Assessing the Costs and Benefits of Investments in Climate Resilience: TVA Case Study and More

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Outline

- **Assessment activities for Energy Infrastructure in the Tennessee Valley:**
  - Allen, M., Wilbanks, T. J., Preston, B. L., Kao, S. C., & Bradbury, J. (2017). Assessing the Costs and Benefits of Resilience Investments: Tennessee Valley Authority Case Study (No. ORNL/TM-2017/13). Oak Ridge National Lab.(ORNL), Oak Ridge, TN (United States). Oak Ridge Leadership Computing Facility (OLCF). Supported by DOE EPSA

- **The Southeastern United States:**
  - Allen, M. R., Fernandez, S. J., Fu, J. S., & Walker, K. A. (2014). Electricity demand evolution driven by storm motivated population movement. J Geogr Nat Disast, 4(126), 2167-0587; Sastry, N., & Gregory, J. (2014). Supported by DOE BER

- **Knoxville, Tennessee**:
  - Nugent, P. J., Omitaomu, O. A., Parish, E. S., Mei, R., Ernst, K. M., Absar, M., & Sylvester, L. (2017). A Web-Based Geographic Information Platform to Support Urban Adaptation to Climate Change. In Advances in Geocomputation (pp. 371-381). Springer, Cham. Supported by Oak Ridge National Laboratory Climate Change Science and Urban Dynamics Institutes.

TVA Case Study: A combination of a severe summer drought and a severe summer heat wave in the 2050s

- **The Third National Climate Assessment** (2014) and other sources indicated that the Southeast region is vulnerable to **more frequent and/or more intense seasonal droughts and heat waves with climate change.**

- **TVA**'s <u>Climate Change Adaptation Plan</u> described adaptation strategies for conditions projected out to the 2030s period, but noted the need for a continuing process to **understand further challenges in the longer run.**

- This case study was set in a Representative Concentrated Pathway (RCP) 8.5 future, which represents "worst case" climate change in line with current global greenhouse gas emission trends. Future climate projections for the TVA region were drawn from **CMIP 5 data, downscaled to a 4 km grid with WRF.**

Focus: A combination of a severe summer drought and a severe summer heat wave in the 2050s

Methods

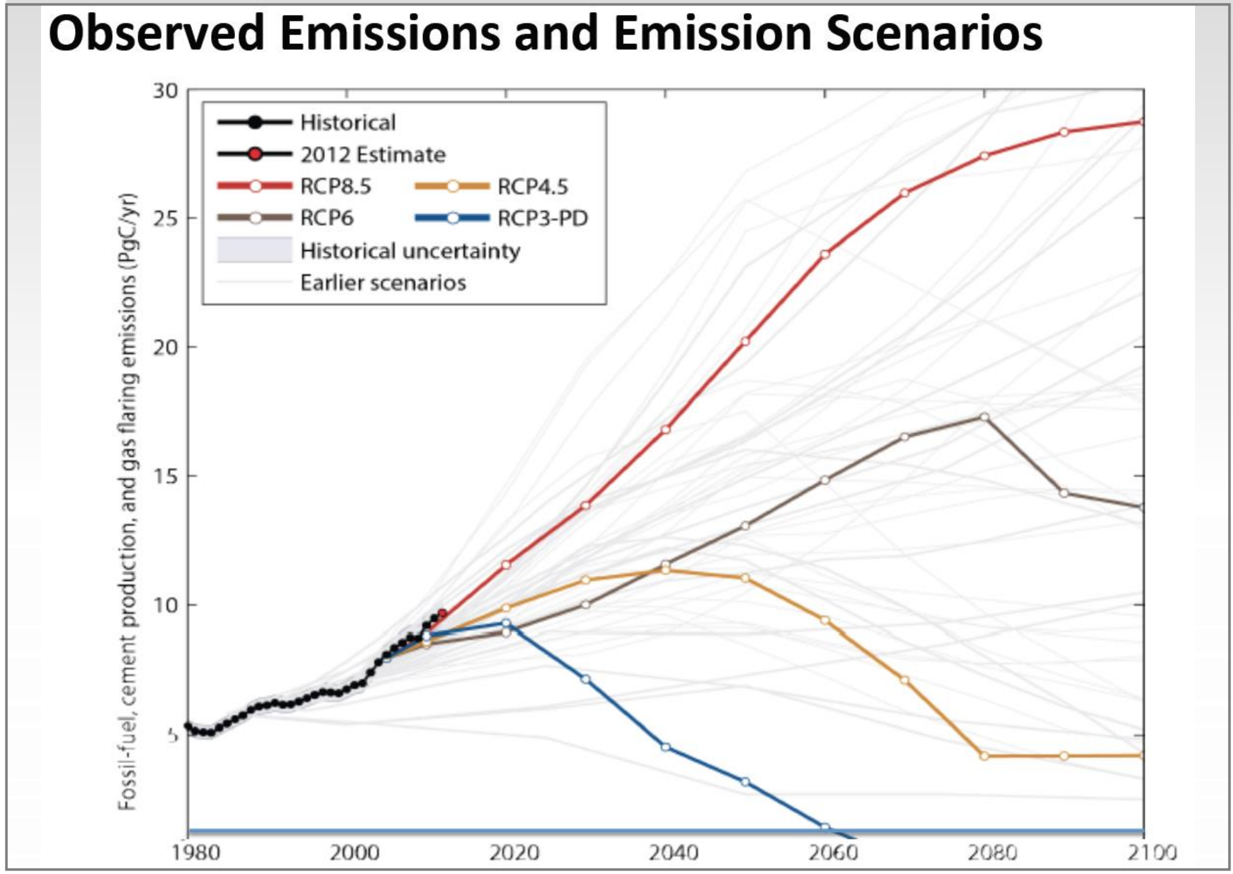
Heat Wave:

