree cover (m^2) was converted to estimated changes in building energy use and avoided power plant emissions based on methods detailed in Nowak et al. (2017). These methods combined field data on urban trees with local urban/community tree and land cover maps, modeling of tree effects on building energy use and pollutant emissions, and state energy and pollutant costs to estimate tree effects on building energy use and associated pollutant emissions at the state to national level in the conterminous U.S. Avoided emissions were estimated for carbon dioxide (CO_2), nitrogen oxides (NO_x), sulfur dioxide (SO_2), volatile organic compounds (VOCs), and particulate matter less than 2.5 microns ($PM_{2.5}$). State specific values of energy changes and avoided emissions per m^2 of tree cover by NLCD land cover class were applied to decadal urban tree cover estimates by NLCD class within urban areas to derived county estimates. Energy and emission values were based on 2018 values. Emissions are reported as the sum value for all avoided emissions. Emissions values are detailed in Nowak et al. (2017) with the exception that the values for avoided NO_2, SO_2 and $PM_{2.5}$ were based on average county health values per tonne of pollution as derived from BenMAP analyses as detailed in Nowak et al. (2014).

2.3. Projection Scenarios

Three county-based projections (2010-2060) of urban forest impacts on carbon storage, building energy use and power plant emissions were conducted:

1. *Current trend* – estimates based on projected trends of increasing urban development and overall urban tree cover.
2. *Conserve Canopy* – although urban forest area will expand in extent due to urban expansion, percent tree cover within urban areas is projected to decline. This scenario holds percent urban tree cover in the current trend analysis at a minimum of the 2010 percent tree cover value for each decade.

3. *Enhance Canopy* – similar to the conserve canopy projections but includes a 10% relative increase in tree cover over the 2010 percent tree cover values.

2.3.1. Current Trend Projections

This scenario projects changes in tree cover and urban forest impacts based on projected urban expansion as described in sections 2.1. and 2.2. This current trend projection is reported for years 2030 and 2060. Subsequent projections of conserved and enhanced canopy are reported for year 2060 as a comparison of change among projections.

2.3.2. Conserve Canopy Projections

This scenario was designed to simulate maintaining, through canopy preservation, a minimum of the 2010 percent tree cover in urban areas of each county through the years. In this scenario, if percent urban tree cover in any year dropped below the starting percent tree cover value in 2010, it was assumed that canopy preservation or tree establishment would occur to prevent this potential loss. However, as percent tree cover could increase, when increases in percent tree cover did occur, they were retained. Thus, percent tree cover in each year could exceed the 2010 minimum but could not be lower than this minimum value. Hectares of tree cover needing to be conserved for each county was calculated and converted to number of trees needing to be conserved or established based on an average tree density of 511 trees per hectare of urban tree cover (Nowak and Greenfield 2018b).

2.3.3. Enhance Canopy Projections

This scenario builds upon the Conserve Canopy scenario of maintaining a base minimum percent urban tree cover and assumes a long-term tree canopy goal of an additional 10% tree cover above the base minimum. This 10% increase is a relative increase, such that if the base minimum tree cover was 50%, the canopy goal would be increased to 55% (a 10% increase).

As tree cover varies by regional conditions, so should canopy enhancement rates based on regional environmental conditions. Urban tree cover is highest in forested regions, followed by grasslands and deserts, mainly due to variations in precipitation and seed sources (Nowak and Greenfield 2018b, 2020). To determine the average percent urban tree cover and percent plantable space within U.S. biomes (Table 1), each county was classified as either forest, grassland or desert based on global biome maps (Bailey 1995; Olson and Dinerstein 2002; Nature Conservancy 2018). Percent potentially plantable space was calculated as 100% minus percent tree cover minus percent impervious cover (i.e., land area that is not covered by trees or impervious surfaces).

The proportion of plantable space needing to be planted to increase tree cover by 10% for each biome was calculated as: TC x 0.1 / PS x 100, where TC = percent tree cover and PS in percent plantable space in ecoregion (Table 1). This establishment of new tree cover within potentially plantable areas distributes more tree cover in areas where trees can be more readily established (i.e., forest areas) and minimizes new tree establishment in more water constrained areas (i.e., grassland and desert areas).

The proportion of plantable space in each county was multiplied by the corresponding %plant (Table 1) to estimate the hectares of new tree cover needed to increase tree cover by 10%.

Table 1. U.S. urban forest cover information by biome.

Biome	% of total US urban area[a]	Tree cover[b]	Plantable space[c]	% plant[d]
Desert	6.6	19.1	45.0	4.2
Forest	78.2	43.2	31.9	13.5
Grassland	15.3	28.8	39.7	7.3
U.S. Average	100	39.4	34.0	11.6

[a] *conterminous United States*
[b] *average percent tree cover in biome (c. 2014)*
[c] *average percent plantable space in biome (c. 2014)*
[d] *percent of plantable space needing to be planted to increase tree cover by 10%*

To create a sustainable canopy, this new desired tree cover was not all added in one year but was distributed and added in equal increments over a 50-year period to prevent large even-aged tree cover additions. For each year, the additional amount of new plantable space created by urban expansion from the previous year was also multiplied by the corresponding %plant (Table 1) and distributed over a 50-year period.

Although the average increase in tree cover among all counties was 10%, the actual increase in tree cover was actually 6.7% nationally (2010 = 39.4% tree cover; 2060 = 42.0%) due to variability among counties in tree cover, urban growth and county size. Because of distributing the desired additional tree cover over a 50-year period, an actual 10% increase in cover will not be attained by 2060, as new cover will continue to be added after 2060. In the long run with sustained additions of new tree cover (%plant in Table 1), a 10% increase would be attained. Estimated increases in tree cover varied from 0.2% to 57% among counties (average = 10%), with a weighted national average of 6.7%. This new tree establishment assumes that the 2010 tree cover percentage is conserved and that the new additional tree cover added annually is also conserved through time. Hectares of new tree cover added each year by county was converted to number of trees needing to be added based on an average tree density of 511 trees per hectare of urban tree cover[2] (Nowak and Greenfield 2018b). Even though percent tree cover varies among biomes, tree density values per unit of tree cover standardizes the values per unit tree cover. Tree density numbers will vary locally based on local conditions.

For all scenarios, the changes in projected urban tree cover were used to project changes in carbon storage and sequestration as detailed in section 2.2.1. For building energy and avoided emission estimates, changes in urban cover were distributed proportionally among tree cover in NLCD classes to estimate annual tree cover in each NLCD class. These new tree cover estimates were used to estimate energy changes and avoided emissions as detailed in section 2.2.2.

3. Results / Discussion

This section displays the results as maps, as well as in tables, for state averages and results for the top 10 and bottom 10 counties relative to the changes in 2060. Note that these projections are based on the assumptions detailed in the methods and are not projections of what will happen, but rather projections of what would happen if the assumptions and trends in the methods hold true. The farther out one projects into the future, the more unlikely that these trends will hold true. However, while the absolute values of change are likely inaccurate over a 50-year projection, the data reveal probable areas of greatest change in the coming years. The projections and trends may change in the future if various policies or other factors change (e.g., economic depression) that would alter future conditions. To that end, by understanding projected changes, management and policies, actions could be implemented to direct the future to the most desirable outcomes.

3.1. Projected Urban Development and Tree Cover

3.1.1. Urban Population

Assuming no increase in the proportion of urban population in counties, the urban population in the conterminous U.S. is projected to increase by 91 million by 2060, increasing from 247.5 million (2010, Figure 2) to 338.4 million (2060). States with the greatest urban population increase are Texas, California and Florida (Table 2). Counties with the greatest urban population increase are Maricopa County, Ariz. (Phoenix area), Harris County, Texas (Houston area) and Clark County, Nev. (Las Vegas area) (Table 3; Figure 3).

State	Population Δ
Texas	14,823,000
California	13,318,000
Florida	10,995,000
Georgia	4,806,000
Arizona	4,202,000
North Carolina	3,004,000
Colorado	2,835,000
Virginia	2,834,000
Washington	2,757,000

Table 2. Projected change (Δ) in urban population (2010-2060) by state.

2. The mean tree density per hectare of tree cover has a standard error of 106 (21% coefficient of variation).

State	Population Δ
Nevada	2,675,000
Utah	1,799,000
Tennessee	1,644,000
New York	1,574,000
Illinois	1,522,000
Maryland	1,439,000
South Carolina	1,316,000
New Jersey	1,283,000
Oregon	1,218,000
Minnesota	1,191,000
Pennsylvania	1,176,000
Louisiana	1,096,000
Missouri	1,042,000
Ohio	999,000
Alabama	938,000
New Mexico	914,000
Massachusetts	892,000
Indiana	873,000
Oklahoma	838,000
Wisconsin	760,000
Kentucky	649,000
Arkansas	646,000
Michigan	578,000
Idaho	576,000
Kansas	566,000
Mississippi	516,000
Connecticut	388,000
New Hampshire	313,000
Nebraska	295,000
Iowa	278,000

State	Population Δ
Delaware	185,000
Montana	171,000
South Dakota	165,000
Wyoming	158,000
West Virginia	153,000
Rhode Island	141,000
Maine	132,000
North Dakota	127,000
Vermont	73,000

Table 3. Projected change (Δ) in urban population (2010-2060) for the 10 counties with highest and lowest change.

County	State	Population Δ
Maricopa County	Arizona	2,812,500
Harris County	Texas	2,295,200
Clark County	Nevada	2,173,500
Los Angeles County	California	1,903,300
Riverside County	California	1,848,000
San Diego County	California	1,275,100
San Bernardino County	California	1,242,100
Collin County	Texas	1,227,600
Gwinnett County	Georgia	1,222,000
Tarrant County	Texas	1,027,400
Genesee County	Michigan	-3,700
Erie County	New York	-8,500
District of Columbia	District of Columbia	-9,100
Lake County	Indiana	-12,000
Allegheny County	Pennsylvania	-15,400
Essex County	New Jersey	-20,300

County	State	Population Δ
Baltimore city	Maryland	-31,200
St. Louis city	Missouri	-48,100
Cuyahoga County	Ohio	-64,000
Wayne County	Michigan	-205,600

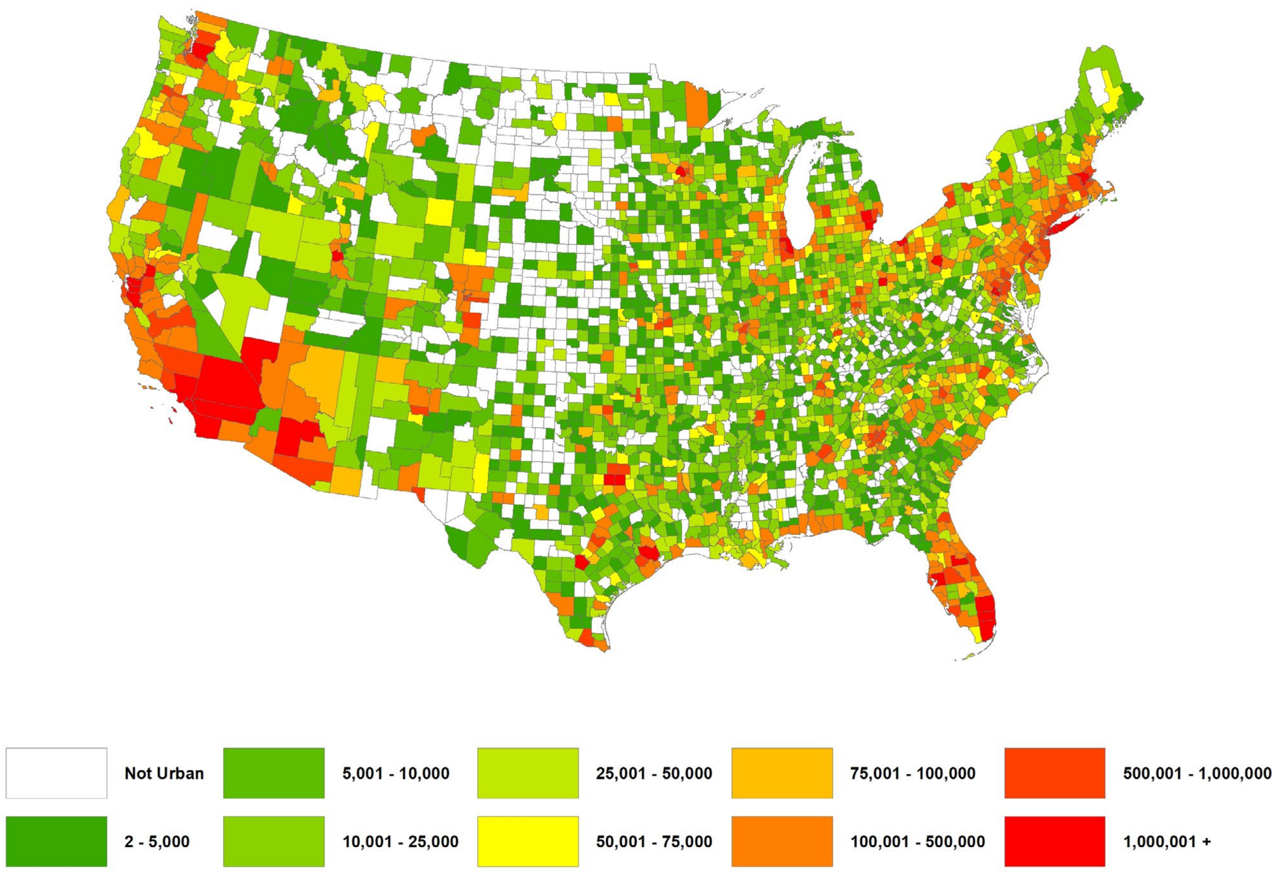


Figure 2. Urban population by county (2010).

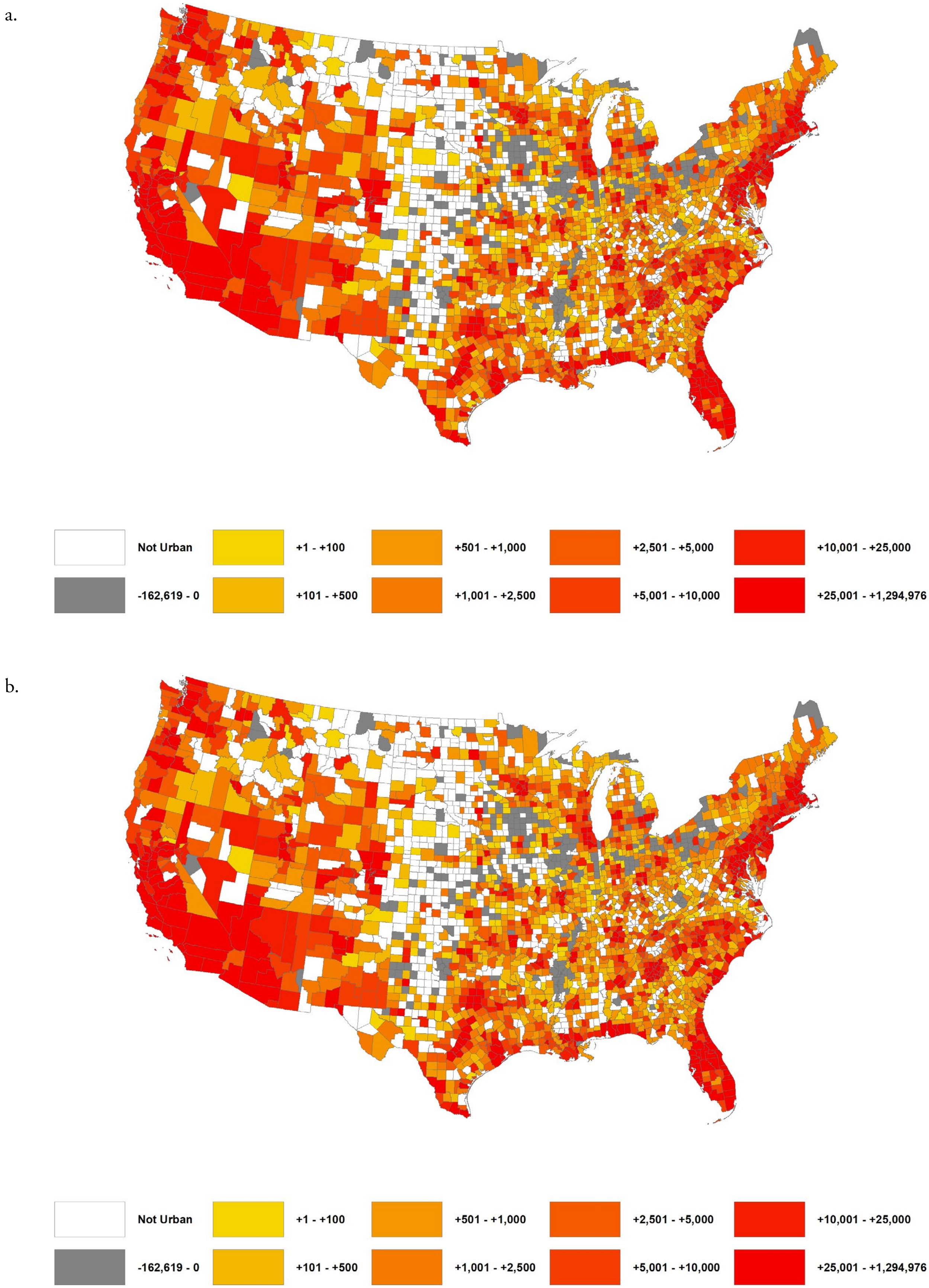


Figure 3. Projected urban population growth: a) 2010-2030, b) 2010-2060. Population growth was not projected for counties with no urban land in 2010.

3.1.2. Urban Land

Urban land in the conterminous U.S. is projected to increase by 38.5 million ha (5.0%) by 2060, increasing from 27.4 million ha (3.6%, 2010, Figure 4) to 66.0 million ha (8.6%, 2060) (Nowak and Greenfield 2018b). States with the greatest projected increase in percent urban land are Rhode Island, Delaware and Connecticut (Table 4). Counties with the greatest increase in percent urban land are Jefferson Parish, La. (near New Orleans), Lake County, Ind. (Gary, Ind. area) and Rockdale County, Ga. (near Atlanta) (Table 5; Figure 5).

State	Urban land Δ (%)
Rhode Island	34.8
Delaware	29.3
Connecticut	27.6
Massachusetts	22.7
New Jersey	22.6
Maryland	21.9
Florida	17.9
North Carolina	13.6
South Carolina	13.6
Pennsylvania	13.3
Ohio	12.7
Indiana	10.5
New Hampshire	10.5
Tennessee	10.4
New York	9.9
California	9.2
Georgia	8.6
Alabama	8.2
Louisiana	8.2
Michigan	8.0
Illinois	7.6
Virginia	7.0
Washington	6.3
Kentucky	5.9

Table 4. Projected change (Δ) in percent urban land (2010-2060) by state (Nowak and Greenfield 2018b).

State	Urban land Δ (%)
West Virginia	5.8
Wisconsin	5.7
Mississippi	5.1
Texas	4.4
Arkansas	4.3
Missouri	4.2
Arizona	4.0
Iowa	3.3
Vermont	3.3
Colorado	3.1
Oklahoma	3.0
Minnesota	2.8
Maine	2.6
Oregon	2.2
Kansas	1.9
Utah	1.8
Idaho	1.4
Nevada	1.4
New Mexico	1.3
Nebraska	1.2
South Dakota	0.8
North Dakota	0.7
Montana	0.6
Wyoming	0.4

Table 5. Projected change (Δ) in percent urban land (2010-2060) for the 10 counties with the greatest increase. Several counties exhibit no urban growth as these counties were 100% urbanized (e.g., New York County, N.Y.).

County	State	Urban land Δ (%)
Jefferson*	Louisiana	37.3
Lake	Indiana	36.5
Rockdale	Georgia	36.5
Alameda	California	36.4
Lehigh	Pennsylvania	36.4
Chesterfield	Virginia	36.4
Muscogee	Georgia	36.3
Bucks	Pennsylvania	36.3
Shelby	Tennessee	36.3
Chester	Pennsylvania	36.2

**Parish*

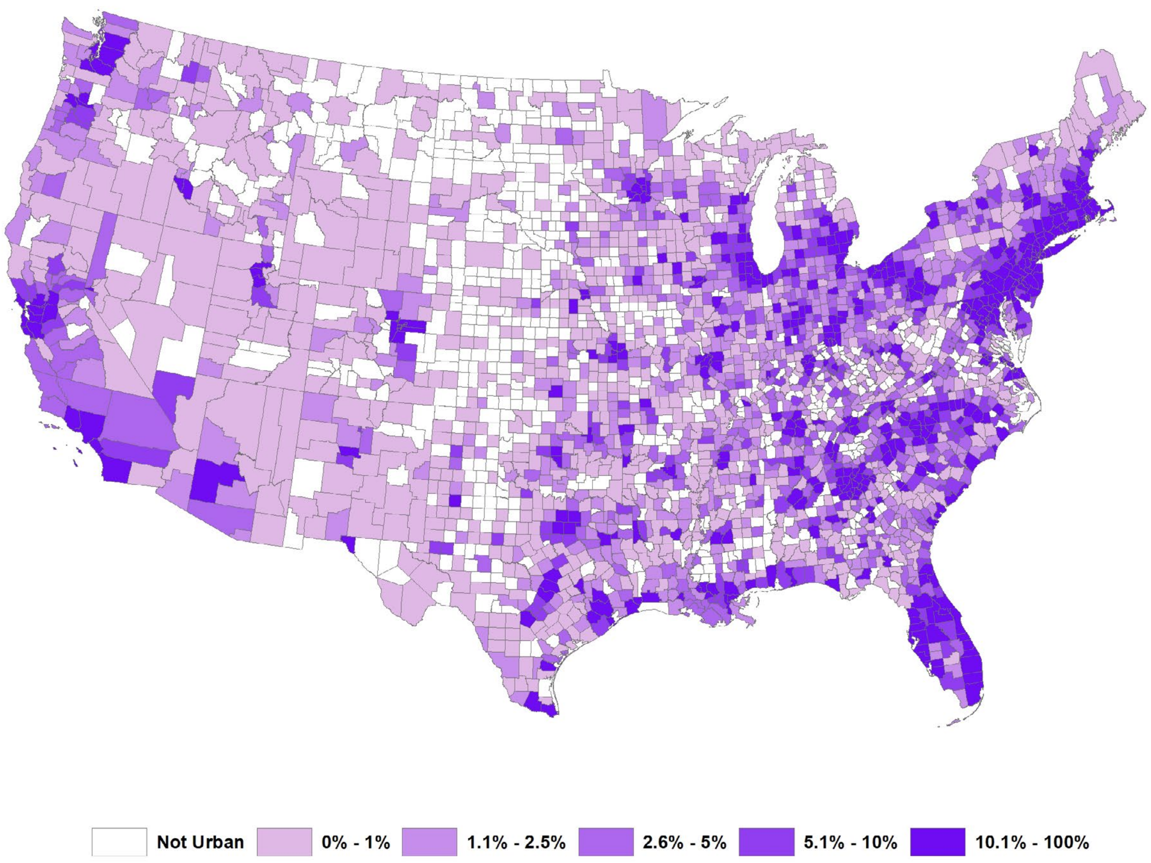
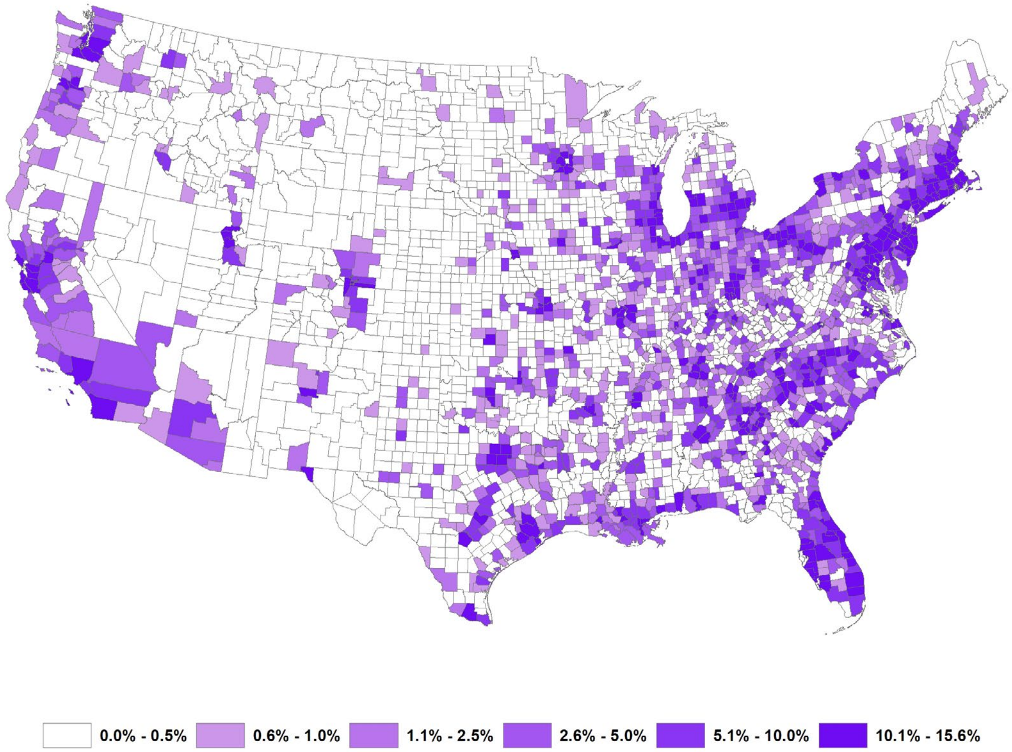


Figure 4. Percent urban land in counties (2010).

a.



b.

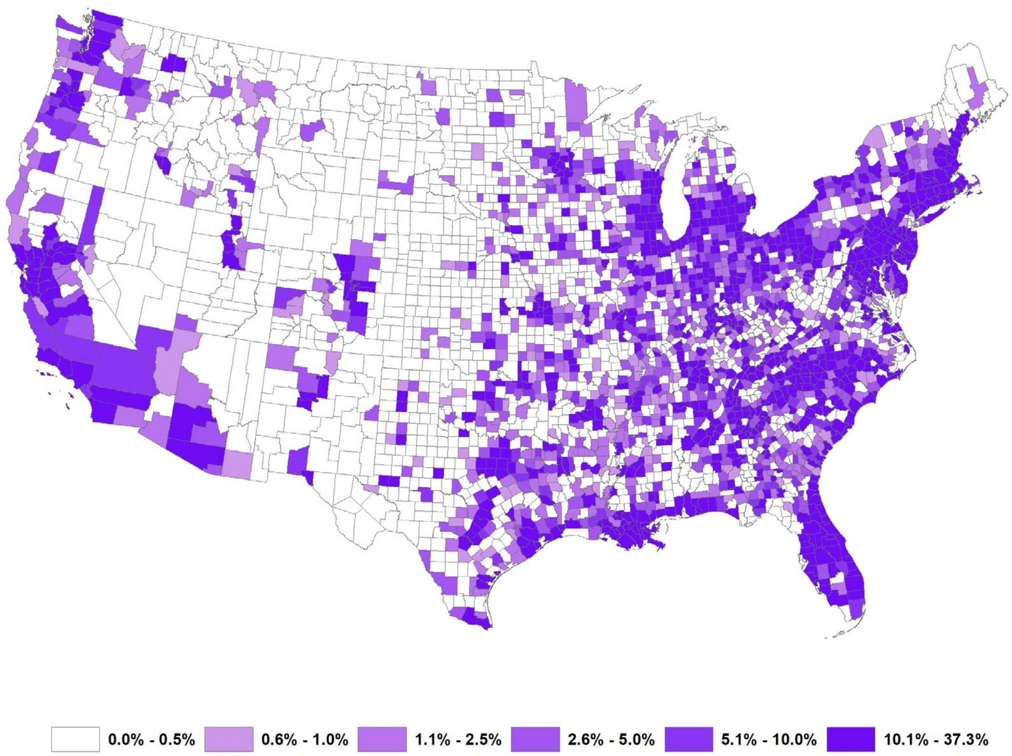


Figure 5. Increase in percent urban land: a) 2010-2030, b) 2010-2060.

3.1.3. Percent Urban Tree Cover

While urban land is projected to expand in the coming decades, the percent urban tree cover is projected to decrease by 5.8% by 2060, decreasing from 39.4% (2010, Figure 6) to 33.6% (2060). Tree cover gained through urban expansion is expected to some of the projected tree cover loss in existing urban areas (see Part 2), but this urban tree cover gain comes from previously rural tree cover (thus, rural lands are losing tree cover). States with the greatest projected decrease in percent urban tree cover are Kansas, Oklahoma and Iowa (Table 6). Many states in the Central plains are projected to lose urban tree cover as these states exhibited recent tree cover loss (c. 2009-2014; Nowak and Greenfield 2018a) and urban expansion is limited within forested areas, which will limit the amount of new existing forest tree cover that is subsumed by urban expansion. Recent trends of tree cover change influence the projections (i.e., areas losing tree cover will continue to lose tree cover), but these recent trends may change in the coming years due changes in policies related to tree protection, new tree plantings and/or natural regeneration changes.

Counties with the greatest decrease in percent urban tree cover are Clayton, Iowa (near Dubuque), McCurtain, Okla. (southeastern Oklahoma) and Ohio, West Virginia (Wheeling, W.Va.) (Table 7; Figure 7). Kansas and Oklahoma had the greatest projected reduction in tree cover. The relatively high loss in Kansas is due mainly to urban expansion while the loss in Oklahoma is also influenced by relatively high recent tree cover losses that are projected into the future. Oklahoma has the most counties in the top 10 with the greatest percent reduction in tree cover. This magnitude of tree cover is likely an overestimate as the current loss in cover will likely not be sustained in the coming decades. This same issue likely holds for other counties with substantial (e.g., >10%) loss in urban tree cover, but these counties are under considerable threat for tree cover loss given current trends.

State	Tree cover Δ (%)
Kansas	-19.2
Oklahoma	-16.8
Iowa	-16.4
Tennessee	-15.8
Nebraska	-15.6
Illinois	-13.9
Arkansas	-13.8
Georgia	-13.5
Montana	-11.8
Kentucky	-11.4
Oregon	-11.3
Missouri	-9.6

Table 6. Projected change (Δ) in percent urban tree cover (2010-2060) by state.

State	Tree cover Δ (%)
Ohio	-9.2
Minnesota	-9.2
Mississippi	-8.9
Indiana	-8.8
North Dakota	-8.7
Arizona	-8.6
Louisiana	-8.5
Texas	-8.1
South Dakota	-7.8
West Virginia	-7.7
Virginia	-5.8
Vermont	-5.6
Alabama	-5.6
Utah	-4.5
Delaware	-3.9
North Carolina	-3.7
Nevada	-3.6
New York	-3.6
Maryland	-3.5
Washington	-3.2
Colorado	-2.2
Wisconsin	-0.9
Maine	-0.6
Massachusetts	0.1
South Carolina	0.2
California	0.2
New Mexico	0.4
Pennsylvania	1.1
New Jersey	1.2
Idaho	1.9

State	Tree cover Δ (%)
Florida	2.0
Wyoming	3.7
New Hampshire	4.4
Michigan	4.7
Connecticut	4.9
Rhode Island	6.8

Table 7. Projected change (Δ) in percent urban tree cover (2010-2060) for the 10 counties with highest and lowest change.

County	State	Tree Cover Δ (%)
Clayton	Iowa	-34.9
McCurtain	Oklahoma	-27.9
Ohio	West Virginia	-26.4
Nevada	Arkansas	-25.9
Delaware	Oklahoma	-25.9
Le Flore	Oklahoma	-25.6
Putnam	Georgia	-25.5
Scott	Mississippi	-25.1
McNairy	Tennessee	-24.1
Atoka	Oklahoma	-24.0
Luce	Michigan	12.5
Owyhee	Idaho	12.7
Keweenaw	Michigan	12.8
Marquette	Michigan	12.8
Mason	Michigan	13.8
Alpena	Michigan	14.1
Muskegon	Michigan	14.7
Erie	Pennsylvania	14.7
Dickinson	Michigan	16.8
Presque Isle	Michigan	18.7

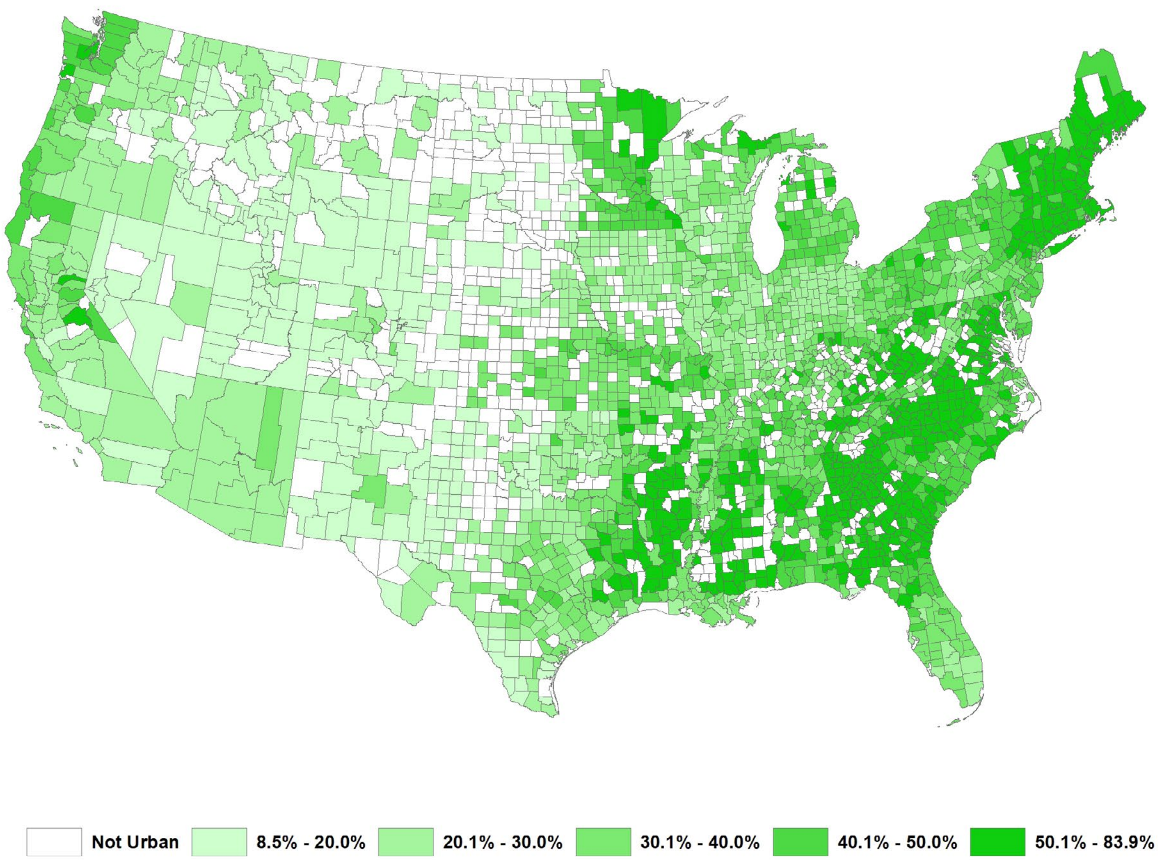


Figure 6. Percent tree cover in urban areas by county (2010).

a.

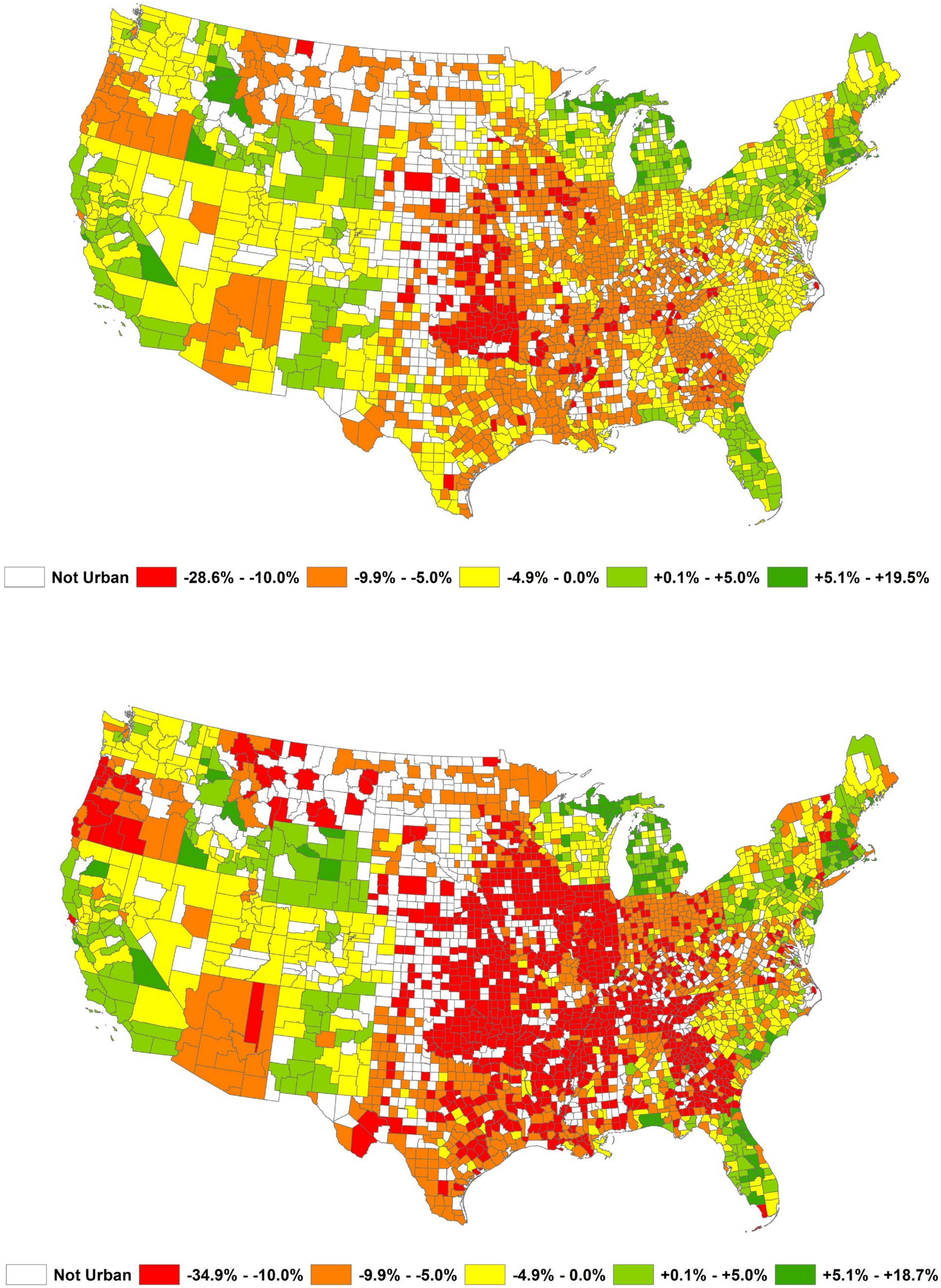


Figure 7. Change in percent urban tree cover: a) 2010-2030, b) 2010-2060. Counties with no urban land in 2010 are excluded.

3.2. Projected Changes in Urban Forest Ecosystem Services and Values

The changes in extent of urban land (i.e., urban expansion) and changes in tree cover within urban areas will directly affect the ecosystem services and values of the urban forest in the future. That is, the amount of future urban tree cover is a main driver of future ecosystem services and values in, and around, urban areas. The actual rate of ecosystem services per unit tree cover will likely change in the future as species composition and environmental conditions change. Many of these future changes are unknown as not only does the environment change urban forests, but so do human actions. Many natural projections of change may be altered by human actions. For example, while species compositions are projected to change (e.g., Iverson and Prasad 2001), management in urban areas may accelerate or diminish the change based on tree planting and removals. Projections do not account for policy changes that could affect tree cover (e.g., large tree planting campaigns) or various forces that could devastate the local urban forest (e.g., hurricanes, insect or disease outbreaks).

Given that urban land is projected to increase and percent tree cover with urban areas is projected to decline, on average approximately 26 million additional new trees will need to be established annually to account for the loss of tree cover and keep percent urban tree cover at current levels in 2060 nationally. In addition, the tree cover that remained during this time also needs to be sustained. Assuming a nominal 1% mortality rate of the base tree cover that remained during this time period, an additional 47 million trees will need to be established annually to sustain the base tree cover. Thus, a total of approximately 73 million trees would need to be established each year to sustain urban tree cover. As about two-thirds of existing trees come from natural regeneration (Nowak 2012), annual tree planting nationally would need to be about 24 million trees to sustain current percent tree cover levels from 2010 to 2060 given current urban tree cover projections. On average, this planting equates to a national rate of one new tree planted annually for every 2.0 hectares (5.0 acres) of urban land. To enhance tree cover by 10%, an average of an additional 19 million trees would need to be established annually.

In the future, climate change could affect carbon storage and sequestration rates, but there are various counter-indications as to what might happen to carbon storage and sequestration. While climate change effects of increased CO_2 and longer growing seasons will increase growth rates (e.g., Taub 2010, Deryng et al. 2016) and potentially stand densities (Devi et al. 2020), decreasing wood densities (Pretzsch et al. 2018) and possible decreased life spans due to increased growth rates when young (Büntgen et al. 2019) may offset carbon gains of increased growth. Given the uncertainties of future carbon densities per m^2 of tree cover, projections of urban forest carbon effects use current carbon storage and sequestration densities.