- We used a **historical 1993 heat wave**, based on observational data and superimposed this temperature change on the RCP 8.5 scenario in 2059. This event represented a **daily maximum temperature increase of 5-7 °F higher than the historical average** daily maxima over a period of 30 days.
- **Water temperatures** were also estimated based on relationship to air temperatures.

Drought:

- A severe drought was simulated using a **Standardized Precipitation Index (SPI)**, which incorporates rainfall conditions for a one-year period. Thus, observational data from the **historic 2007 drought** was similarly superimposed on regional conditions under the RCP 8.5 scenario. Estimated **lake evaporation in 2055** was also accounted for (due to higher air temperatures).
- This resulted in an **overall drying effect** for the Cumberland Basin

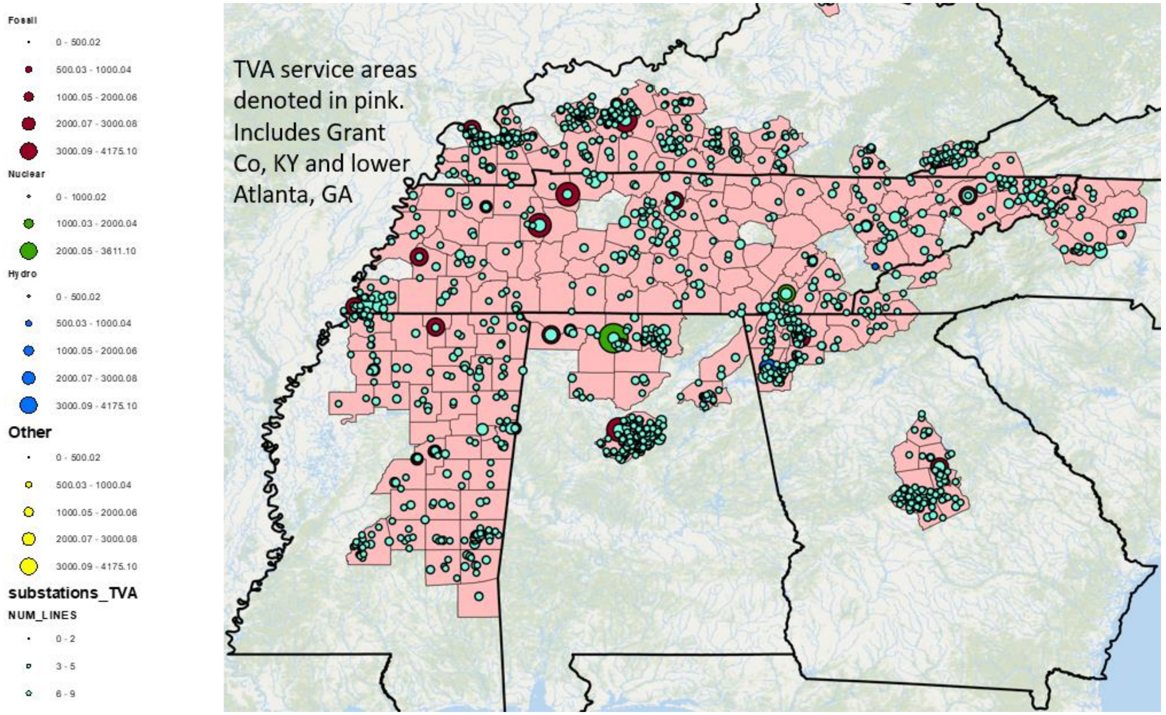
Emissions are Following RCP 8.5 Trajectory