3.2.1. Carbon Storage and Value

Carbon storage values are related to tree species, sizes and densities, while annual carbon sequestration relates these same factors plus annual growth and mortality rates. Carbon storage is estimated based on the national average carbon storage density (kgC/m^2 tree cover) from several U.S. cities. Gross carbon sequestration (kgC/m^2 tree cover/yr) is based on state-specific growth rates and average tree competition and conditions as derived from the sample of U.S. cities. Net sequestration accounts for carbon losses due to mortality and tree decomposition and are estimated as 74% of gross sequestration (Nowak et al. 2013).

Carbon storage in U.S. urban forests is projected to increase by 975 million tonnes (+114%) by 2060, increasing from 852 million tonnes (2010, Figure 8) to 1.83 billion tonnes (2060). Given the 2020 value of the social cost of carbon ($188/tC in 2018 dollars; Interagency Working Group on Social Cost of Carbon 2016), the carbon storage value of the urban forest will increase by $183 billion by 2060, increasing from $160 billion (2010) to $343 billion (2060). This increase in carbon storage is due to the expansion of urban land. While urban forest storage will increase, carbon storage in rural forests will decrease as there will be less rural forest land. On average, only about 14% of urban lands contain forested stands (Nowak et al. 2013). Thus, as rural forested areas convert to urban land, they will lose a large proportion of their forest extent and, thus, associated carbon storage.

States with the greatest projected increase in urban forest carbon storage are Florida, California and North Carolina (Table 8). Counties with the greatest increase in urban forest carbon storage are Worchester County, Mass. and San Bernardino and Los Angeles counties, Calif. (Table 9; Figure 9).

Table 8. Projected change (Δ) in urban forest carbon storage (tonnes) in storage (2010-2060) by state.

State	Storage Δ (t)
Florida	84,522,000
California	77,767,000
North Carolina	70,312,000
Michigan	59,071,000
Pennsylvania	50,976,000
New York	48,279,000
South Carolina	42,681,000
Texas	40,077,000
Georgia	38,284,000
Alabama	34,307,000
Washington	32,721,000
Louisiana	29,823,000
Ohio	26,235,000
Massachusetts	24,697,000
Maryland	22,836,000
Virginia	22,656,000
Wisconsin	22,562,000
Mississippi	20,947,000
Connecticut	19,963,000

State	Storage Δ (t)
New Jersey	18,235,000
Tennessee	17,197,000
Missouri	15,938,000
Minnesota	14,608,000
Arkansas	13,781,000
Maine	12,373,000
Indiana	12,346,000
West Virginia	12,273,000
New Hampshire	12,173,000
Kentucky	9,970,000
Colorado	9,213,000
Arizona	8,664,000
Oregon	6,941,000
Rhode Island	6,112,000
Illinois	5,424,000
New Mexico	5,297,000
South Dakota	4,851,000
Delaware	3,811,000
Idaho	3,531,000
Utah	3,089,000
Vermont	2,910,000
Kansas	2,254,000
Wyoming	2,182,000
Nevada	2,160,000
Iowa	1,277,000
Montana	996,000
North Dakota	-109,000
Nebraska	-381,000
Oklahoma	-757,000
Total U.S.[a]	974,875,000

[a] *conterminous United States*

Table 9. Projected change (Δ) in urban forest carbon storage (tonnes) in storage (2010-2060) for the 10 counties with highest and lowest change.

County	State	Storage Δ (t)
Worcester	Massachusetts	7,503,600
San Bernardino	California	7,413,200
Los Angeles	California	7,040,900
Riverside	California	6,684,300
San Diego	California	6,276,200
Muskegon	Michigan	6,255,000
Snohomish	Washington	5,671,300
Pierce	Washington	5,174,300
Palm Beach	Florida	5,143,700
Collier	Florida	4,851,600
Tarrant	Texas	-532,200
Pinellas	Florida	-558,400
Tulsa	Oklahoma	-602,600
Oklahoma	Oklahoma	-716,600
Norfolk	Massachusetts	-823,500
DeKalb	Georgia	-861,900
Cuyahoga	Ohio	-1,057,800
Cook	Illinois	-1,071,300
Cobb	Georgia	-1,207,900
Gwinnett	Georgia	-1,220,300

Table 11. Projected change (Δ) in urban forest annual net carbon sequestration (tonnes, 2010-2060) for the 10 counties with highest and lowest change.

County	State	Sequestration Δ (t/yr)
San Bernardino	California	375,000
Los Angeles	California	356,200
Riverside	California	338,100
Palm Beach	Florida	317,700
San Diego	California	317,500
Collier	Florida	299,700
Volusia	Florida	270,900
Worcester	Massachusetts	247,800
Polk	Florida	247,300
Maricopa	Arizona	214,200
Tarrant	Texas	-25,500
Tulsa	Oklahoma	-26,000
Norfolk	Massachusetts	-27,200
Oklahoma	Oklahoma	-30,900
Cuyahoga	Ohio	-34,100
Pinellas	Florida	-34,500
Cook	Illinois	-39,400
DeKalb	Georgia	-39,600
Cobb	Georgia	-55,400
Gwinnett	Georgia	-56,000

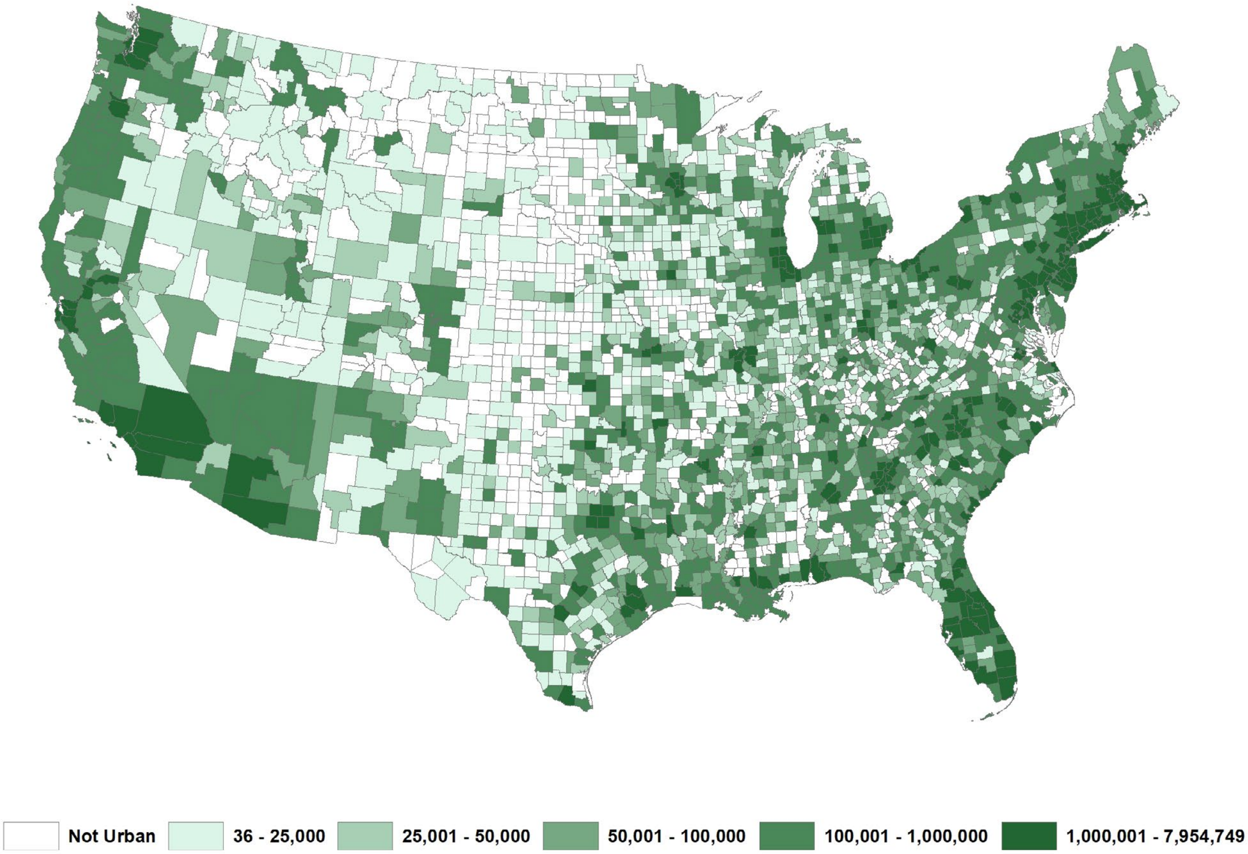
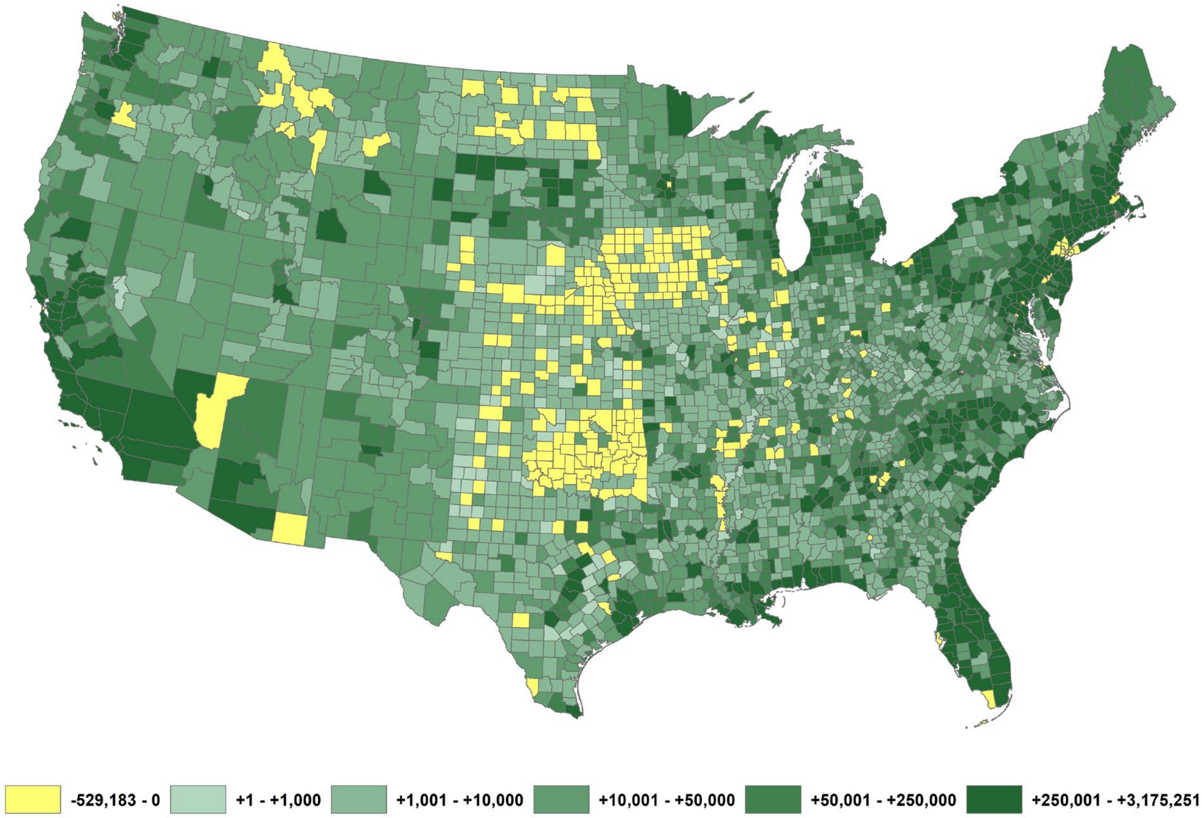


Figure 8. Carbon storage (tonnes) in urban areas by county (2010).

a.



b.

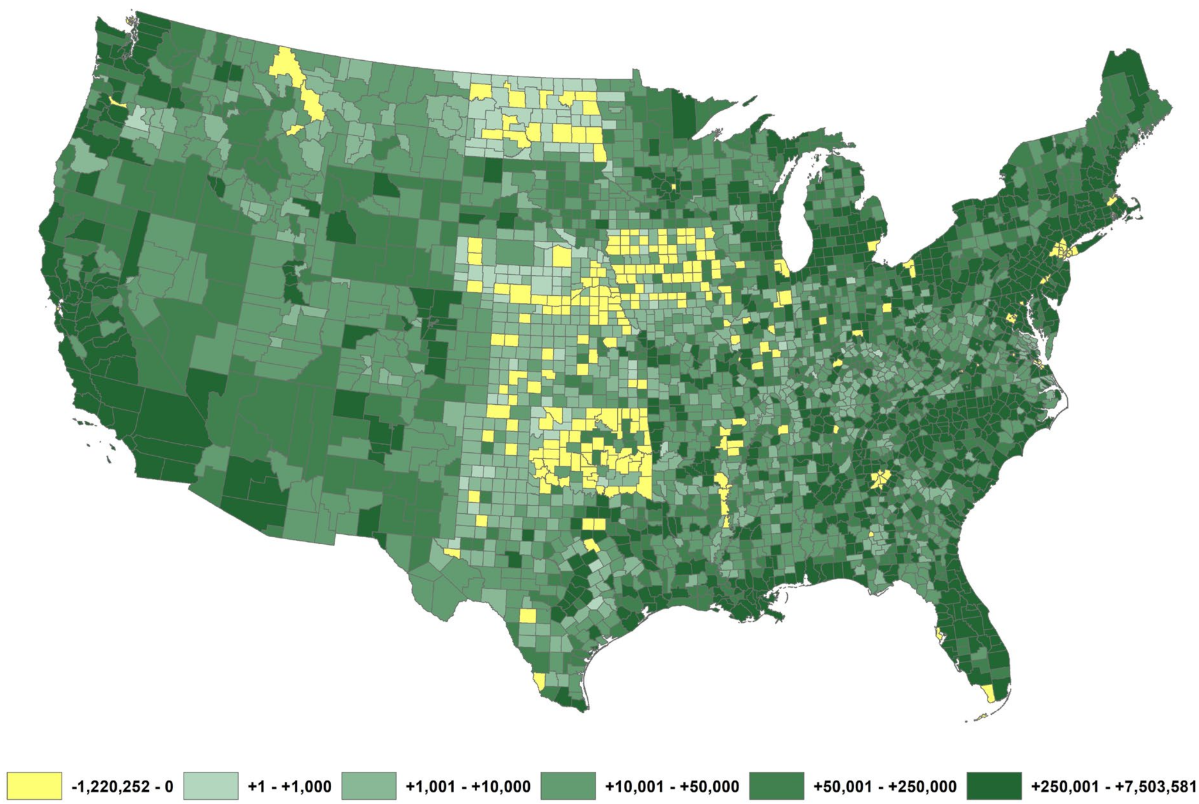


Figure 9. Change in urban forest carbon storage in urban areas (tC): a) 2010-2030, b) 2010-2060.

Annual net carbon sequestration by U.S. urban forests is projected to increase by 39.3 million tonnes per year (+116%) by 2060, increasing from 34.0 million t/yr (2010, Figure 10) to 73.3 million t/yr (2060). States with the greatest projected increase in urban forest annual carbon sequestration are Florida, California and North Carolina (Table 10). Counties with the greatest increase in urban forest annual carbon sequestration are San Bernardino, Los Angeles and Riverside counties in Southern California (Table 11; Figure 11).

Table 10. Projected change (Δ) in urban forest net annual carbon sequestration (tonnes, 2010-2060) by state.

State	Sequestration Δ (t/yr)
Florida	5,221,000
California	3,934,000
North Carolina	2,853,000
Texas	1,918,000
South Carolina	1,876,000
Georgia	1,757,000
Michigan	1,690,000
Pennsylvania	1,617,000
Louisiana	1,540,000
Alabama	1,530,000
New York	1,507,000
Washington	1,098,000
Maryland	959,000
Mississippi	937,000
Virginia	863,000
Ohio	846,000
Massachusetts	816,000
New Jersey	697,000
Tennessee	678,000
Wisconsin	660,000
Connecticut	620,000
Arkansas	593,000
Missouri	591,000
Minnesota	435,000
Indiana	401,000
Arizona	399,000

State	Sequestration Δ (t/yr)
West Virginia	385,000
Kentucky	371,000
Maine	356,000
New Hampshire	343,000
Colorado	236,000
Oregon	218,000
Rhode Island	205,000
Illinois	200,000
New Mexico	181,000
Delaware	166,000
South Dakota	149,000
Utah	86,000
Idaho	84,000
Kansas	83,000
Vermont	81,000
Nevada	58,000
Wyoming	52,000
Iowa	40,000
Montana	24,000
North Dakota	-3,000
Nebraska	-12,000
Oklahoma	-33,000
Total U.S.[a]	39,297,000

[a] *conterminous United States*

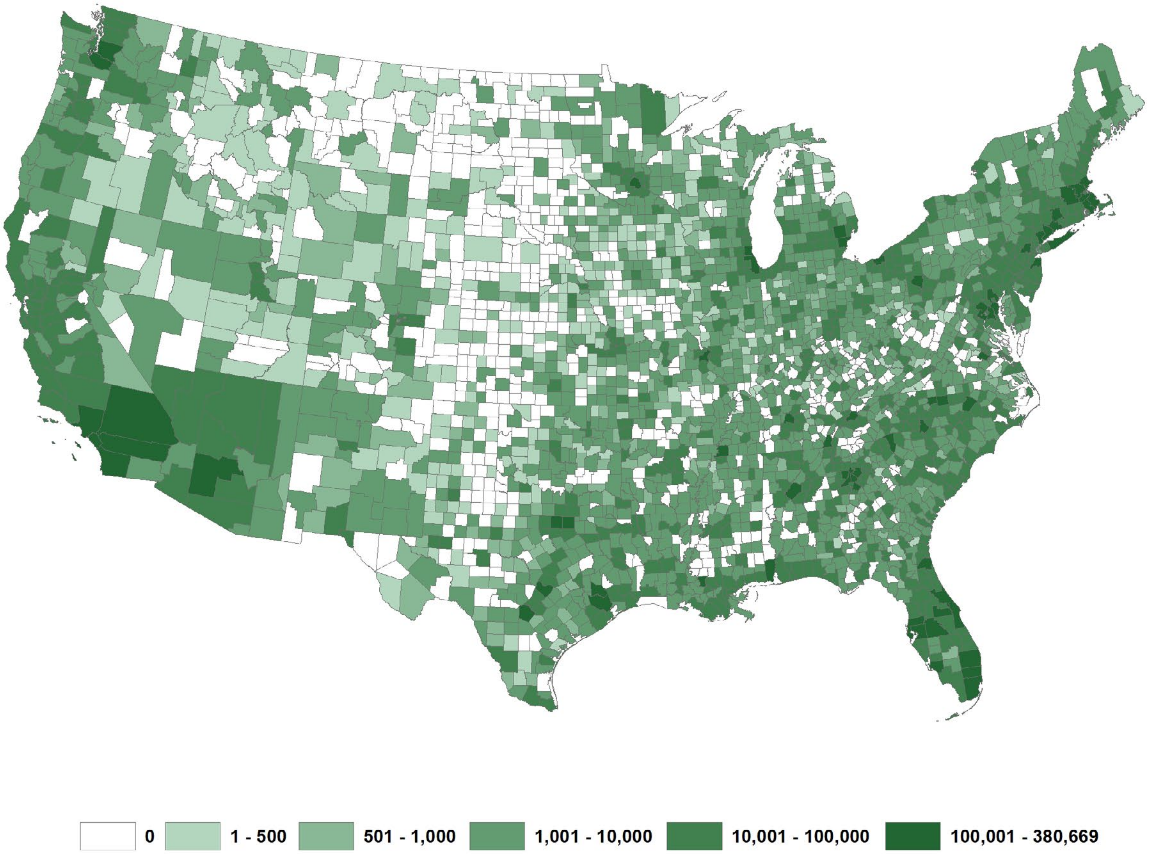
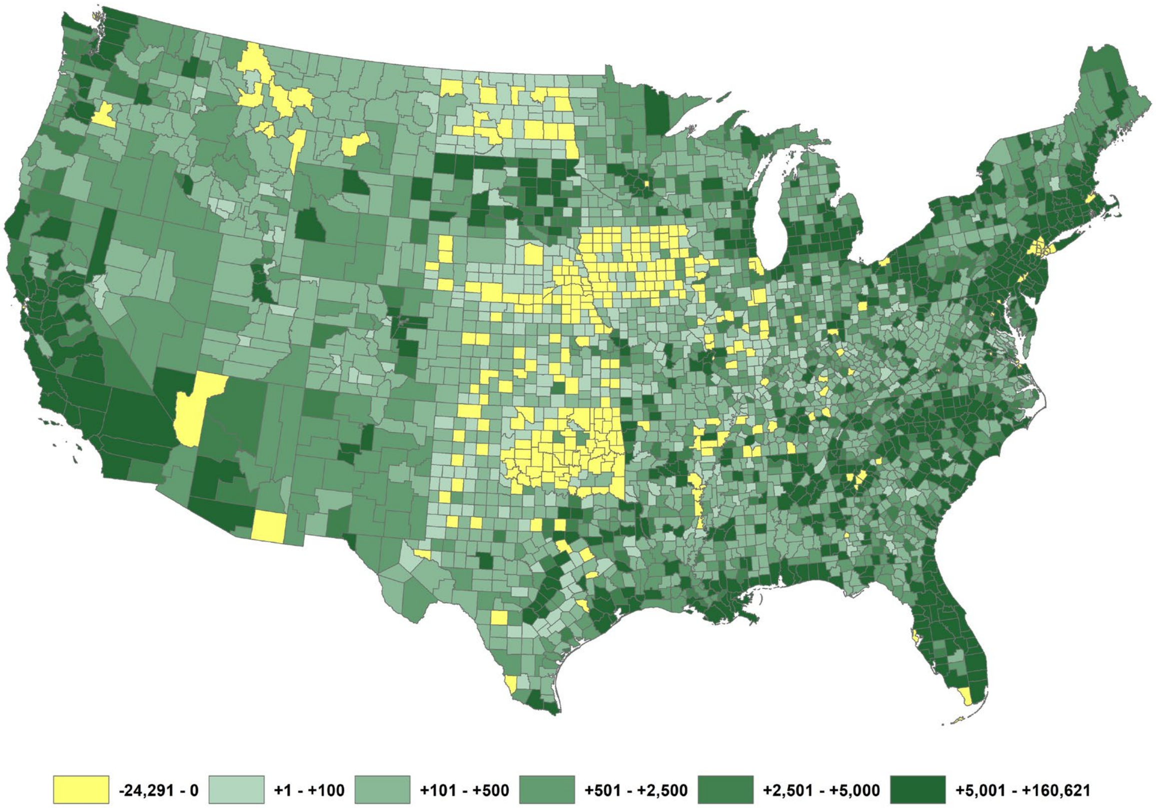


Figure 10. Net carbon sequestration (tonnes/yr) in urban areas by county (2010).

a.



b.

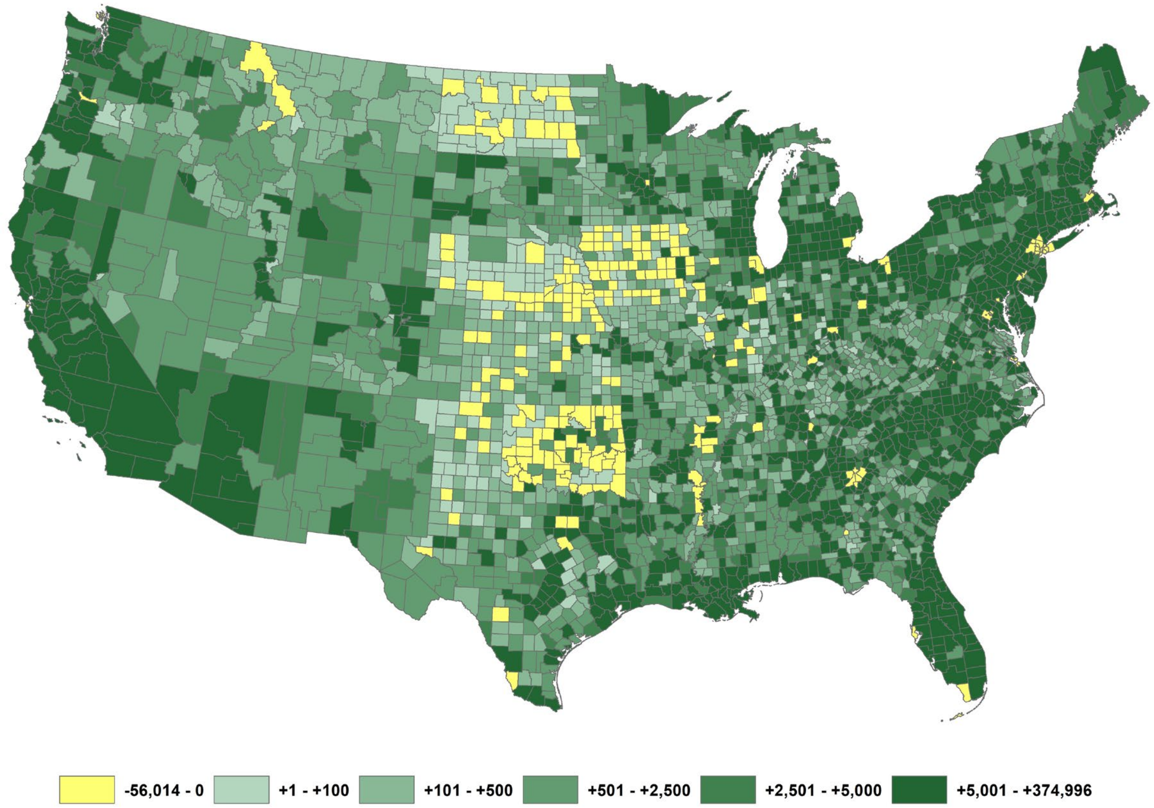


Figure 11. Change in net urban forest carbon sequestration (tC/yr): a) 2010-2030, b) 2010-2060.

3.2.1.1. Projected Changes in Carbon Storage with Conserved or Enhanced Canopy

The projections in section 3.2.1 are based on current projections of urban expansion and tree cover change. Other scenarios were developed based on conserving or enhancing tree cover. Relative to the current declining tree cover projection, conserving tree cover at its current percent tree cover would add an additional 314 million tonnes of carbon storage ($59.0 billion) by 2060; enhancing urban tree cover by 2060 would add an additional 462 million tonnes of carbon storage ($86.8 billion) (Table 12).

Table 12. Amounts and differences (million tonnes) in 2060 carbon storage and annual carbon sequestration (seq.) based on current projected trends, canopy conservation and canopy enhancement scenarios.

Scenario	Storage	Diff[a]	Seq.	Diff[a]
Trend	1,826.8	na	73.3	na
Conserve	2,140.5	313.8	85.7	12.4
Enhance	2,288.7	461.9	91.6	18.3

[a] difference from trend scenario
na – not applicable

States with the greatest increase in carbon storage due to the conservation or enhancement of current percent tree cover are Texas, Georgia and Illinois (Table 13). State with the greatest increase in annual carbon sequestration in 2060 with canopy conservation and enhancement are Texas, Georgia and Tennessee (Table 14). Counties that have the greatest increases in carbon storage and sequestration from canopy conservation or enhancement tend to be in Arizona, Oklahoma and Texas (Tables 15-16).

Table 13. Differences in 2060 state carbon storage (tonnes) for conserve canopy and enhance canopy scenarios vs. the current trend scenario.

State	Conserve[a]	State	Enhance[b]
Texas	32,944,000	Texas	40,471,000
Georgia	25,165,000	Georgia	29,116,000
Illinois	23,078,000	Illinois	28,318,000
Tennessee	21,664,000	Tennessee	26,319,000
Ohio	18,364,000	Ohio	25,836,000
Indiana	11,467,000	Florida	18,318,000
Arizona	11,429,000	Indiana	16,525,000
Oklahoma	11,268,000	California	14,371,000
Louisiana	10,077,000	New York	13,987,000

State	Conserve[a]	State	Enhance[b]
Missouri	9,871,000	Louisiana	13,335,000
Kansas	9,758,000	Arizona	13,007,000
Iowa	9,367,000	North Carolina	12,977,000
Arkansas	9,335,000	Oklahoma	12,762,000
New York	8,621,000	Missouri	12,012,000
Kentucky	8,393,000	Arkansas	11,023,000
Virginia	7,944,000	Virginia	10,978,000
Alabama	7,438,000	Alabama	10,840,000
Oregon	7,234,000	Kentucky	10,776,000
North Carolina	7,180,000	Iowa	10,698,000
Minnesota	7,103,000	Kansas	10,597,000
Mississippi	6,914,000	Pennsylvania	10,310,000
Florida	4,511,000	Minnesota	9,302,000
Washington	4,157,000	Oregon	9,179,000
Nebraska	4,053,000	Mississippi	8,610,000
Maryland	3,407,000	Washington	7,598,000
West Virginia	3,342,000	Michigan	7,453,000
South Dakota	2,831,000	South Carolina	6,581,000
California	2,811,000	Maryland	5,947,000
Massachusetts	2,807,000	Massachusetts	5,879,000
Pennsylvania	2,469,000	Wisconsin	5,825,000
Montana	2,409,000	New Jersey	4,817,000
Utah	2,236,000	Colorado	4,673,000
South Carolina	2,214,000	Nebraska	4,632,000
Colorado	1,958,000	South Dakota	4,102,000
Nevada	1,900,000	West Virginia	3,967,000
Wisconsin	1,830,000	Utah	3,302,000
Michigan	1,407,000	Montana	3,044,000
New Jersey	1,379,000	Nevada	2,470,000
North Dakota	967,000	Connecticut	1,986,000
Delaware	853,000	Delaware	1,783,000

State	Conserve[a]	State	Enhance[b]
Maine	586,000	New Mexico	1,778,000
Vermont	576,000	North Dakota	1,243,000
New Mexico	81,000	Maine	1,085,000
Rhode Island	70,000	New Hampshire	941,000
Idaho	55,000	Idaho	915,000
New Hampshire	30,000	Vermont	812,000
Wyoming	19,000	Rhode Island	651,000
Connecticut	0	Wyoming	508,000
Total U.S.[a]	313,772,000	Total U.S.[a]	461,904,000

[a] *difference in carbon storage: conserve scenario minus current trend scenario*
[b] *difference in carbon storage: enhance scenario minus current trend scenario*
[c] *conterminous United States*

Table 14. Differences in 2060 state annual carbon sequestration (tonnes) for conserve canopy and enhance canopy scenarios vs the current trend scenario.

State	Conserve[a]	State	Enhance[b]
Texas	1,577,000	Texas	1,937,000
Georgia	1,155,000	Georgia	1,337,000
Tennessee	854,000	Florida	1,131,000
Illinois	849,000	Illinois	1,042,000
Ohio	592,000	Tennessee	1,037,000
Arizona	526,000	Ohio	833,000
Louisiana	520,000	California	727,000
Oklahoma	486,000	Louisiana	688,000
Arkansas	402,000	Arizona	599,000
Indiana	373,000	Oklahoma	551,000
Missouri	366,000	Indiana	537,000
Kansas	359,000	North Carolina	527,000
Alabama	332,000	Alabama	484,000
Kentucky	312,000	Arkansas	474,000
Mississippi	309,000	Missouri	445,000
Virginia	303,000	New York	437,000

State	Conserve[a]	State	Enhance[b]
Iowa	292,000	Virginia	418,000
North Carolina	291,000	Kentucky	401,000
Florida	279,000	Kansas	390,000
New York	269,000	Mississippi	385,000
Oregon	228,000	Iowa	334,000
Minnesota	212,000	Pennsylvania	327,000
Maryland	143,000	Oregon	289,000
California	142,000	South Carolina	289,000
Washington	139,000	Minnesota	277,000
Nebraska	125,000	Washington	255,000
West Virginia	105,000	Maryland	250,000
South Carolina	97,000	Michigan	213,000
Massachusetts	93,000	Massachusetts	194,000
South Dakota	87,000	New Jersey	184,000
Pennsylvania	78,000	Wisconsin	170,000
Utah	63,000	Nebraska	143,000
Montana	58,000	South Dakota	126,000
Wisconsin	54,000	West Virginia	124,000
New Jersey	53,000	Colorado	120,000
Nevada	51,000	Utah	92,000
Colorado	50,000	Delaware	78,000
Michigan	40,000	Montana	73,000
Delaware	37,000	Nevada	66,000
North Dakota	28,000	Connecticut	62,000
Maine	17,000	New Mexico	61,000
Vermont	16,000	North Dakota	36,000
New Mexico	3,000	Maine	31,000
Rhode Island	2,000	New Hampshire	27,000
Idaho	1,000	Idaho	22,000
New Hampshire	1,000	Rhode Island	22,000
Connecticut	0	Vermont	22,000

State	Conserve[a]	State	Enhance[b]
Wyoming	0	Wyoming	12,000
Total U.S.[a]	12,378,000	Total U.S.[a]	18,291,000

[a] *difference in carbon storage: conserve scenario minus current trend scenario*
[b] *difference in carbon storage: enhance scenario minus current trend scenario*
[c] *conterminous United States*

Table 15. Differences in 2060 county carbon storage (tonnes) for conserve canopy and enhance canopy scenarios vs. the current trend scenario. Data are presented for the top 10 counties related to differences in carbon storage. Many counties had limited to no change in carbon storage as they are projected to increase in carbon storage given current projections.

County	State	Conserve[a]	County	State	Enhance[b]
Maricopa	Arizona	6,311,000	Maricopa	Arizona	7,206,000
Pima	Arizona	2,617,000	Harris	Texas	3,250,000
Harris	Texas	2,521,000	Pima	Arizona	2,937,000
Sedgwick	Kansas	2,296,000	Shelby	Tennessee	2,487,000
Oklahoma	Oklahoma	2,088,000	Sedgwick	Kansas	2,483,000
Shelby	Tennessee	2,061,000	Suffolk	New York	2,442,000
Hamilton	Tennessee	2,000,000	Cook	Illinois	2,381,000
Suffolk	New York	1,843,000	Oklahoma	Oklahoma	2,363,000
Fulton	Georgia	1,708,000	Hamilton	Tennessee	2,179,000
Tulsa	Oklahoma	1,640,000	Los Angeles	California	2,166,000

[a] *difference in carbon storage: conserve scenario minus current trend scenario*
[b] *difference in carbon storage: enhance scenario minus current trend scenario*

Table 16. Differences in 2060 county annual carbon sequestration (tonnes) for conserve canopy and enhance canopy scenarios vs. the current trend scenario. Data are presented for the top 10 counties related to differences in annual carbon sequestration. Many counties had limited to no change in carbon sequestration.

County	State	Conserve[a]	County	State	Enhance[b]
Maricopa	Arizona	291,000	Maricopa	Arizona	332,000
Harris	Texas	121,000	Harris	Texas	156,000
Pima	Arizona	120,000	Pima	Arizona	135,000
Oklahoma	Oklahoma	90,000	Los Angeles	California	110,000
Sedgwick	Kansas	85,000	Oklahoma	Oklahoma	102,000
Shelby	Tennessee	81,000	Brevard	Florida	101,000
Hamilton	Tennessee	79,000	Shelby	Tennessee	98,000
Fulton	Georgia	78,000	Tarrant	Texas	97,000
Tarrant	Texas	75,000	Sedgwick	Kansas	91,000
Tulsa	Oklahoma	71,000	Dallas	Texas	90,000

[a] *difference in carbon storage: conserve scenario minus current trend scenario*
[b] *difference in carbon storage: enhance scenario minus current trend scenario*

3.2.2. Building Energy Conservation

Building energy conservation values are related to average tree distributions around buildings among land cover classes and changes in land cover distribution and tree cover with land cover classes (Nowak et al. 2017). The values are also related to state-specific energy costs and types of energy used to heat and cool buildings, as well regionally specific tree cover effects on building energy use depending on tree size and orientation around a building. As urban areas increase, total building energy use will increase. On average, urban trees reduce building energy use by 7.2% (Nowak and Greenfield 2017). Thus, as building energy use will increase with urban expansion, so will energy conservation values due to trees around buildings.

Projections of tree effects on building energy use assume that energy costs and fuel types stay consistent in the future (2030 and 2060). In reality, energy types and distributions will likely change in the future as energy efficiencies and building designs change. Energy costs are also likely to increase in the coming years.

U.S. urban forests are projected to reduce building energy costs by an additional $3.5 billion/year by 2060, with savings increasing from $4.1 billion/yr (2010, Figure 12) to $7.7 billion/yr (2060). This increase in energy savings is due to the expansion of urban land. While urban forests will save energy, overall energy costs will increase as urban land expands. States with the greatest projected increase in energy savings are California, Florida and Massachusetts (Table 17). Counties with the greatest projected increase in energy savings are Riverside and San Bernardino in southern California and Maricopa, Ariz. (Table 18; Figure 13).

State	Annual Energy Savings Increase ($)
California	554,418,000
Florida	306,442,000
Massachusetts	230,724,000
New York	222,295,000
Michigan	218,845,000
Pennsylvania	196,116,000
Texas	177,433,000
Connecticut	140,805,000
Arizona	124,084,000
Maryland	110,795,000
Wisconsin	109,441,000
Missouri	101,952,000
Ohio	97,594,000
New Jersey	97,514,000
Louisiana	87,983,000
Kentucky	60,653,000
New Hampshire	58,817,000
Indiana	57,974,000
Maine	54,586,000
Rhode Island	53,296,000
Minnesota	50,612,000
Alabama	47,245,000
West Virginia	44,223,000
North Carolina	38,040,000
Virginia	37,189,000
Mississippi	35,508,000
Illinois	30,819,000
South Carolina	28,236,000
New Mexico	28,113,000
Georgia	26,574,000

Table 17. Projected increase in urban forest energy savings (2010-2060) by state.

State	Annual Energy Savings Increase ($)
Delaware	20,632,000
Washington	15,141,000
Vermont	12,127,000
Nevada	11,568,000
Kansas	11,260,000
Tennessee	11,066,000
Colorado	9,923,000
South Dakota	8,702,000
Arkansas	8,242,000
Idaho	6,823,000
Montana	5,155,000
Iowa	4,658,000
Utah	1,622,000
Wyoming	1,219,000
Oregon	518,000
North Dakota	-631,000
Nebraska	-3,847,000
Oklahoma	-6,473,000
Total U.S.[a]	3,543,789,000

[a] *Conterminous United States*

Table 18. Projected change in urban forest energy savings (2010-2060) for the 10 counties with highest and lowest change.

County	State	Annual Energy Savings Increase ($)
Riverside	California	162,417,000
San Bernardino	California	115,825,000
Maricopa	Arizona	90,471,000
Worcester	Massachusetts	58,255,000
Plymouth	Massachusetts	40,184,000
Fresno	California	37,812,000
Suffolk	New York	33,234,000
Hartford	Connecticut	29,609,000
Bristol	Massachusetts	28,333,000
Kern	California	28,045,000
Tulsa	Oklahoma	-2,436,000
Douglas	Nebraska	-2,674,000
DuPage	Illinois	-3,123,000
Oklahoma	Oklahoma	-3,334,000
Cuyahoga	Ohio	-3,466,000
Nassau	New York	-3,781,000
Hamilton	Ohio	-3,868,000
Pinellas	Florida	-4,604,000
Richmond	New York	-5,138,000
Cook	Illinois	-6,200,000