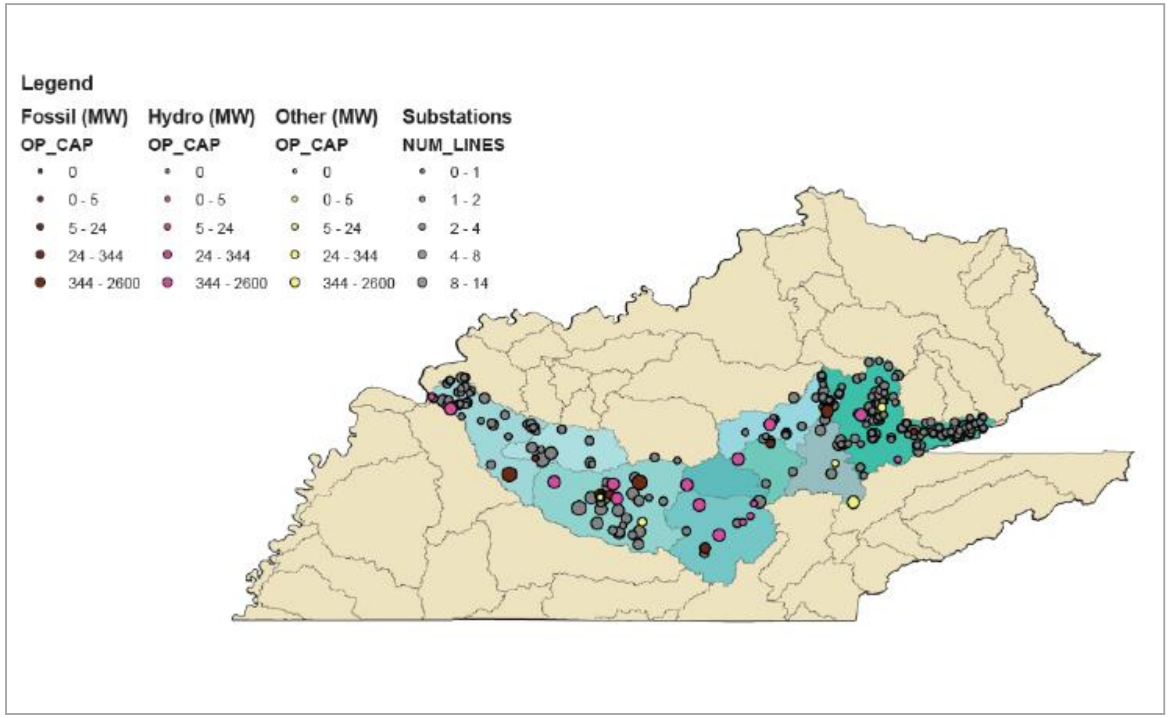
Source: Peters, G. P., Andrew, R. M., Boden, T., Canadell, J. G., Ciais, P., Le Quéré, C., ... & Wilson, C. (2012). The challenge to keep global warming below 2 C. Nature Climate Change, 3(1), 4.