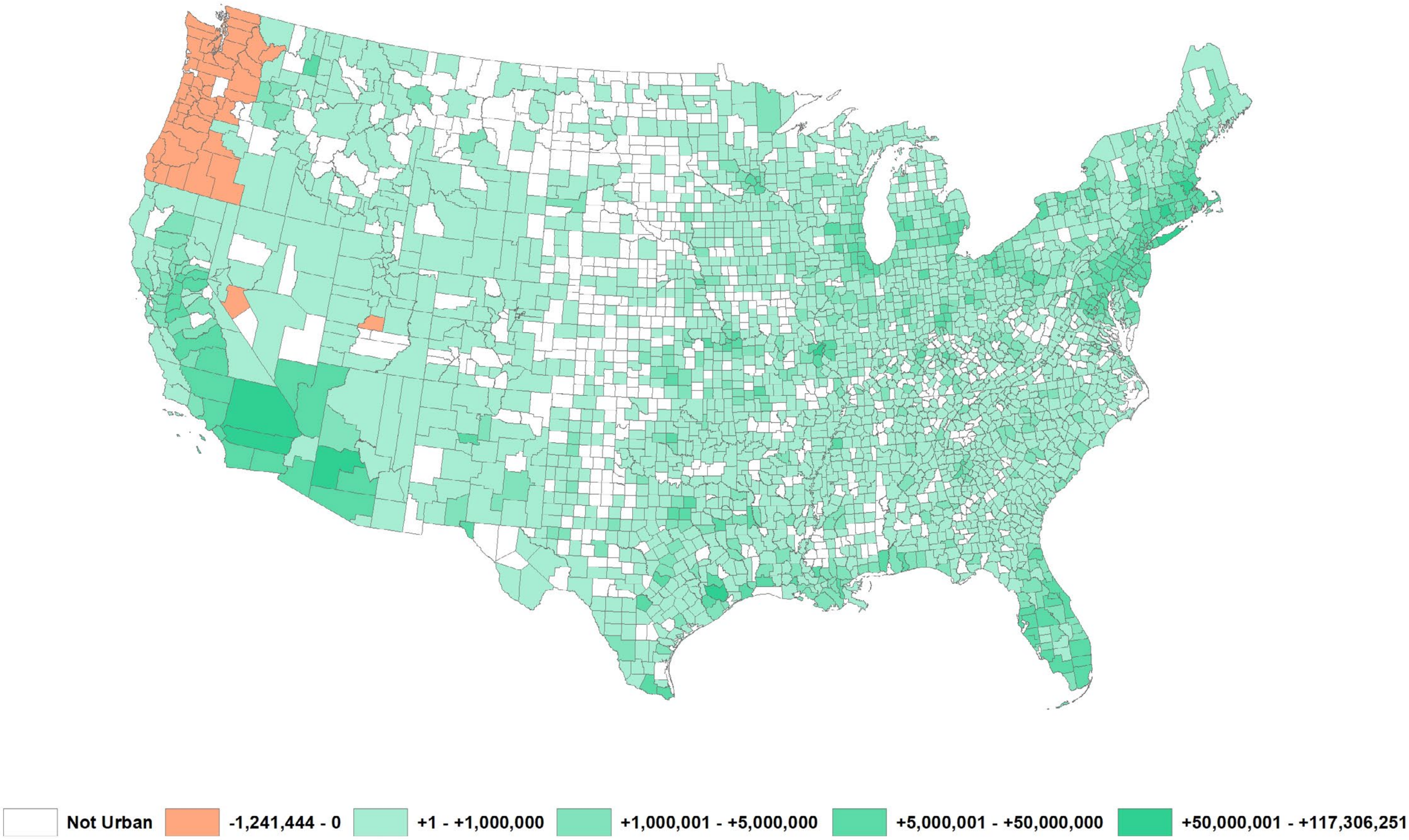
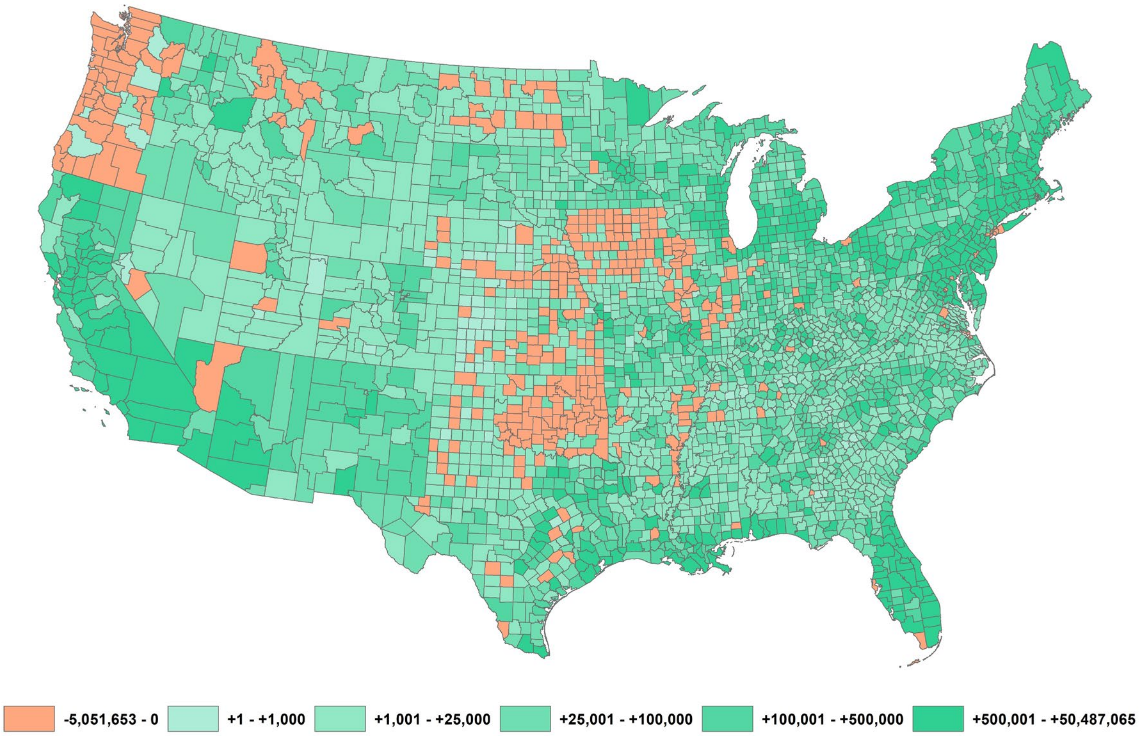


Figure 12. Estimated energy savings ($) in urban areas by county (2010).

a.



b.

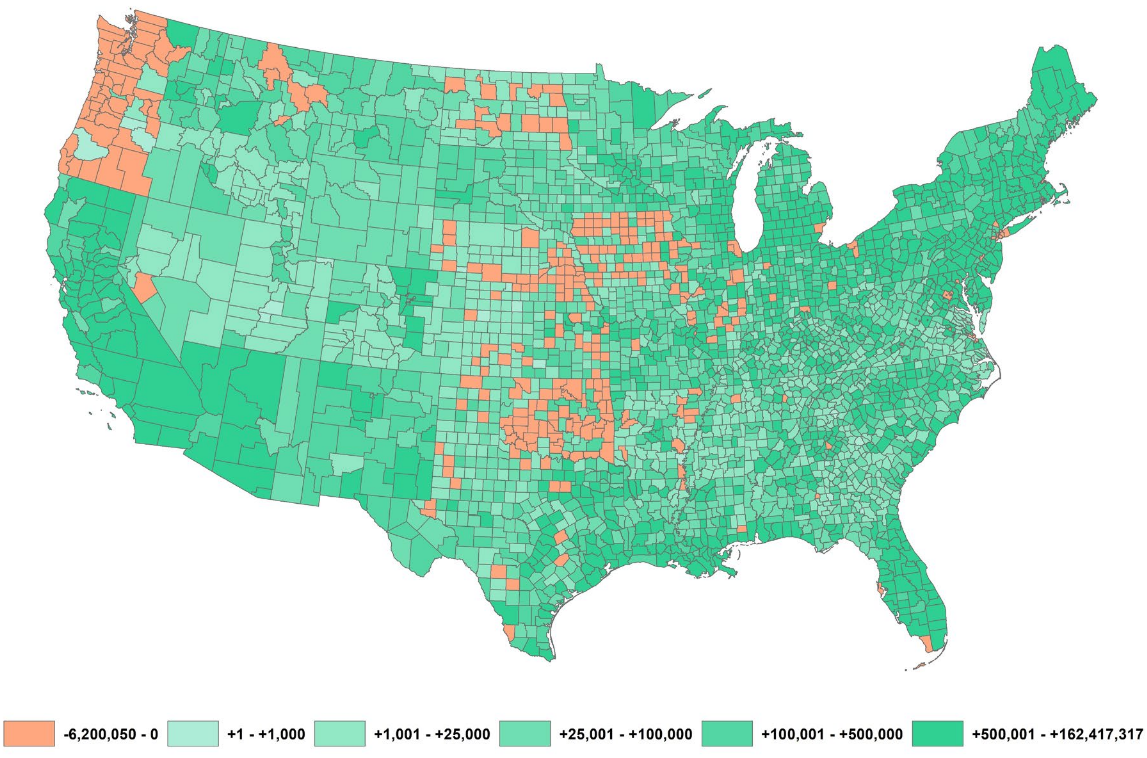


Figure 13. Change in urban forest energy conservation values in urban areas ($): a) 2010-2030, b) 2010-2060.

3.2.2.1. Projected Changes in Energy Conservation with Conserved or Enhanced Canopy

The projections in section 3.2.2 are based on current projections of urban expansion and tree cover change. Other scenarios were developed based on conserving or enhancing tree cover. Relative to the current national trend of declining percent tree cover, conserving tree cover at its current percent tree cover would save an additional $1.6 billion in energy costs in 2060; enhancing urban tree cover by 2060 would save an additional $2.3 billion per year (Table 19).

Table 19. Amounts and differences (million $) in 2060 energy savings based on current projected trends, canopy conservation and canopy enhancement scenarios.

Scenario	Energy Savings ($)	Diff[a]
Trend	7,676	na
Conserve	9,248	1,572
Enhance	9,952	2,276

[a] difference from trend scenario
na – not applicable

States with the greatest increase in energy savings due to the conservation or enhancement of current percent tree cover are Texas, Arizona and Illinois (Table 20). Counties that have the greatest energy savings from canopy conservation or enhancement tend to be in Arizona, Kansas and Texas (Table 21).

Table 14. Differences in 2060 state annual carbon sequestration (tonnes) for conserve canopy and enhance canopy scenarios vs the current trend scenario.

State	Conserve[a]	State	Enhance[b]
Texas	188,723,000	Texas	231,965,000
Arizona	183,849,000	Arizona	209,816,000
Illinois	154,997,000	Illinois	193,116,000
Kansas	132,458,000	Kansas	143,500,000
Ohio	95,280,000	Ohio	134,494,000
Missouri	93,876,000	Missouri	115,406,000
Indiana	63,892,000	New York	98,587,000
New York	62,796,000	Florida	92,550,000
Kentucky	59,229,000	California	92,357,000
Iowa	51,401,000	Indiana	92,337,000
Louisiana	45,253,000	Kentucky	76,662,000
Oklahoma	40,813,000	Massachusetts	71,500,000

State	Conserve[a]	State	Enhance[b]
Massachusetts	38,343,000	Louisiana	59,882,000
Nebraska	34,475,000	Iowa	58,844,000
Florida	28,335,000	Pennsylvania	52,967,000
Minnesota	28,193,000	Oklahoma	46,555,000
Virginia	21,860,000	Nebraska	39,252,000
Nevada	19,835,000	Minnesota	36,514,000
Georgia	19,764,000	Michigan	35,075,000
Maryland	19,340,000	Maryland	33,843,000
California	18,948,000	New Jersey	32,207,000
Montana	17,016,000	Wisconsin	31,320,000
Tennessee	16,212,000	Virginia	30,688,000
Pennsylvania	14,088,000	Nevada	26,413,000
West Virginia	13,059,000	Georgia	22,785,000
Mississippi	12,993,000	Montana	20,994,000
Alabama	12,533,000	Tennessee	19,709,000
New Jersey	9,791,000	Alabama	17,343,000
Wisconsin	9,618,000	Connecticut	16,681,000
South Dakota	9,444,000	Mississippi	16,229,000
North Dakota	8,982,000	West Virginia	15,562,000
Michigan	8,022,000	South Dakota	12,731,000
Arkansas	7,521,000	North Dakota	11,729,000
Delaware	5,365,000	New Mexico	10,883,000
Washington	5,029,000	Delaware	10,879,000
North Carolina	4,333,000	Arkansas	8,905,000
Vermont	2,868,000	Washington	8,685,000
Maine	2,765,000	North Carolina	7,893,000
Colorado	2,402,000	Rhode Island	7,062,000
South Carolina	1,606,000	Colorado	5,458,000
Utah	1,213,000	Maine	5,156,000
Rhode Island	1,152,000	South Carolina	4,863,000
Oregon	927,000	New Hampshire	4,858,000

State	Conserve[a]	State	Enhance[b]
New Mexico	667,000	Vermont	3,983,000
New Hampshire	150,000	Utah	1,824,000
Idaho	125,000	Idaho	1,773,000
Wyoming	12,000	Oregon	1,229,000
Connecticut	0	Wyoming	313,000
Total U.S.[c]	1,571,811,000	Total U.S.[c]	2,276,144,000

[a] *difference in energy savings: conserve scenario minus current trend scenario*
[b] *difference in energy savings: enhance scenario minus current trend scenario*
[c] *conterminous United States*

Table 21. Differences in 2060 county annual energy savings ($) for conserve canopy and enhance canopy scenarios vs the current trend scenario. Data are presented for the top and bottom 10 counties related to differences in energy savings.

County	State	Conserve[a]	County	State	Enhance[b]
Maricopa	Arizona	132,969,000	Maricopa	Arizona	151,830,000
Sedgwick	Kansas	41,890,000	Sedgwick	Kansas	45,302,000
Harris	Texas	24,051,000	Harris	Texas	31,012,000
Pima	Arizona	21,129,000	Clark	Nevada	25,648,000
Clark	Nevada	19,240,000	Suffolk	New York	25,251,000
Suffolk	New York	19,057,000	Pima	Arizona	23,709,000
Johnson	Kansas	16,795,000	Middlesex	Massachusetts	20,688,000
Hidalgo	Texas	15,653,000	Cook	Illinois	20,685,000
Middlesex	Massachusetts	14,071,000	Johnson	Kansas	18,595,000
St. Louis	Missouri	13,745,000	St. Louis	Missouri	18,384,000
Whatcom	Washington	-32,000	Snohomish	Washington	-57,000
Cowlitz	Washington	-35,000	Thurston	Washington	-59,000
Thurston	Washington	-36,000	Clackamas	Oregon	-63,000
Clark	Washington	-50,000	Lane	Oregon	-71,000
Clackamas	Oregon	-52,000	Kitsap	Washington	-82,000
Lane	Oregon	-56,000	Pierce	Washington	-102,000
Kitsap	Washington	-70,000	Clark	Washington	-120,000

County	State	Conserve[a]	County	State	Enhance[b]
Washington	Oregon	-160,000	Washington	Oregon	-192,000
Multnomah	Oregon	-199,000	Multnomah	Oregon	-252,000
King	Washington	-236,000	King	Washington	-379,000

[a] *difference in energy savings: conserve scenario minus current trend scenario*
[b] *difference in energy savings: enhance scenario minus current trend scenario*

3.2.3. Avoided Emissions

The projected changes in building energy use will alter emissions from the sources of fuels used to produce the energy. State or national emission factors and costs by fuel type were used to estimate changes in emissions due to changes in building energy use (Nowak et al. 2017). The emission factors and costs from 2010 were held constant for the years 2030 and 2060.

U.S. urban forests are projected to reduce emissions due to reduced building energy use by an additional value of $1.1 billion/year by 2060, with emission reduction values increasing from $1.4 billion/yr (2010, Figure 14) to $2.6 billion/yr (2060). Carbon emissions from energy production will be reduced by an additional 4.7 million tonnes per year by 2060, increasing avoided emissions from 6.1 million tC/yr (2010) to 10.8 million tC/yr (2060). This increased reduction in emissions is due to the expansion of urban land and urban forests. While urban forests will reduce emissions, overall emissions will increase as urban land expands. States with the greatest projected reduction in carbon emissions are Michigan, Florida and Pennsylvania (Table 22). States with the greatest value from reduced emissions (CO_2, NO_x, SO_2, CO, CH_4, VOCs, PM_{10} and $PM_{2.5}$) are Florida, California and Michigan (Table 23). Counties with the greatest reduction in carbon emissions are Maricopa County, Ariz., Worchester County, Mass.; and Riverside County, Calif. (Table 24; Figure 15). Counties with the greatest reduction in total avoided emissions are Riverside and San Bernardino counties in southern California and Maricopa County, Ariz. (Table 25; Figure 16).

Table 22. Projected change (Δ) in avoided carbon emissions due to urban forest energy savings (tonnes, 2010-2060) by state.

State	Avoided C Emissions Δ (t)
Michigan	504,000
Florida	411,000
Pennsylvania	329,000
Wisconsin	261,000
Texas	257,000
Massachusetts	245,000
New York	238,000
Ohio	238,000
Missouri	221,000

State	Avoided C Emissions Δ (t)
Maryland	190,000
California	177,000
Indiana	148,000
Louisiana	140,000
Kentucky	137,000
Arizona	131,000
New Jersey	121,000
Connecticut	120,000
Minnesota	114,000
West Virginia	109,000
Illinois	71,000
New Hampshire	50,000
New Mexico	49,000
Alabama	48,000
Virginia	46,000
Mississippi	45,000
Rhode Island	44,000
North Carolina	40,000
Delaware	37,000
Georgia	36,000
Maine	34,000
Kansas	24,000
South Dakota	21,000
Montana	15,000
Iowa	13,000
Nevada	12,000
Arkansas	10,000
Colorado	9,000
Tennessee	9,000
South Carolina	7,000

State	Avoided C Emissions Δ (t)
Washington	4,000
Utah	2,000
Idaho	1,000
Wyoming	1,000
Vermont	0
North Dakota	-2,000
Oregon	-4,000
Nebraska	-10,000
Oklahoma	-12,000
Total U.S.[a]	4,684,000

[a] *Conterminous United States*

Table 23. Projected change (Δ) in avoided emissions in urban areas (2010-2060) by state.

State	Avoided Emissions Δ ($)
Florida	122,369,000
California	122,115,000
Michigan	99,252,000
Pennsylvania	70,540,000
Texas	53,881,000
Massachusetts	53,136,000
Wisconsin	51,158,000
Ohio	49,385,000
New York	46,629,000
Maryland	44,376,000
Missouri	43,428,000
Louisiana	36,103,000
Indiana	30,410,000
Arizona	29,998,000
New Jersey	28,929,000
Kentucky	28,716,000
Connecticut	26,273,000

State	Avoided Emissions Δ ($)
West Virginia	22,939,000
Minnesota	22,564,000
North Carolina	15,690,000
Alabama	14,415,000
Illinois	13,505,000
Maine	13,444,000
Mississippi	12,449,000
Georgia	11,911,000
Virginia	11,233,000
New Hampshire	9,948,000
New Mexico	9,284,000
Rhode Island	8,801,000
Delaware	8,720,000
South Carolina	5,571,000
Kansas	4,595,000
South Dakota	4,105,000
Montana	3,215,000
Tennessee	3,016,000
Iowa	2,901,000
Nevada	2,532,000
Arkansas	2,291,000
Colorado	2,127,000
Washington	1,739,000
Idaho	1,461,000
Wyoming	1,274,000
Utah	973,000
Vermont	346,000
Oregon	-200,000
North Dakota	-485,000

State	Avoided Emissions Δ ($)
Nebraska	-1,967,000
Oklahoma	-2,510,000
Total U.S.[a]	1,141,380,000

[a] *Conterminous United States*

Table 24. Projected change (Δ) in total avoided carbon emissions from energy savings (tonnes, 2010-2060) for the 10 counties with highest and lowest change.

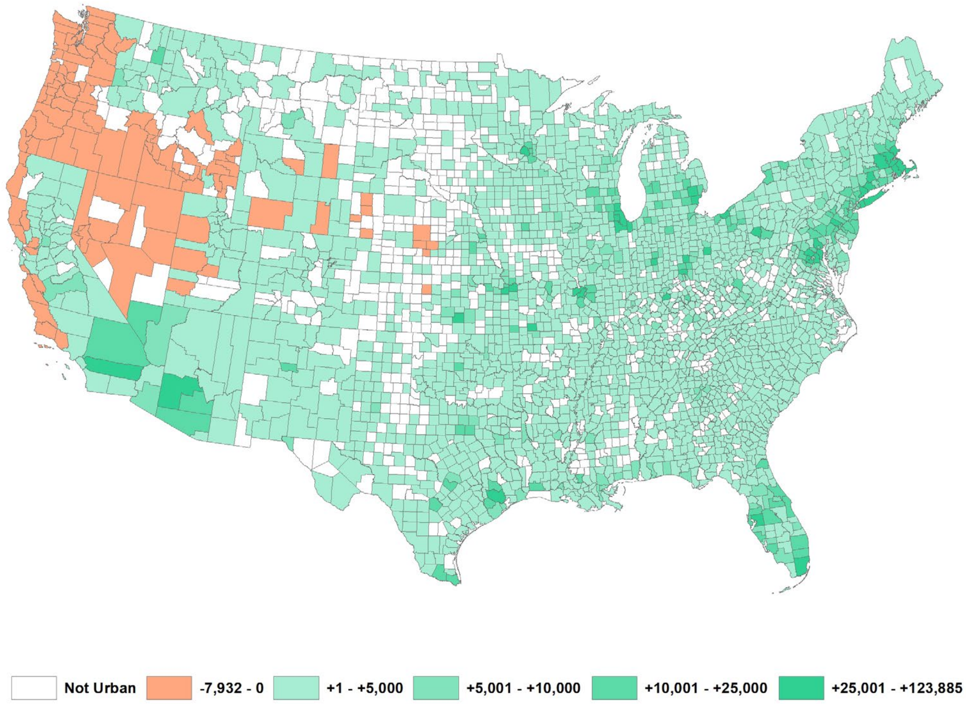
County	State	Avoided Carbon Δ (t)
Maricopa	Arizona	95,500
Worcester	Massachusetts	61,500
Riverside	California	60,500
San Bernardino	California	43,500
Plymouth	Massachusetts	42,400
Ottawa	Michigan	41,500
Berrien	Michigan	36,500
Muskegon	Michigan	34,700
Palm Beach	Florida	33,200
Suffolk	New York	31,200
King	Washington	-4,500
Richmond	New York	-4,700
Marion	Indiana	-4,900
Pinellas	Florida	-6,100
Oklahoma	Oklahoma	-6,200
Douglas	Nebraska	-7,100
DuPage	Illinois	-7,600
Cuyahoga	Ohio	-8,500
Hamilton	Ohio	-9,000
Cook	Illinois	-15,100

Table 25. Projected change (Δ) in avoided emissions (2010-2060) for the 10 counties with highest and lowest change.