TVA Infrastructure Considered in the Case Study

Tennessee Valley Authority Electric Facilities



Cumberland River Basin Electricity Facilities

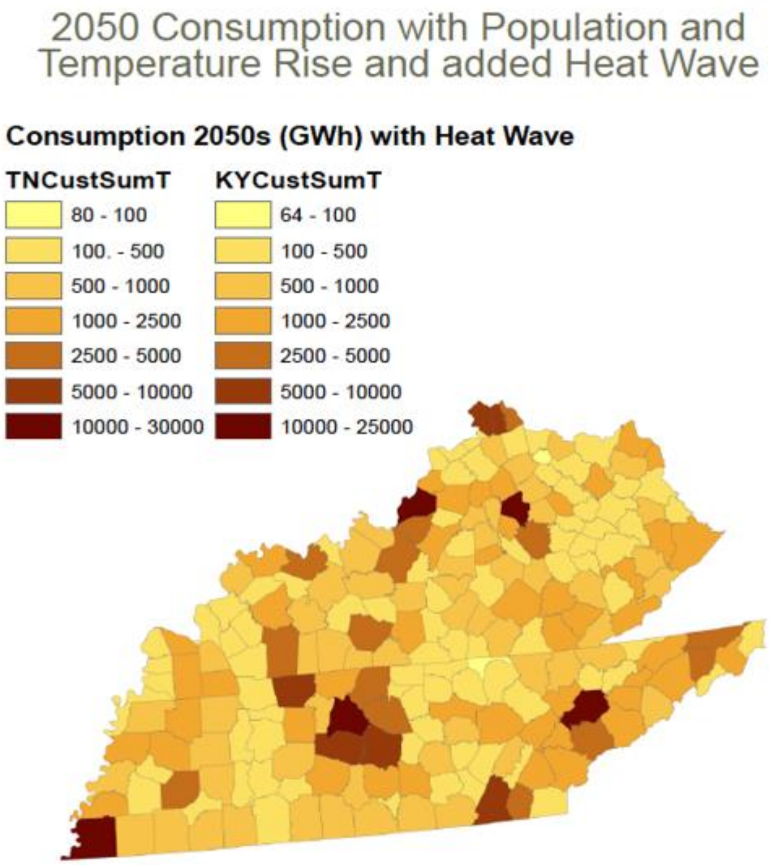


The majority of TVA's power is produced from coal and nuclear reactors, 40% and 33% respectively. The remainder is produced from natural gas (13%), hydroelectric generators (10%), and renewables (3%)

Electricity demand increases substantially with population growth and temperature increase

Increase in demand under 2050 heat wave = 108,000 MWh/day

Total Annual Consumption	Condition	Change
2010 – 53,919 GWh	Historical data	
2050 – 81,991 GWh	RCP 8.5 warming, no heat wave	52% above 2010
2050 – 93,470 GWh	RCP 8.5 warming, *plus heat wave*	73% above 2010



To determine increased electricity demand/consumption due to a heat wave in the 2050s, simulated heat wave cconditions were incorporated into the August 2059 electricity consumption calculations.

Electricity production would also be affected by RCP 8.5 temperature increases, drought and heat wave

Historical

- Current electricity production capacity in the Cumberland River basin includes:
  - **Hydropower** = 914 MW
  - **Fossil-based thermal power generation** = 4,200 MW
  - **"Other"** – a pumped storage plant (857 MW)
  - **Waste Products, PV, and Wind Power** (270 MW)

  (Note the dominance of thermal power generation)

Projected

Impacts estimated based on historical experiences (1993 heat wave and 2007 drought)

- **Hydropower**:
  - Affected by **reduced water flow**, due to drought, **increased evaporation**, and **increased demands for cooling**, hydropower generation estimated to be **35-60% of normal**, depending on TVA allocations for alternative uses
- **Fossil energy power generation**:
  - Affected by higher air temperature effects on **gas turbine efficiency**, reductions **in availability of cooling water**, higher intake water temperatures **reducing cooling efficiency**, and possible **violations of EPA-mandated "mixing zone" temperature** limits (case specific).
  - Estimated that downriver large power plants would be forced to shut down at least one unit, with a net **40% reduction in summer capacity**, compared with normal.
- **Summary**:
  - **Results in potential loss of up to 2,300 MW** of total generation capacity for the Cumberland River basin

"Order of Magnitude" cost for impacts and options for increasing climate resilience

Costs of Impacts

Costs of electricity shortages, if met by purchases of electricity from the wholesale market (the practice in the past):

- Increase in demand from present consumption = **108,000 MWh/day**
- Shortfall due to reduced internal generation, assuming $40 MWh from the wholesale market compared with costs of internal generation, would be **$377,462/day for hydro** and **$112,896/day for fossil thermal** (more costly internally due to maintenance and fuel costs) – total would almost certainly require a rate increase

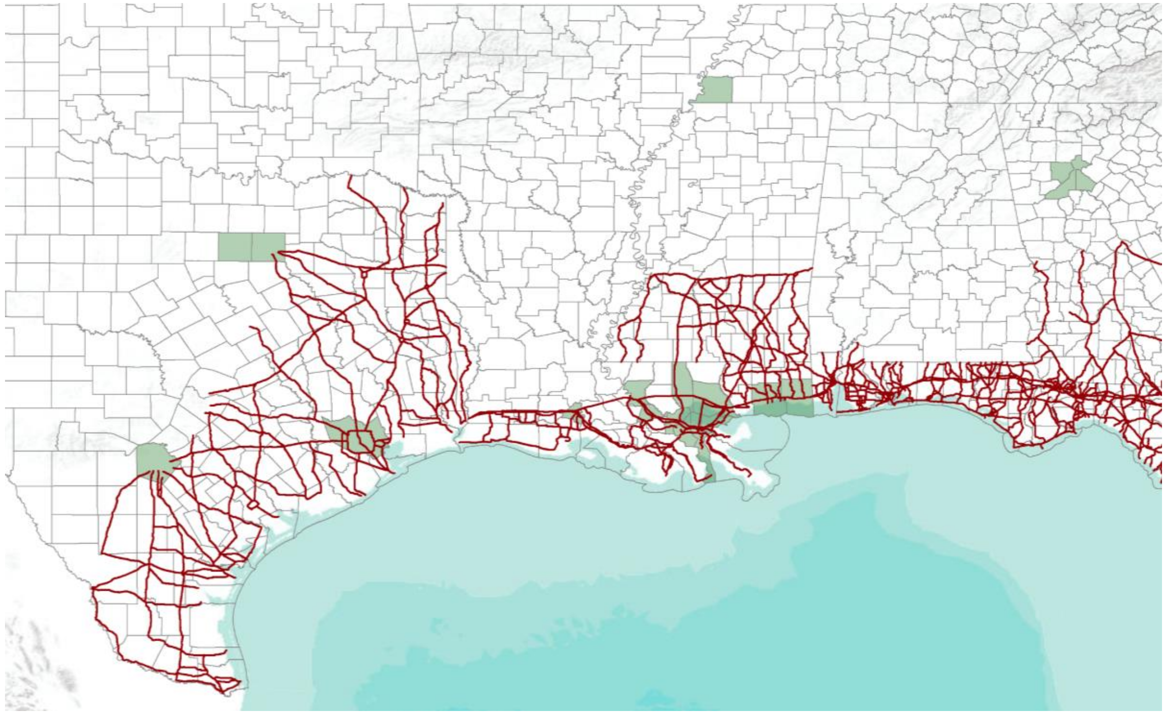
- Costs of electricity outages are also worth considering
  - Electricity blackouts not projected except in a worst case of a sudden thermal power plant shutdown (e.g., Duke Energy in 2007)
  - Would involve **loss in revenues for TVA** and also significant costs to some manufacturing and digital economy customers

TVA Integrated Resource Plan, 2015

- Enhanced efficiency and "smart grid" operations
- Change in thermal power plant cooling approaches: cooling towers or combined cooling towers and once-through cooling – effective but potentially expensive. Could also consider other technologies (e.g., dry cooling)
- Natural gas in place of coal when new plants are added: e.g., natural gas-combined cycle capacity – relatively low cost per MW of capacity
- Increase in alternative electricity generation technologies that are not water-consumptive – low capacity costs but low capacity factors
- Increased energy storage – costs are highly dependent on location
- Expansions of long-distance interconnections to improve ability to move power to take advantage of regional differences in conditions

The Southeast: additional climate adaptation concern for the Tennessee Valley…

Evacuation Routes in Red, Top 20 Hurricane Katrina Relocation Destinations in Green