County	State	Avoided Emissions Δ ($)
Riverside	California	35,877,000
Maricopa	Arizona	22,706,000
San Bernardino	California	19,580,000
Worcester	Massachusetts	13,368,000
Palm Beach	Florida	11,870,000
Fresno	California	9,310,000
Plymouth	Massachusetts	9,010,000
Ottawa	Michigan	8,021,000
Sacramento	California	7,302,000
Berrien	Michigan	7,199,000
Marion	Indiana	-1,013,000
District of Columbia*	District of Columbia	-1,203,000
Richmond	New York	-1,222,000
Oklahoma	Oklahoma	-1,242,000
Douglas	Nebraska	-1,371,000
DuPage	Illinois	-1,520,000
Cuyahoga	Ohio	-1,978,000
Hamilton	Ohio	-2,024,000
Pinellas	Florida	-3,079,000
Cook	Illinois	-3,216,000

**Federal district*

a.



b.

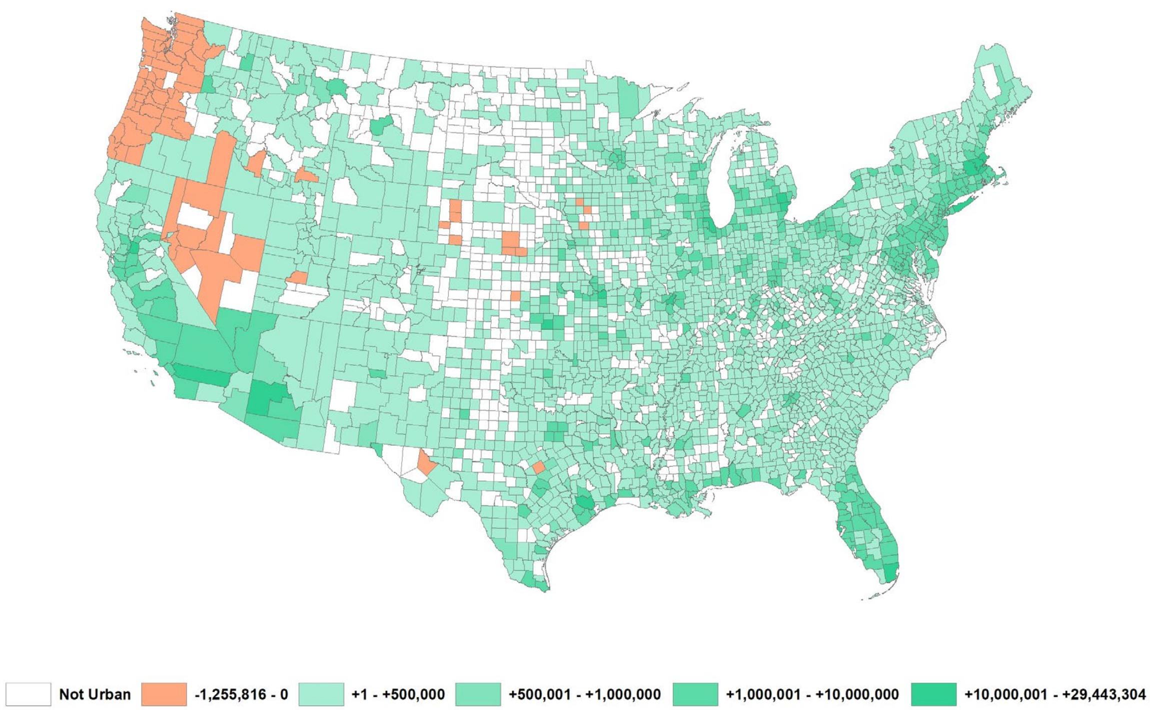
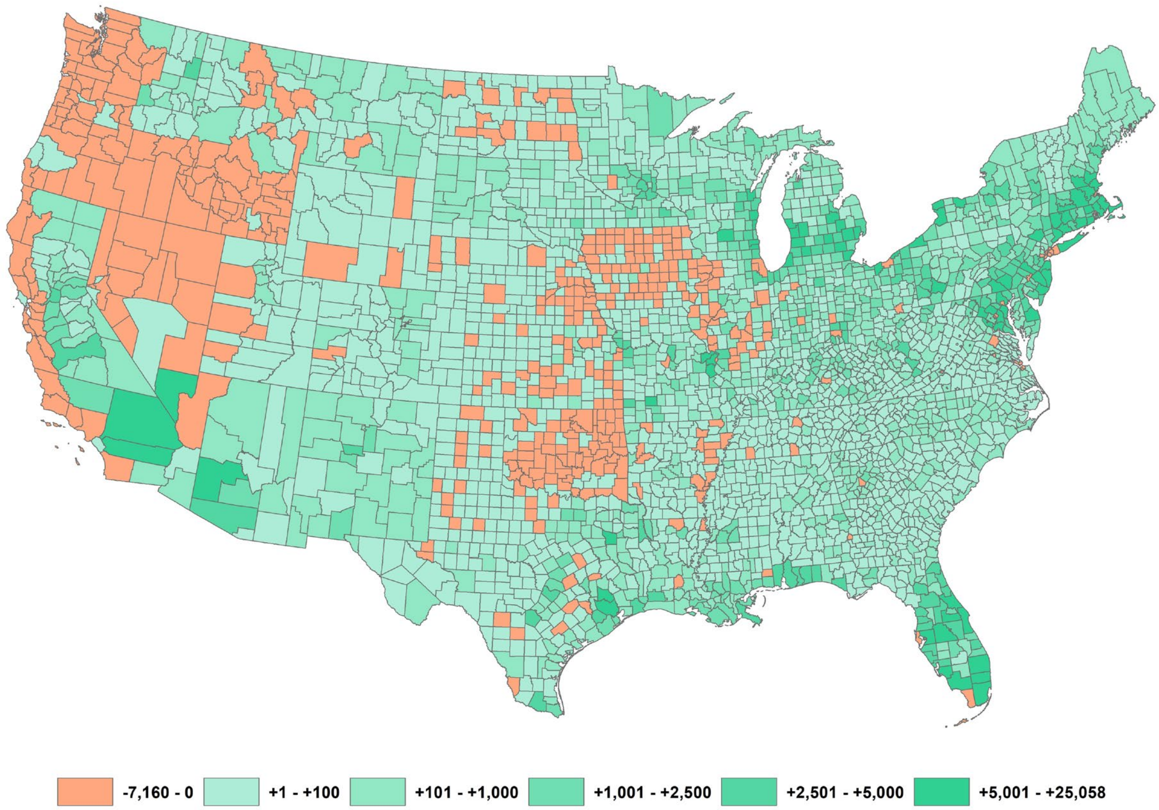


Figure 14. Estimated: a) avoided carbon emissions (tonnes) and b) value of all avoided emissions due to energy conservation (2010) in urban areas.

a.



b.

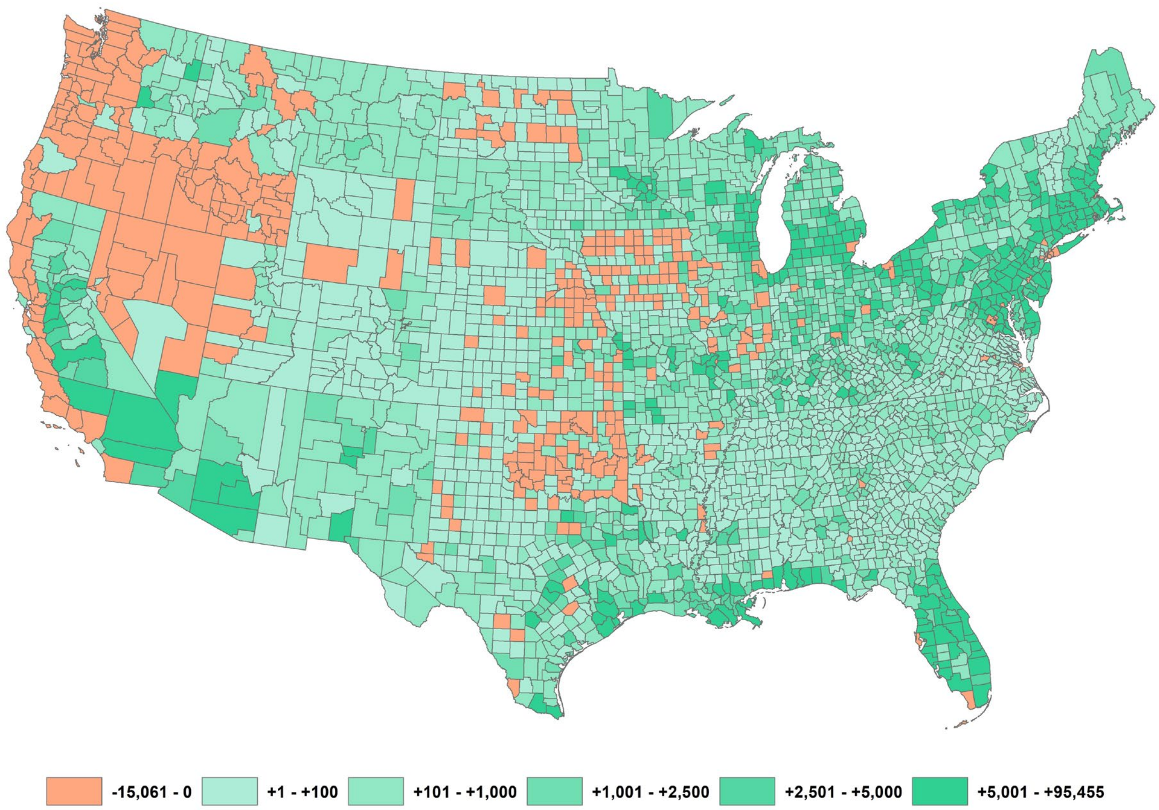
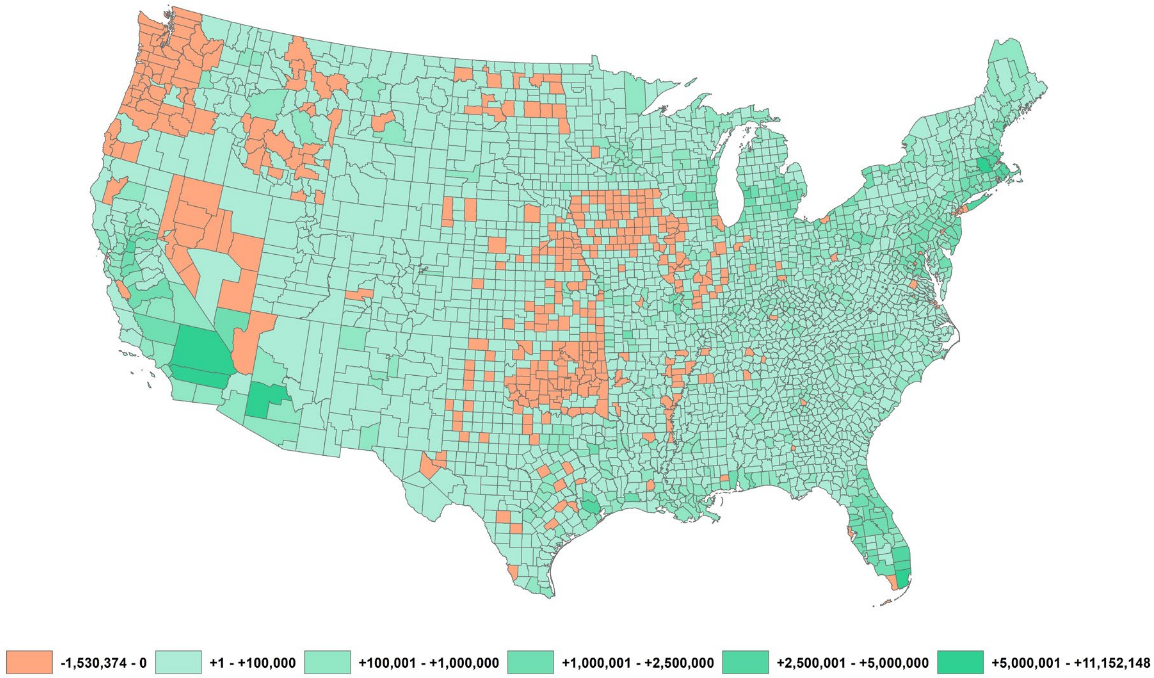


Figure 15. Change in avoided carbon emissions in urban areas (tonnes): a) 2010-2030, b) 2010-2060.

a.



b.

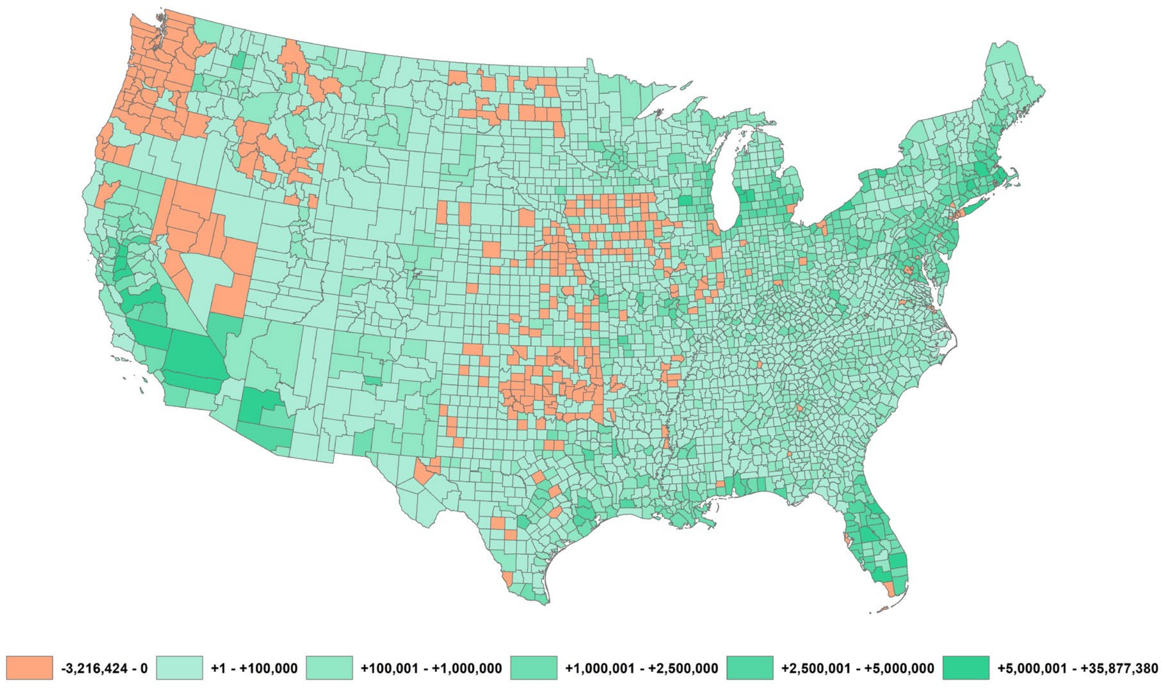


Figure 16. Change in value of avoided emissions in urban areas ($): a) 2010-2030, b) 2010-2060.

3.2.3.1. Projected Changes in Avoided Emissions with Conserved or Enhanced Canopy

The projections in section 3.2.3 are based on current projections of urban expansion and tree cover change. Other scenarios were developed based on conserving or enhancing tree cover. Relative to the current declining tree cover projection, conserving tree cover at its current percent tree cover would avoid the emission of an additional 2.8 million tonnes of carbon by 2060 and avoid pollutant emissions with an associated cost of $615 million per year. Enhancing urban tree cover by 2060 would avoid the emission of an additional 3.9 million tonnes of carbon by 2060 and avoid pollutant emissions with an associated cost of $875 million per year (Table 26).

Table 26. Amounts and differences in 2060 avoided annual carbon emissions and total value from reduced annual pollutant emissions based on current projected trends, canopy conservation and canopy enhancement scenarios.

Scenario	Carbon[a]	Diff[b]	Emission[c]	Diff[b]
Trend	10.7	na	2,587	na
Conserve	13.6	2.8	3,202	615
Enhance	14.7	3.9	3,462	875

[a] *million tonnes of avoided carbon emissions*
[b] *difference from trend scenario*
[c] *annual value (million $) from reduced CO_2, NO_x, SO_2, CO, CH_4, VOCs, PM_{10} and $PM_{2.5}$ emissions*
na – not applicable

States with the greatest increase in avoided carbon emissions and reduced pollutant emission environmental costs in 2060, due to the conservation or enhancement of current percent tree cover, are Illinois, Kansas, Texas and Ohio (Table 27-28). Counties that have the greatest increase in avoided carbon emissions from canopy conservation or enhancement tend to be in Arizona, Kansas and Illinois (Tables 29). Counties that have the greatest reduction in pollutant emission costs from canopy conservation or enhancement tend to be in Arizona, Kansas, Illinois and Texas (Tables 30).

Table 27. Differences in 2060 state annual avoided carbon emissions (tonnes) for conserve canopy and enhance canopy scenarios vs. the current trend scenario.

State	Conserve[a]	State	Enhance[b]
Illinois	366,000	Illinois	456,000
Kansas	279,000	Texas	336,000
Texas	273,000	Ohio	325,000
Ohio	230,000	Kansas	303,000
Missouri	203,000	Missouri	250,000
Arizona	194,000	Indiana	237,000
Indiana	164,000	Arizona	221,000

State	Conserve[a]	State	Enhance[b]
Iowa	148,000	Kentucky	173,000
Kentucky	133,000	Iowa	169,000
Nebraska	89,000	Florida	123,000
Oklahoma	75,000	Nebraska	102,000
Louisiana	72,000	New York	98,000
Minnesota	63,000	Louisiana	95,000
New York	61,000	Pennsylvania	87,000
Montana	48,000	Oklahoma	86,000
Massachusetts	40,000	Minnesota	82,000
Florida	38,000	Michigan	80,000
Maryland	33,000	Massachusetts	75,000
West Virginia	32,000	Wisconsin	74,000
Virginia	29,000	Montana	59,000
North Dakota	28,000	Maryland	58,000
Georgia	26,000	New Jersey	40,000
Pennsylvania	23,000	Virginia	40,000
Wisconsin	23,000	West Virginia	38,000
Nevada	22,000	North Dakota	37,000
South Dakota	22,000	Georgia	30,000
Michigan	18,000	South Dakota	30,000
Mississippi	16,000	Nevada	29,000
Alabama	13,000	California	27,000
New Jersey	12,000	Mississippi	20,000
Tennessee	12,000	Delaware	19,000
Delaware	10,000	New Mexico	19,000
Arkansas	9,000	Alabama	18,000
California	6,000	Connecticut	14,000
Washington	5,000	Tennessee	14,000
North Carolina	4,000	Arkansas	11,000
Colorado	2,000	North Carolina	8,000
Maine	2,000	Washington	8,000

State	Conserve[a]	State	Enhance[b]
Utah	2,000	Rhode Island	6,000
New Mexico	1,000	Colorado	5,000
Rhode Island	1,000	New Hampshire	4,000
Connecticut	0	Maine	3,000
Idaho	0	Utah	3,000
New Hampshire	0	South Carolina	1,000
South Carolina	0	Idaho	0
Vermont	0	Vermont	0
Wyoming	0	Wyoming	0
Oregon	-6,000	Oregon	-7,000
Total U.S.[c]	2,827,000	Total U.S.[c]	3,912,000

[a] *difference in avoided carbon emissions: conserve scenario minus current trend scenario*
[b] *difference in avoided carbon emissions: enhance scenario minus current trend scenario*
[c] *conterminous United States*

Table 28. Differences in value of 2060 state annual reduced pollutant emissions ($) for conserve canopy and enhance canopy scenarios vs. the current trend scenario.