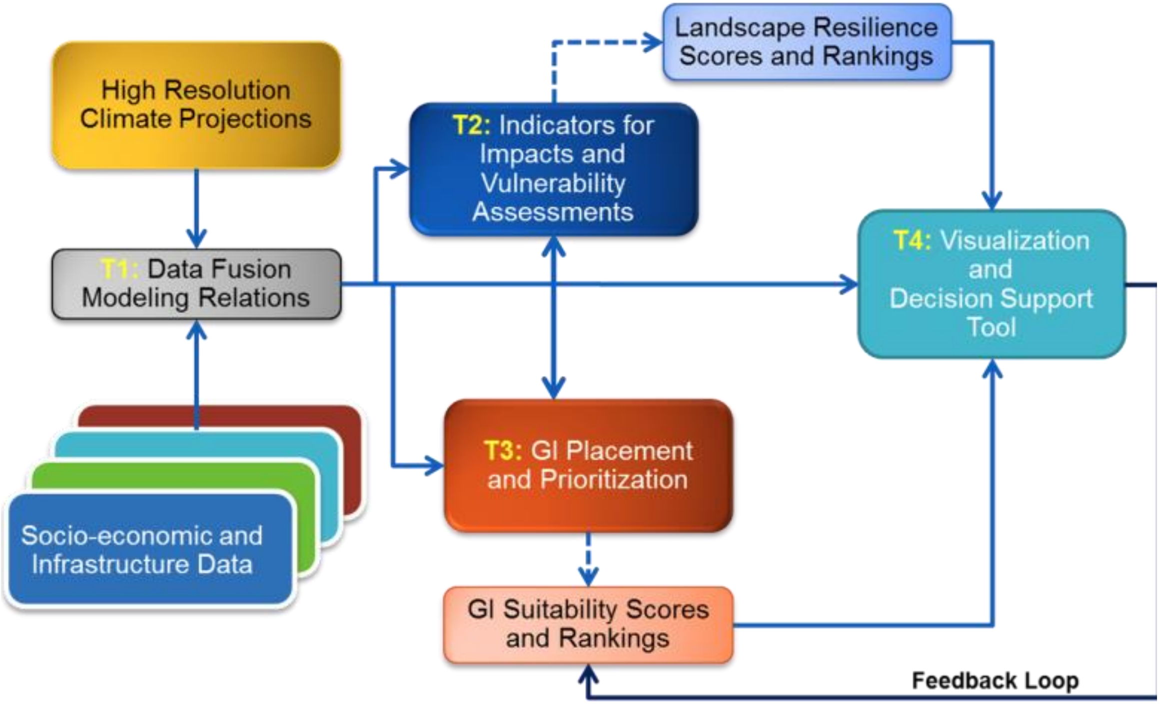
Sources: Allen, M. R., Fernandez, S. J., Fu, J. S., & Walker, K. A. (2014). Electricity demand evolution driven by storm motivated population movement. J Geogr Nat Disast, 4(126), 2167-0587; Sastry, N., & Gregory, J. (2014). The location of displaced New Orleans residents in the year after Hurricane Katrina. Demography, 51(3), 753-775.

Location	Percentage
New Orleans Metropolitan Area	52.5
Pre-Hurricane Katrina dwelling	31.4
Different dwelling in City of New Orleans	13.2
Metropolitan New Orleans, outside City of New Orleans	7.9
Elsewhere in Louisiana	12.3
Texas	18.3
South Region outside Louisiana and Texas	11.7
Georgia	3.4
Alabama	1.8
Mississippi	1.7
Florida	1.7
Maryland	0.7
Arkansas	0.7
Tennessee	0.6
South Carolina	0.4

Knoxville, Tennessee: Climate Assessment for a City

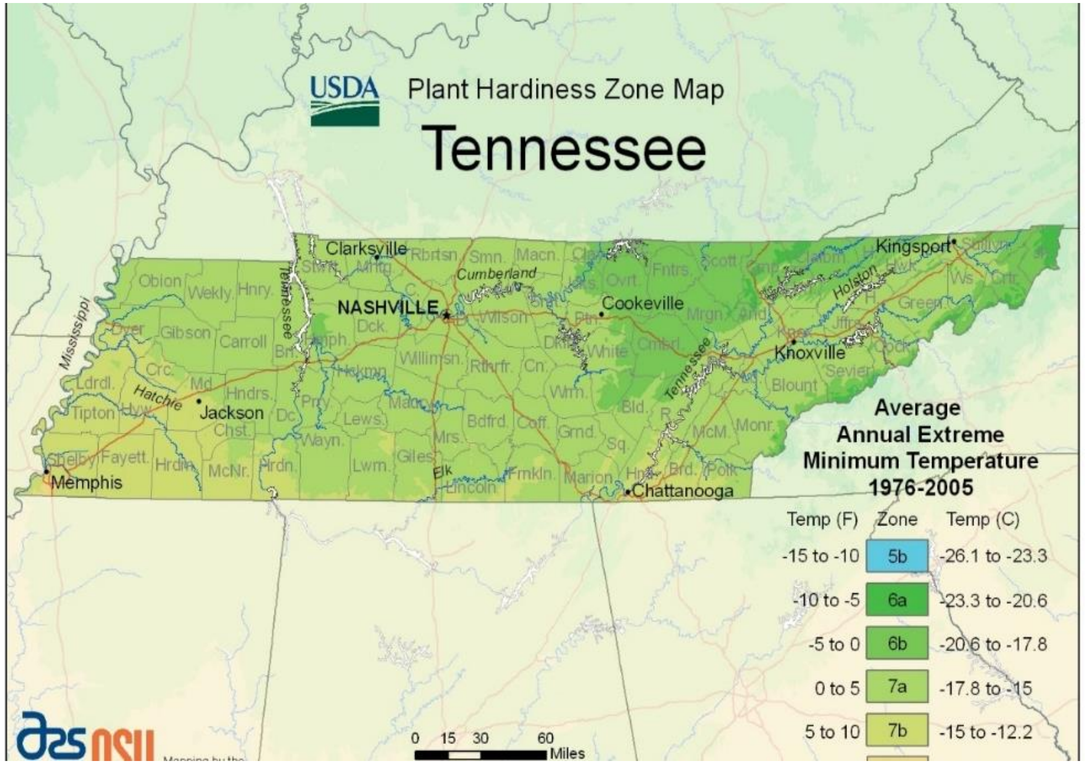
City of Knoxville, Tennessee

Urban-CAT



Climate Change and Green Infrastructure for Flood Mitigation

USDA Plant Hardiness Zones for TN



Ten dynamically downscaled (RegCM) CMIP5 climate model output used to calculate Plant Hardiness Zones and the changes that occur between periods 1980–2005 and 2025–2050 indicate that the Knoxville, TN area and surrounding watersheds will increase to the next warmer Plant Hardiness Zone.

Native Species	Zones	Non-native Species	Zones
Kentucky Coffeetree	3 – 8	London Planetree	5 – 9
Thornless Honeylocust	3 – 9	Sawtooth Oak	5 – 9
Willow Oak	5 – 9	Trident Maple	5 – 8
Shumard Oak	5 – 9	Chinese Pistache	6 – 9
Bald Cypress	4 – 10	Silver Linden	4 – 7
Yellowwood	4 – 8	Lace-bark Elm	5 – 9
Eastern Hophornbean	3 – 9	Zelkova	5 – 8
Overcup Oak	5 – 9	Kousa Dogwood	5 – 8
Eastern Redbud	4 – 9	Crapemyrtle	7 – 10

If the Knoxville area shifts into the next warmer Hardiness Zone:

Trees at their Hardiness Zone limit

Trees outside their Hardiness Zone limit

Limitations of Climate Assessments

- Cost-benefit analysis is always a challenge for assessing benefits of current investments for reducing long-term threats with uncertainties. Generally, it may be optimal for current or near-term investments in resilience to offer other benefits as well ("co-benefits"). Important to recognize that climate change risks are escalating.
- Future losses are based on past examples. Future extreme events, however, may be much more extreme.
- Humans, their institutions and their decision-making processes in the context of their environment need to be better understood.
- Resilience investments and cooperative action are needed to address these climate risks:
  - **Demand growth**: requires range of possible strategies for adding capacity (less needed under lower temperature scenarios)
  - **Warming surface water sources for cooling**: requires power plant revitalization strategies that reduce requirements for cooling water from surface water sources, including changes in cooling technology and some shifts toward alternative power generation technologies

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