State	Conserve[a]	State	Enhance[b]
Illinois	71,933,000	Illinois	89,886,000
Texas	56,895,000	Texas	69,997,000
Kansas	54,465,000	Ohio	69,684,000
Ohio	49,387,000	Kansas	59,004,000
Arizona	44,250,000	Arizona	50,499,000
Missouri	40,367,000	Missouri	49,650,000
Indiana	33,621,000	Indiana	48,589,000
Kentucky	28,750,000	Florida	41,835,000
Iowa	27,722,000	Kentucky	37,253,000
Louisiana	19,057,000	Iowa	31,687,000
Nebraska	17,272,000	Louisiana	25,256,000
Oklahoma	15,300,000	New York	25,012,000
New York	15,263,000	California	22,902,000
Florida	14,017,000	Nebraska	19,649,000

State	Conserve[a]	State	Enhance[b]
Minnesota	12,566,000	Pennsylvania	19,251,000
Montana	11,578,000	Oklahoma	17,451,000
Massachusetts	9,296,000	Massachusetts	17,332,000
Georgia	9,234,000	Minnesota	16,303,000
Maryland	7,925,000	Michigan	16,094,000
Virginia	7,649,000	Wisconsin	14,655,000
West Virginia	6,795,000	Montana	14,222,000
North Dakota	5,867,000	Maryland	13,854,000
Pennsylvania	5,243,000	Virginia	10,835,000
California	4,892,000	Georgia	10,674,000
Tennessee	4,760,000	New Jersey	10,639,000
Mississippi	4,686,000	West Virginia	8,090,000
Nevada	4,648,000	North Dakota	7,650,000
South Dakota	4,526,000	Nevada	6,204,000
Wisconsin	4,501,000	South Dakota	6,086,000
Alabama	3,934,000	Mississippi	5,850,000
Michigan	3,724,000	Tennessee	5,792,000
New Jersey	3,325,000	Alabama	5,428,000
Delaware	2,314,000	Delaware	4,663,000
Arkansas	2,127,000	New Mexico	3,600,000
North Carolina	1,839,000	North Carolina	3,351,000
Washington	1,077,000	Connecticut	3,125,000
Utah	821,000	Arkansas	2,521,000
Maine	637,000	Washington	1,823,000
Colorado	481,000	Maine	1,238,000
South Carolina	315,000	Utah	1,226,000
New Mexico	222,000	Rhode Island	1,174,000
Rhode Island	193,000	Colorado	1,109,000
Vermont	84,000	South Carolina	961,000
Idaho	26,000	New Hampshire	822,000
New Hampshire	25,000	Idaho	390,000

State	Conserve[a]	State	Enhance[b]
Wyoming	10,000	Wyoming	332,000
Connecticut	0	Vermont	117,000
Oregon	-138,000	Oregon	-161,000
Total U.S.[c]	614,697,000	Total U.S.[c]	875,090,000

[a] *difference in avoided carbon emissions: conserve scenario minus current trend scenario*
[b] *difference in avoided carbon emissions: enhance scenario minus current trend scenario*
[c] *conterminous United States*

Table 29. Differences in 2060 county annual avoided carbon emissions (tonnes) for conserve canopy and enhance canopy scenarios vs the current trend scenario. Data are presented for the top and bottom 10 counties related to differences in avoided carbon emissions.

County	State	Conserve[a]	County	State	Enhance[b]
Maricopa	Arizona	140,400	Maricopa	Arizona	160,300
Sedgwick	Kansas	88,500	Sedgwick	Kansas	95,800
Johnson	Kansas	35,500	Cook	Illinois	50,000
Harris	Texas	34,800	Harris	Texas	44,900
St. Louis	Missouri	29,800	St. Louis	Missouri	39,900
Cook	Illinois	29,200	Johnson	Kansas	39,300
Lancaster	Nebraska	26,200	Franklin	Ohio	32,300
Will	Illinois	25,200	Clark	Nevada	30,100
Clark	Nevada	22,600	Will	Illinois	30,000
Hidalgo	Texas	22,600	Lancaster	Nebraska	29,200
Clark	Washington	-300	Kitsap	Washington	-500
Whatcom	Washington	-300	Jackson	Oregon	-700
Kitsap	Washington	-400	Clark	Washington	-700
Jackson	Oregon	-500	Pierce	Washington	-700
Marion	Oregon	-500	Marion	Oregon	-800
Clackamas	Oregon	-700	Clackamas	Oregon	-900
Lane	Oregon	-700	Lane	Oregon	-900
Multnomah	Oregon	-1,200	Multnomah	Oregon	-1,600
King	Washington	-1,500	Washington	Oregon	-1,900
Washington	Oregon	-1,600	King	Washington	-2,300

[a] *difference in avoided carbon emissions: conserve scenario minus current trend scenario*
[b] *difference in avoided carbon emissions: enhance scenario minus current trend scenario*

Table 30. Differences in value of 2060 county annual reduced pollutant emissions ($) for conserve canopy and enhance canopy scenarios vs. the current trend scenario. Data are presented for the top and bottom 10 counties related to differences in avoided pollutant emissions.

County	State	Conserve[a]	County	State	Enhance[b]
Maricopa	Arizona	33,374,000	Maricopa	Arizona	38,107,000
Sedgwick	Kansas	17,214,000	Sedgwick	Kansas	18,616,000
Harris	Texas	8,076,000	Cook	Illinois	10,693,000
Johnson	Kansas	7,008,000	Harris	Texas	10,413,000
Cook	Illinois	6,247,000	St. Louis	Missouri	7,921,000
St. Louis	Missouri	5,922,000	Johnson	Kansas	7,759,000
Lancaster	Nebraska	5,046,000	Franklin	Ohio	6,962,000
Will	Illinois	4,902,000	Clark	Nevada	6,280,000
Franklin	Ohio	4,725,000	Pinellas	Florida	6,154,000
Clark	Nevada	4,711,000	Will	Illinois	5,843,000
Multnomah	Oregon	-48,000	Clackamas	Oregon	-75,000
Jackson	Oregon	-50,000	Lane	Oregon	-75,000
Lane	Oregon	-59,000	Kitsap	Washington	-81,000
Clackamas	Oregon	-61,000	Buena Vista	Iowa	-92,000
Coryell	Texas	-68,000	Coryell	Texas	-101,000
Kitsap	Washington	-69,000	Clark	Washington	-106,000
Buena Vista	Iowa	-73,000	Pierce	Washington	-111,000
Washington	Oregon	-113,000	Washington	Oregon	-136,000
King	Washington	-232,000	King	Washington	-373,000
Crawford	Iowa	-872,000	Crawford	Iowa	-1,023,000

[a] *difference in avoided carbon emissions: conserve scenario minus current trend scenario*
[b] *difference in avoided carbon emissions: enhance scenario minus current trend scenario*

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AMERICAN FORESTS
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Climate Change and Urban Forests: Part 2: Urban Forest Projections within Existing Urban Areas

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1. Introduction

This report is Part 2 of a two-part report. Part 1 is designed to aid in understanding the future impacts of urban forests on climate change mitigation given projected future urban expansion. Part 2 is designed to aid in understanding the future impacts of urban forests on climate change mitigation with no urban expansion. Results are projected at the county level across the conterminous United States for the years 2010 and 2060.

This report projects tree cover change in urban areas through 2060, and its associated impacts on carbon storage, building energy use and associated carbon emissions from building energy use. Changes (2010-2030; 2010-2060) within urban areas are assessed for each county. Three future scenarios are assessed:

1. *Current Trend* – tree cover change based on projected urban growth.
2. *Conserve Canopy* – similar to current trend projections, but percent urban tree cover held to a minimum of the 2010 percent tree cover value.
3. *Enhance Canopy* – similar to conserve canopy projections, but also includes a 10% relative increase in tree cover.

Results in the report are presented within tables. Methods for each projection will be discussed first, followed by resulting tables illustrating variations in these themes across the conterminous U.S. The results are based on extrapolating recent percent urban tree cover changes among states (c. 2009-2014) (Nowak and Greenfield, 2018a). As most states had declining percent tree cover in urban areas, these losses are projected to continue in the future. There are numerous reasons why these recent trends could change (e.g., changes in policies, tree planting, storms, insects and diseases, development), but these results illustrate the potential change if the reason tree cover changes continue into the future. These projections are not indications of what will happen, but rather projections of what would happen if the current trends hold true.

2. Methods

2.1. Projected Changes in Urban Tree Cover

Projected tree cover changes were estimated using urban tree cover change data from c. 2009-2014 (Nowak and Greenfield 2018a). Average annual percent change in state tree cover change was used to project annual tree cover changes for each county with the state. For example, if state urban tree cover changed from 50% to 49% between 2009 and 2014, that would equate to a 1% drop over 5 years, or -0.2% per year. The -0.2% annual change was converted to a relative change based on the starting tree cover percentage (e.g., -0.2/50 = -0.004% change per relative to existing tree cover). This relative change value was applied to the tree cover from the previous year to project tree cover annually (e.g., tree cover in county in 2010 = 40%; 2011 = (40% x -0.004) + 40% = 39.8%; 2012 = (39.8% x -0.004) + 39.8% = 39.7%, … 2060 = 32.7%).

2.2. Carbon Storage and Sequestration

Projected decadal urban tree cover (m^2) was converted to total carbon storage and net annual sequestration based on national urban forest carbon storage values (7.69 kgC/ m^2 tree cover) and state specific net sequestration values (Nowak et al. 2013). Net sequestration values are based on estimated gross sequestration due to tree growth minus an estimated loss of carbon due to decomposition from tree death and decay. Net sequestration rates vary depending upon land use and tree health. Based on field data assessments from several cities, the average net sequestration rate averages 74% of the gross sequestration rate (Nowak et al. 2013).

2.3. Building Energy Use and Altered Power Plant Emissions

Projected decadal urban tree cover (m^2) was converted to estimated changes in building energy use and avoided power plant emissions based on methods detailed in Nowak et al. (2017). These methods combined field data on urban trees with local urban/community tree and land cover maps, modeling of tree effects on building energy use and pollutant emissions, and state energy and pollutant costs to estimate tree effects on building energy use and associated pollutant emissions at the state to national level in the conterminous U.S. Avoided emissions were estimated for carbon dioxide (CO_2), nitrogen oxides (NO_x), sulfur dioxide (SO_2), carbon monoxide (CO), methane (CH_4), volatile organic compounds (VOCs), and particulate matter less than 10 microns (PM_{10}) and less than 2.5 microns ($PM_{2.5}$). State-specific values of energy changes and avoided emissions per m2 of tree cover by NLCD land cover class were applied to decadal urban tree cover estimates by NLCD class within urban areas to derived county estimates. Energy and emission values were based on 2018 values. Emissions are reported as the sum value for all avoided emissions. Emissions values are detailed in Nowak et al. (2017) with the exception that the values for avoided NO_2, SO_2 and $PM_{2.5}$ were based on average county health values per tonne of pollution as derived from BenMAP analyses as detailed in Nowak et al. (2014).

2.4. Projection Scenarios

Three projections (2010-2060) of urban forest impacts on carbon storage, building energy use and power plant emissions were conducted:

1. *Current trend* – a base projection based on recent trends in tree cover change

2. *Conserve Canopy* – this scenario holds percent urban tree cover at a minimum of 2010 percent tree cover value

3. *Enhance Canopy* – similar to conserve canopy projections, but includes a 10% relative increase in tree cover (e.g., 2010 tree cover = 50%, 2060 tree cover = 55%)

For all scenarios, the changes in projected urban tree cover were used to project changes in carbon storage and sequestration, building energy savings and avoided emission estimates. That is, the changes in these ecosystem services and values are proportional to the changes in urban tree cover.

3. Results / Discussion

This section displays tables of state averages, as well as tables for the top 10 and bottom 10 counties relative to the changes in 2060. Note that these projections are based on the assumptions detailed in the methods and are not projections of what will happen, but rather projections of what would happen if the assumptions and trends in the methods hold true. The farther one projects into the future, the more unlikely that these trends will hold true. However, while the absolute values of change are likely inaccurate over a 50-year projection, the data reveal probable areas of greatest change in the coming years. The projections and trends may change in the future if various policies change or other factors change (e.g., economic depression) that would alter future conditions. To that end, by understanding projected changes, management and policies, actions could be implemented to direct the future to the most desirable outcomes.

3.1. Urban Tree Cover

The percent urban tree cover in existing urban areas is projected to decrease by 8.3% by 2060, decreasing from 39.4% (2010) to 31.1% (2060). States with the greatest projected decrease in percent urban tree cover are Oklahoma, Georgia and Tennessee (Table 1). Oklahoma is projected to lose the greatest percent urban tree cover as this state exhibited the highest recent tree cover loss (c. 2009-2014; Nowak and Greenfield 2018a). Projected trends may change in the coming years due to changes in policies related to tree protection, new tree plantings and/or natural regeneration changes.

Counties with the greatest decrease in percent urban tree cover were all in Oklahoma, while counties with the greatest projected increase were all in Wyoming. These patterns are directly related to the average state changes between c. 2009-2014. This magnitude of tree cover change in these states are likely an overestimate as the current change in cover will likely not be sustained in the coming decades.

Table 1. Projected change (Δ) in percent urban tree cover (2010-2060) by state.

State	Tree cover Δ (%)
Oklahoma	-20.6
Georgia	-16.7
Tennessee	-15.5
Arkansas	-15.1
Rhode Island	-15.0
Montana	-14.6
Oregon	-14.5
Alabama	-14.3
Ohio	-14.0
Vermont	-13.5
Louisiana	-12.7
Iowa	-12.4
Kentucky	-11.8
Virginia	-11.7
Mississippi	-11.5
Florida	-11.1
South Carolina	-11.0
Nebraska	-11.0
Massachusetts	-10.5
New York	-10.2
Michigan	-9.5
Kansas	-8.9
Texas	-8.8
New Hampshire	-8.7
Arizona	-8.0
Missouri	-7.5
North Dakota	-7.4
Illinois	-7.1
Maine	-6.8
West Virginia	-6.7
Indiana	-6.0

State	Tree cover Δ (%)
Idaho	-5.7
Delaware	-5.4
Pennsylvania	-5.3
Wisconsin	-5.0
North Carolina	-5.0
New Jersey	-4.8
Maryland	-4.6
Nevada	-3.6
Utah	-2.9
Connecticut	-2.6
Washington	-1.7
California	0.0
Colorado	0.0
Minnesota	0.0
New Mexico	0.0
South Dakota	4.4
Wyoming	8.6

3.2. Projected Changes in Urban Forest Ecosystem Services and Values

The changes in urban tree cover will directly affect the ecosystem services and values of the urban forest in the future. That is, the amount of future urban tree cover is a main driver of future ecosystem services and values. The actual rate of ecosystem services per unit tree cover will likely change in the future as species composition and environmental conditions change. Many of these future changes are unknown as not only does the environment change urban forests, but so do human actions. Many natural projections of change may be altered by human actions. For example, while species compositions may be projected to change, management in urban areas may accelerate or diminish the change based on tree planting and removals. Projections do not account for future policy changes that could affect tree cover (e.g., large tree planting campaigns) or various forces that could devastate the local urban forest (e.g., hurricanes, insect or disease outbreaks).

Given a projected loss of 2.3 million hectares of tree cover between 2010 and 2060, and an average 511 trees per hectare of tree cover (Nowak and Greenfield 2018b), approximately 24 million trees would need to be established annually to account for tree cover loss. In addition, the tree cover that remained during this time period also needs to be sustained. Assuming a nominal 1% mortality rate, an additional 45 million trees are likely established annually to sustain the base tree cover. Thus, a total of approximately 69 million trees would need to be established each year to sustain urban tree cover. As about two-thirds of existing trees come from natural regeneration (Nowak 2012), annual tree planting nationally would need to be about 23 million trees to sustain current percent tree cover levels from 2010 to 2060, given current urban tree cover projections. On average, this planting equates to a national rate of one new tree planted annually for every 1.2 hectares (3.0 acres) of urban land.

Given that 80.7% of the U.S. population lives in urban areas and a 2019 U.S. population of 328.2 million people, approximately 265 million people live in U.S. urban areas. Planting 23 million trees per year equates to each urban resident planting one tree every 11.5 years. As the average person lives 78.5 years, each urban resident would need to plant about seven trees during their lifetime to sustain tree cover in existing urban areas.

In the future, climate change could affect carbon storage and sequestration rates, but there are various counter-indications as to what might happen to carbon storage and sequestration. While climate change effects of increased CO_2 and longer growing seasons will increase growth rates (e.g., Taub 2010, Deryng et al. 2016) and potentially stand densities (Devi et al. 2020), decreasing wood densities (Pretzsch et al. 2018) and possible decreased life spans due to increased growth rates when young (Büntgen et al. 2019) may offset carbon gains of increased growth. Given the uncertainties of future carbon densities per m^2 of tree cover, projections of urban forest carbon effects use current carbon storage and sequestration densities.

3.2.1. Carbon Storage and Value

Carbon storage values are related to tree species, sizes and densities, while annual carbon sequestration relates these same factors plus annual growth and mortality rates. Carbon storage is estimated based on the national average carbon storage density (kgC/m^2 tree cover) from several U.S. cities. Gross carbon sequestration (kgC/m^2 tree cover/yr) is based on state specific growth rates and average tree competition and conditions as derived from the sample of U.S. cities. Net sequestration accounts for carbon losses due to mortality and tree decomposition and are estimated as 74% of gross sequestration (Nowak et al. 2013).

Carbon storage in existing U.S. urban forests is projected to decrease by 180 million tonnes (-21%) by 2060, declining from 852 million tonnes (2010) to 671 million tonnes (2060) (Table 2). Given the 2020 value of the social cost of carbon ($188/tC in 2018 dollars; Interagency Working Group on Social Cost of Carbon 2016), the carbon storage value of the urban forest will decrease by $34 billion by 2060, declining from $160 billion (2010) to $126 billion (2060). If tree cover is enhanced by 10%, carbon storage could increase to 937 million tonnes ($176 billion).

Table 2. Amounts and differences (million tonnes) in 2060 carbon storage and annual carbon sequestration (seq.) based on current projected trends, canopy conservation and canopy enhancement scenarios.

Scenario	Storage	Diff[a]	Seq.	Diff[a]
Trend	671.4	na	26.6	na
Conserve	851.9	180.5	34.0	7.4
Enhance	937.1	265.7	37.4	10.8

[a] difference from trend scenario
na – not applicable

States with the greatest increase in carbon storage and sequestration due to the conservation or enhancement of current percent tree cover are Florida, Georgia and Texas (Tables 3-4). Counties that have the greatest increases in carbon storage and sequestration from canopy conservation or enhancement tend to be in Texas, Arizona, Georgia and Florida (Tables 5-6).

Table 3. Differences in 2060 state carbon storage (tonnes) for conserve canopy and enhance canopy scenarios vs. the current trend scenario.

State	Conserve[a]	State	Enhance[b]
Florida	17,646,000	Florida	23,229,000
Georgia	16,197,000	Georgia	22,341,000
Texas	15,612,000	Texas	20,977,000
Ohio	12,462,000	Ohio	15,819,000
Tennessee	9,062,000	New York	12,679,000
New York	8,646,000	Tennessee	11,763,000
Michigan	7,055,000	Michigan	10,084,000
Massachusetts	6,524,000	Massachusetts	10,033,000
Virginia	6,466,000	North Carolina	9,873,000
Alabama	6,350,000	Virginia	9,199,000
Illinois	5,732,000	Pennsylvania	8,729,000
Oklahoma	5,418,000	Alabama	8,458,000
South Carolina	5,329,000	Illinois	8,327,000
Louisiana	5,083,000	South Carolina	7,620,000
Pennsylvania	5,017,000	Louisiana	6,852,000
North Carolina	4,683,000	Oklahoma	6,095,000
Arizona	3,493,000	New Jersey	5,541,000
Kentucky	3,377,000	Missouri	4,871,000
Arkansas	3,357,000	Indiana	4,638,000

State	Conserve[a]	State	Enhance[b]
Oregon	3,267,000	Kentucky	4,516,000
Missouri	3,080,000	Arkansas	4,474,000
Indiana	3,071,000	Arizona	4,473,000
New Jersey	2,918,000	California	4,160,000
Mississippi	2,587,000	Oregon	4,009,000
Iowa	2,400,000	Maryland	3,966,000
Wisconsin	1,955,000	Mississippi	3,765,000
Maryland	1,885,000	Wisconsin	3,060,000
Kansas	1,749,000	Connecticut	3,034,000
Rhode Island	1,268,000	Iowa	2,948,000
Nebraska	1,157,000	Washington	2,896,000
New Hampshire	1,147,000	Kansas	2,497,000
Connecticut	975,000	New Hampshire	1,863,000
West Virginia	885,000	Minnesota	1,744,000
Montana	868,000	Rhode Island	1,668,000
Washington	852,000	West Virginia	1,617,000
Idaho	574,000	Nebraska	1,400,000
Nevada	545,000	Montana	1,004,000
Utah	532,000	Maine	953,000
Maine	503,000	Utah	830,000
Delaware	456,000	Nevada	735,000
Vermont	427,000	Delaware	730,000
North Dakota	271,000	Idaho	700,000
California	0	Vermont	594,000
Minnesota	0	Colorado	547,000
Colorado	0	North Dakota	314,000
New Mexico	0	New Mexico	265,000
South Dakota	-201,000	South Dakota	-106,000
Wyoming	-334,000	Wyoming	-291,000
U.S. Total[c]	180,593,000		265,728,000

[a] *difference in carbon storage: conserve scenario minus current trend scenario*
[b] *difference in carbon storage: enhance scenario minus current trend scenario*
[c] *conterminous United States*

Table 4. Differences in 2060 state annual carbon sequestration (tonnes) for conserve canopy and enhance canopy scenarios vs. the current trend scenario.

State	Conserve[a]	State	Enhance[b]
Florida	1,090,000	Florida	1,435,000
Texas	747,000	Georgia	1,026,000
Georgia	743,000	Texas	1,004,000
Ohio	402,000	Ohio	510,000
Tennessee	357,000	Tennessee	463,000
Alabama	283,000	North Carolina	401,000
New York	270,000	New York	396,000
Louisiana	262,000	Alabama	377,000
Virginia	246,000	Louisiana	354,000
South Carolina	234,000	Virginia	350,000
Oklahoma	234,000	South Carolina	335,000
Massachusetts	215,000	Massachusetts	331,000
Illinois	211,000	Illinois	306,000
Michigan	202,000	Michigan	288,000
North Carolina	190,000	Pennsylvania	277,000
Arizona	161,000	Oklahoma	263,000
Pennsylvania	159,000	New Jersey	212,000
Arkansas	144,000	California	210,000
Kentucky	126,000	Arizona	206,000
Mississippi	116,000	Arkansas	193,000
Missouri	114,000	Missouri	181,000
New Jersey	112,000	Mississippi	168,000
Oregon	103,000	Kentucky	168,000
Indiana	100,000	Maryland	167,000
Maryland	79,000	Indiana	151,000
Iowa	75,000	Oregon	126,000
Kansas	64,000	Washington	97,000
Wisconsin	57,000	Connecticut	94,000
Rhode Island	43,000	Iowa	92,000
Nebraska	36,000	Kansas	92,000

State	Conserve[a]	State	Enhance[b]
New Hampshire	32,000	Wisconsin	90,000
Connecticut	30,000	Rhode Island	56,000
Washington	29,000	New Hampshire	53,000
West Virginia	28,000	Minnesota	52,000
Montana	21,000	West Virginia	51,000
Delaware	20,000	Nebraska	43,000
Utah	15,000	Delaware	32,000
Nevada	15,000	Maine	27,000
Maine	14,000	Montana	24,000
Idaho	14,000	Utah	23,000
Vermont	12,000	Nevada	20,000
North Dakota	8,000	Idaho	17,000
California	0	Vermont	16,000
Minnesota	0	Colorado	14,000
Colorado	0	North Dakota	9,000
New Mexico	0	New Mexico	9,000
South Dakota	-6,000	South Dakota	-3,000
Wyoming	-8,000	Wyoming	-7,000
U.S. Total[c]	7,407,000		10,809,000

[a] *difference in annual carbon sequestration: conserve scenario minus current trend scenario*
[b] *difference in annual carbon sequestration: enhance scenario minus current trend scenario*
[c] *conterminous United States*

Table 5. Differences in 2060 county carbon storage (tonnes) for conserve canopy and enhance canopy scenarios vs. the current trend scenario with no urban expansion. Data are presented for the top and bottom 10 counties related to differences in carbon storage.

County	State	Conserve[a]	County	State	Enhance[b]
Harris	Texas	2,314,600	Harris	Texas	3,110,100
Maricopa	Arizona	1,859,000	Maricopa	Arizona	2,379,900
Fulton	Georgia	1,510,400	Fulton	Georgia	2,083,400
Oklahoma	Oklahoma	1,361,500	Middlesex	Massachusetts	1,991,900
Gwinnett	Georgia	1,348,800	Suffolk	New York	1,897,800
Jefferson	Alabama	1,306,600	Gwinnett	Georgia	1,860,500
Hillsborough	Florida	1,303,600	Cook	Illinois	1,787,800
Shelby	Tennessee	1,297,100	Jefferson	Alabama	1,740,500
Middlesex	Massachusetts	1,295,200	Hillsborough	Florida	1,715,900
Suffolk	New York	1,294,000	Oakland	Michigan	1,697,100
Park	Wyoming	-18,500	Park	Wyoming	-16,100
Fremont	Wyoming	-18,800	Fremont	Wyoming	-16,300
Albany	Wyoming	-27,300	Pennington	South Dakota	-21,800
Sheridan	Wyoming	-27,500	Albany	Wyoming	-23,800
Sweetwater	Wyoming	-29,100	Sheridan	Wyoming	-23,900
Campbell	Wyoming	-38,100	Sweetwater	Wyoming	-25,400
Pennington	South Dakota	-41,300	Minnehaha	South Dakota	-30,400
Laramie	Wyoming	-52,900	Campbell	Wyoming	-33,100
Natrona	Wyoming	-57,100	Laramie	Wyoming	-46,000
Minnehaha	South Dakota	-57,400	Natrona	Wyoming	-49,600

[a] *difference in carbon storage: conserve scenario minus current trend scenario*
[b] *difference in carbon storage: enhance scenario minus current trend scenario*

Table 6. Differences in 2060 county annual carbon sequestration (tonnes) for conserve canopy and enhance canopy scenarios vs. the current trend scenario with no urban expansion. Data are presented for the top and bottom 10 counties related to differences in annual carbon sequestration.

County	State	Conserve[a]	County	State	Enhance[b]
Harris	Texas	110,800	Harris	Texas	148,800
Maricopa	Arizona	85,600	Maricopa	Arizona	109,600
Hillsborough	Florida	80,500	Hillsborough	Florida	106,000
Fulton	Georgia	69,300	Fulton	Georgia	95,600
Duval	Florida	68,600	Duval	Florida	90,300
Gwinnett	Georgia	61,900	Gwinnett	Georgia	85,400
Orange	Florida	60,100	Orange	Florida	79,100
Oklahoma	Oklahoma	58,800	Jefferson	Alabama	77,600
Jefferson	Alabama	58,300	Dallas	Texas	76,900
Dallas	Texas	57,200	Cobb	Georgia	74,700
Park	Wyoming	-400	Park	Wyoming	-400
Fremont	Wyoming	-400	Fremont	Wyoming	-400
Albany	Wyoming	-600	Albany	Wyoming	-600
Sheridan	Wyoming	-600	Sheridan	Wyoming	-600
Sweetwater	Wyoming	-700	Sweetwater	Wyoming	-600
Campbell	Wyoming	-900	Pennington	South Dakota	-700
Laramie	Wyoming	-1,300	Campbell	Wyoming	-800
Pennington	South Dakota	-1,300	Minnehaha	South Dakota	-900
Natrona	Wyoming	-1,400	Laramie	Wyoming	-1,100
Minnehaha	South Dakota	-1,800	Natrona	Wyoming	-1,200

[a] *difference in annual carbon sequestration: conserve scenario minus current trend scenario*
[b] *difference in annual carbon sequestration: enhance scenario minus current trend scenario*

3.2.2. Building Energy Conservation

Building energy conservation values are related to average tree distributions around buildings among land cover classes and changes in land cover distribution and tree cover with land cover classes (Nowak et al. 2017). The values are also related to state-specific energy costs and types of energy used to heat and cool buildings, as well as regionally specific tree cover effects on building energy use depending on tree size and orientation around a building. On average, urban trees reduce building energy use by 7.2% (Nowak and Greenfield 2017).

Projections of tree effects on building energy use assume that energy costs and fuel types stay consistent in the future (2030 and 2060). In reality, energy types and distributions will likely change in the future as energy efficiencies and building designs change. Energy costs are also likely to increase in the coming years.

Energy conservation in existing U.S. urban forests is projected to decrease by $855 million by 2060, declining from $4.1 billion (2010) to $3.3 billion (2060). Conserving tree cover at its current percent tree cover would save an additional $855 million in energy costs in 2060; enhancing urban tree cover by 2060 would save an additional $1.3 billion per year (Table 7).

Table 7. Amounts and differences (million $) in 2060 energy savings based on current projected trends, canopy conservation and canopy enhancement scenarios.

Scenario	Energy Savings ($)	Diff[a]
Trend	3,278	na
Conserve	4,132	855
Enhance	4,545	1,268

[a] difference from trend scenario
na – not applicable

States with the greatest increase in energy savings due to the conservation or enhancement of current percent tree cover are Florida, Texas and Massachusetts (Table 8). Counties that have the greatest energy savings from canopy conservation or enhancement tend to be from the same states (Table 9).

Table 8. Differences in 2060 state annual energy savings ($) for conserve canopy and enhance canopy scenarios vs. the current trend scenario.

State	Conserve[a]	State	Enhance[b]
Florida	87,374,000	Texas	116,712,000
Texas	86,860,000	Florida	115,014,000
Massachusetts	66,857,000	Massachusetts	102,815,000
Ohio	63,597,000	New York	88,578,000
New York	60,399,000	Ohio	80,728,000
Arizona	60,002,000	Arizona	76,817,000
Illinois	40,567,000	Illinois	58,936,000
Michigan	34,132,000	Missouri	52,630,000
Missouri	33,279,000	Michigan	48,790,000
Kansas	26,865,000	Pennsylvania	43,225,000
Pennsylvania	24,842,000	Kansas	38,343,000
Kentucky	23,811,000	New Jersey	33,045,000
Louisiana	23,352,000	Kentucky	31,840,000
Oklahoma	20,881,000	Louisiana	31,481,000
Indiana	17,405,000	California	31,341,000
New Jersey	17,405,000	Indiana	26,287,000
Virginia	16,468,000	Connecticut	26,217,000
Rhode Island	14,545,000	Maryland	24,454,000
Iowa	13,590,000	Oklahoma	23,490,000
Georgia	11,669,000	Virginia	23,427,000
Maryland	11,624,000	Rhode Island	19,127,000
Wisconsin	11,209,000	Wisconsin	17,541,000
Nebraska	10,126,000	Iowa	16,697,000
Alabama	9,638,000	Georgia	16,096,000
Connecticut	8,421,000	Alabama	12,839,000
Tennessee	7,273,000	Nebraska	12,257,000
Montana	6,466,000	New Hampshire	10,393,000
New Hampshire	6,399,000	Tennessee	9,441,000
Nevada	6,238,000	Mississippi	8,763,000
Mississippi	6,021,000	Nevada	8,418,000

State	Conserve[a]	State	Enhance[b]
South Carolina	4,502,000	West Virginia	7,536,000
West Virginia	4,126,000	Montana	7,478,000
Arkansas	3,146,000	Minnesota	6,739,000
North Carolina	3,019,000	South Carolina	6,438,000
Delaware	2,937,000	North Carolina	6,365,000
Maine	2,655,000	Maine	5,032,000
Vermont	2,299,000	Delaware	4,701,000
North Dakota	2,166,000	Arkansas	4,192,000
Idaho	1,202,000	Vermont	3,196,000
Washington	548,000	North Dakota	2,502,000
Oregon	324,000	Washington	1,865,000
Utah	266,000	New Mexico	1,807,000
California	0	Idaho	1,466,000
Colorado	0	Colorado	659,000
Minnesota	0	Utah	416,000
New Mexico	0	Oregon	398,000
Wyoming	-290,000	Wyoming	-252,000
South Dakota	-1,504,000	South Dakota	-795,000
U.S. Total[c]	854,871,000		1,268,115,000

[a] *difference in energy savings: conserve scenario minus current trend scenario*
[b] *difference in energy savings: enhance scenario minus current trend scenario*
[c] *conterminous United States*

Table 9. Differences in 2060 county annual energy savings ($) for conserve canopy and enhance canopy scenarios vs. the current trend scenario. Data are presented for the top and bottom 10 counties related to differences in energy savings.

County	State	Conserve[a]	County	State	Enhance[b]
Maricopa	Arizona	41,857,000	Maricopa	Arizona	53,588,000
Harris	Texas	18,950,000	Harris	Texas	25,462,000
Middlesex	Massachusetts	14,987,000	Middlesex	Massachusetts	23,047,000
Suffolk	New York	14,167,000	Suffolk	New York	20,777,000
Cook	Illinois	10,004,000	Cook	Illinois	14,534,000
St. Louis	Missouri	8,665,000	St. Louis	Missouri	13,704,000
Norfolk	Massachusetts	8,469,000	Norfolk	Massachusetts	13,024,000
Worcester	Massachusetts	8,194,000	Worcester	Massachusetts	12,601,000
Essex	Massachusetts	7,748,000	Essex	Massachusetts	11,915,000
Sedgwick	Kansas	7,662,000	Plymouth	Massachusetts	11,123,000
Beadle	South Dakota	-66,000	Clark	Washington	-51,000
Lawrence	South Dakota	-68,000	Laramie	Wyoming	-55,000
Washington	Oregon	-70,000	Brown	South Dakota	-63,000
Hughes	South Dakota	-77,000	Pierce	Washington	-76,000
Lincoln	South Dakota	-82,000	Snohomish	Washington	-78,000
Codington	South Dakota	-86,000	Washington	Oregon	-86,000
Brown	South Dakota	-119,000	Pennington	South Dakota	-119,000
Multnomah	Oregon	-133,000	Multnomah	Oregon	-164,000
Pennington	South Dakota	-226,000	King	Washington	-176,000
Minnehaha	South Dakota	-394,000	Minnehaha	South Dakota	-208,000

[a] *difference in energy savings: conserve scenario minus current trend scenario*
[b] *difference in energy savings: enhance scenario minus current trend scenario*

3.2.3. Avoided Emissions

The projected changes in building energy use will alter emissions from the sources of fuels used to produce the energy. State or national emission factors and costs by fuel type were used to estimate changes in emissions due to changes in building energy use (Nowak et al. 2017). The emission factors and costs from 2010 were held constant for the year 2060.

Avoided pollutant emissions in existing U.S. urban areas is projected to decrease by $318 million by 2060, declining from $1.4 billion (2010) to $1.1 billion (2060). Relative to the current declining tree cover projection, conserving tree cover at its current percent tree cover would avoid the emission of an additional 1.4 million tonnes of carbon by 2060 and avoid pollutant emissions (CO_2, NO_x, SO_2, CO, CH_4, VOCs, PM_{10} and $PM_{2.5}$) with an associated value of $318 million per year. Enhancing urban tree cover by 2060 would avoid the emission of an additional 2.0 million tonnes of carbon by 2060, and avoid pollutant emissions with an associated value of $462 million per year (Table 10).

Table 10. Amounts and differences in 2060 avoided annual carbon emissions and total value from reduced annual pollutant emissions based on current projected trends, canopy conservation and canopy enhancement scenarios.

Scenario	Carbon[a]	Diff[b]	Emission[c]	Diff[b]
Trend	4.7	na	1,128	na
Conserve	6.1	1.4	1,446	318
Enhance	6.7	2.0	1,590	462

[a] *million tonnes of avoided carbon emissions*
[b] *difference from trend scenario*
[c] *annual value (million $) from reduced CO_2, NO_x, SO_2, CO, CH_4, VOCs, PM_{10} and $PM_{2.5}$ emissions*
na – not applicable

States with the greatest increase in 2060 in avoided carbon and pollutant emissions due to the conservation or enhancement of current percent tree cover are Ohio, Texas and Florida (Tables 11-12). Counties that have the greatest increase in avoided carbon and pollutant emissions from canopy conservation or enhancement are Maricopa, Ariz.; Harris, Texas; and Cook, Ill. (Tables 13-14).

Table 11. Differences in 2060 state annual avoided carbon emissions (tonnes) for conserve canopy and enhance canopy scenarios vs the current trend scenario.

State	Conserve[a]	State	Enhance[b]
Ohio	153,400	Florida	49,714,000
Texas	125,600	Ohio	42,108,000
Florida	115,900	Texas	36,218,000
Illinois	96,500	Illinois	28,042,000
Michigan	77,800	Massachusetts	24,431,000
Missouri	72,200	Missouri	22,729,000

State	Conserve[a]	State	Enhance[b]
Massachusetts	70,500	Michigan	22,255,000
Arizona	63,400	New York	21,647,000
New York	59,900	Arizona	18,364,000
Kansas	56,700	Pennsylvania	15,903,000
Kentucky	53,600	Kansas	15,805,000
Indiana	44,700	Kentucky	15,472,000
Pennsylvania	40,900	Indiana	13,854,000
Iowa	39,000	Louisiana	13,448,000
Oklahoma	38,500	New Jersey	10,436,000
Louisiana	37,100	Maryland	10,323,000
Wisconsin	26,600	Oklahoma	8,882,000
Nebraska	26,300	Iowa	8,778,000
New Jersey	21,600	Virginia	8,279,000
Virginia	21,400	Wisconsin	8,233,000
Maryland	19,900	Georgia	7,555,000
Montana	18,200	California	7,334,000
Georgia	15,600	Nebraska	6,181,000
Rhode Island	12,100	Montana	5,259,000
West Virginia	10,200	Connecticut	4,923,000
Alabama	9,800	Alabama	4,010,000
Mississippi	7,500	West Virginia	3,929,000
Connecticut	7,100	Rhode Island	3,178,000
Nevada	6,900	Mississippi	3,109,000
North Dakota	6,800	Minnesota	3,038,000
New Hampshire	5,400	Tennessee	2,909,000
Delaware	5,200	North Carolina	2,677,000
Tennessee	5,000	Delaware	2,012,000
Arkansas	3,700	Nevada	1,976,000
North Carolina	3,100	New Hampshire	1,752,000
Maine	1,700	North Dakota	1,683,000

State	Conserve[a]	State	Enhance[b]
South Carolina	1,100	Maine	1,266,000
Utah	300	South Carolina	1,249,000
Washington	0	Arkansas	1,182,000
Vermont	0	New Mexico	598,000
Idaho	0	Idaho	295,000
California	0	Utah	293,000
Minnesota	0	Washington	160,000
New Mexico	0	Colorado	125,000
Colorado	0	Vermont	98,000
Wyoming	-100	Oregon	-151,000
Oregon	-3,100	Wyoming	-284,000
South Dakota	-3,600	South Dakota	-382,000
U.S. Total[c]	1,378,900		462,308,000

[a] *difference in reduced pollutant emissions: conserve scenario minus current trend scenario*
[b] *difference in reduced pollutant emissions: enhance scenario minus current trend scenario*
[c] *conterminous United States*

Table 13. Differences in 2060 state annual avoided carbon emissions (tonnes) for conserve canopy and enhance canopy scenarios vs. the current trend scenario. Data are presented for the top and bottom 10 counties related to differences in energy savings.

County	State	Conserve[a]	County	State	Enhance[b]
Maricopa	Arizona	44,200	Maricopa	Arizona	56,600
Harris	Texas	27,400	Harris	Texas	36,800
Cook	Illinois	24,200	Cook	Illinois	35,200
St. Louis	Missouri	18,800	St. Louis	Missouri	29,800
Hamilton	Ohio	16,300	Middlesex	Massachusetts	24,200
Sedgwick	Kansas	16,200	Sedgwick	Kansas	23,100
Middlesex	Massachusetts	15,700	Hamilton	Ohio	20,700
Franklin	Ohio	14,700	Suffolk	New York	19,500
Oakland	Michigan	13,500	Oakland	Michigan	19,300
Cuyahoga	Ohio	13,300	Franklin	Ohio	18,600
Ada	Idaho	-300	Ada	Idaho	-300
Brown	South Dakota	-300	Marion	Oregon	-400
Marion	Oregon	-300	Snohomish	Washington	-400
King	Washington	-300	Minnehaha	South Dakota	-500
Lane	Oregon	-400	Lane	Oregon	-500
Clackamas	Oregon	-500	Pierce	Washington	-500
Pennington	South Dakota	-500	Clackamas	Oregon	-600
Washington	Oregon	-700	Washington	Oregon	-800
Multnomah	Oregon	-800	Multnomah	Oregon	-1,000
Minnehaha	South Dakota	-900	King	Washington	-1,100

[a] *difference in avoided carbon emissions: conserve scenario minus current trend scenario*
[b] *difference in avoided carbon emissions: enhance scenario minus current trend scenario*

Table 14. Differences in value of 2060 state annual reduced pollutant emissions ($) for conserve canopy and enhance canopy scenarios vs. the current trend scenario. Data are presented for the top and bottom 10 counties related to differences in energy savings.

County	State	Conserve[a]	County	State	Enhance[b]
Maricopa	Arizona	10,506,000	Maricopa	Arizona	13,450,000
Harris	Texas	6,368,000	Harris	Texas	8,556,000
Cook	Illinois	5,174,000	Cook	Illinois	7,517,000
St. Louis	Missouri	3,734,000	St. Louis	Missouri	5,905,000
Hamilton	Ohio	3,663,000	Middlesex	Massachusetts	5,451,000
Middlesex	Massachusetts	3,544,000	Hamilton	Ohio	4,650,000
Miami-Dade	Florida	3,413,000	Sedgwick	Kansas	4,495,000
Pinellas	Florida	3,388,000	Miami-Dade	Florida	4,493,000
Franklin	Ohio	3,166,000	Pinellas	Florida	4,459,000
Sedgwick	Kansas	3,149,000	Suffolk	New York	4,376,000
Clackamas	Oregon	-40,000	Clackamas	Oregon	-49,000
Codington	South Dakota	-42,000	Pennington	South Dakota	-51,000
Washington	Oregon	-47,000	Washington	Oregon	-58,000
King	Washington	-52,000	Snohomish	Washington	-71,000
Brown	South Dakota	-58,000	Coryell	Texas	-78,000
Coryell	Texas	-58,000	Laramie	Wyoming	-80,000
Laramie	Wyoming	-92,000	Pierce	Washington	-89,000
Pennington	South Dakota	-96,000	Minnehaha	South Dakota	-104,000
Minnehaha	South Dakota	-198,000	King	Washington	-178,000
Crawford	Iowa	-368,000	Crawford	Iowa	-453,000

[a] *difference in reduced pollutant emissions: conserve scenario minus current trend scenario*
[b] *difference in reduced pollutant emissions: enhance scenario minus current trend scenario*

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