

Synergistic Effects of Urban Park Vegetation on Energy Conservation, Carbon Reduction, and Ecological Safety: A Case Study of Chongqing

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Abstract: Urban parks ask vegetation to serve several masters at once: carbon storage, building energy savings through cooling, and urban ecological safety. How well these goals can be met together is the question we take up here, using Chongqing—a dense, mountainous city in southwestern China—as a case study. All figures come from published field measurements that we checked against their sources. A single *Ficus concinna* tree, for instance, saved roughly 2,290 kWh of electricity per year through transpiration cooling, which translates into about 1,442 kg of avoided indirect CO₂ emissions. The best-performing communities fixed 12,677.76 g of carbon per day and stored 74,607.30 kg. Multi-layered tree–shrub–herb stands were also better at holding soil, cutting the erosion modulus by 40.4% relative to tree–herb monocultures. Of all the heat-island drivers we examined, NDVI mattered most ($q = 0.782$). Chongqing’s parks, however, are held back by low energy–carbon efficiency, overly uniform planting (tree–herb stands make up 57.94%), weak slope protection, and intensive maintenance. We close with four strategies: high-carbon multi-layered communities, stronger mountain protection, native near-natural planting, and improved spatial layout of green infrastructure.

Keywords: urban park; energy conservation and carbon reduction; ecological safety; plant community configuration; synergistic coupling effect; Chongqing

DOI: <https://doi.org/10.68249/jstnei.2026.0017>

1 Introduction

The WMO Greenhouse Gas Bulletin No. 21 puts the global average atmospheric CO₂ concentration for 2024 at 423.9 ± 0.2 ppm, 1.5 times the pre-industrial level. The 3.5 ppm year-on-year rise was the largest since instrumental records began in 1957^[1]. Cities generate a large share of these emissions, and their green spaces can respond in two distinct ways: storing carbon directly, and trimming energy demand indirectly. Then there are the ecological safety roles that receive less attention—soil and water conservation, biodiversity, and disaster shelter.

Chongqing illustrates the problem well. Hemmed in by valley terrain and dominated by a subtropical high-pressure system, this dense southwestern mountain city suffers brutally hot summers. On July 16, 2026, its power grid peaked at 31.4 million kW—1.12 million kW above the 2025 record—driven mainly by air-conditioning^[2]. Parks offer some relief. Tree canopies shade the ground while transpiration draws off heat, cooling the surrounding air and cutting the cooling load on nearby buildings; carbon reduction, energy security, and ecological safety are thus linked through a single piece of infrastructure. Notably, earlier studies report that the carbon avoided through such transpiration cooling can be several times what a tree sequesters directly via photosynthesis. In hot cities, then, the energy-saving value of park vegetation may be badly underestimated.

For the most part, though, carbon sequestration and cooling have been studied separately, with little attention to how

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the two reinforce one another. A separate concern is data quality: some publications cite figures that cannot be traced to their source, or reference literature that does not support the claim. We therefore restrict ourselves to published field data that we were able to verify against the originals. On that basis we analyze the energy-saving, carbon-reduction, and ecological-safety performance of Chongqing's park vegetation, identify where it falls short, and propose ways to improve all three together.

2 Study area and analytical framework

2.1 Overview of urban parks in Chongqing

Chongqing's central urban area had 1,149 urban parks by 2026, covering 15,218 ha in total—114 comprehensive parks, 401 community parks, and 81 specialized parks^[3]. The 14th Five-Year Plan period (2021–2025) added nearly 600 more across the city^[4]. Roughly 480 commonly cultivated species, representing 103 families and 256 genera, grow in these parks; *Ficus virens* var. *sublanceolata*, *Ficus concinna*, *Cinnamomum camphora*, and *Koelreuteria bipinnata* are the principal backbone trees. Mountain terrain imposes its own constraints: slopes are steep, soils are thin, and rainfall arrives in intense bursts, all of which keeps landslide and debris-flow risk high.

2.2 Synergistic framework

Two pathways connect park vegetation to energy conservation and carbon reduction. Directly, plants photosynthesize and store carbon as biomass. Indirectly, canopies shade surfaces while transpiration dissipates heat; both effects cool the local air, lower air-conditioning demand in adjacent buildings, and thereby reduce power-sector emissions. For ecological safety we focus on three things: soil and water conservation (and slope stability with it), biodiversity support, and disaster preparedness, including wildfire risk.

What couples these two sets of functions is community structure. Dense, multi-layered stands with a high leaf area index transpire more, bind soil more effectively, and provide more varied habitat; open, simplified stands are weaker on every count. The analysis below uses verified field data from Chongqing itself and from areas with comparable climates.

3 Energy conservation and carbon reduction effects

3.1 Direct carbon sequestration

Zhang et al.^[5] measured photosynthetic rates across 36 communities and 49 species in six parks along Chongqing's Liangjiang Greenway (Huahui Garden, Bailin Park, Dongbu Park, Lianhu Park, Jiangyucheng Sports Park, and Shizishan Sports Park). A clear hierarchy emerged: trees fixed the most carbon, shrubs less, herbs least. All 17 species rated as high or relatively high in carbon sequestration were trees—among them *Ficus virens* var. *sublanceolata*, *Albizia julibrissin*, *Platanus × acerifolia*, *Jacaranda mimosifolia*, *Gleditsia sinensis*, *Ficus concinna*, *Ulmus parvifolia*, *Magnolia denudata*, *Robinia pseudoacacia*, *Broussonetia papyrifera*, *Bauhinia purpurea*, *Pterocarya stenoptera*, *Erythrina variegata*, and *Cinnamomum camphora*. The standout individual was an A1-size *Ficus virens*, fixing 21,718.87 g/d and holding 24,509.5 kg of carbon.

At community scale, Bailin Park's Community 8—*Ficus virens* and *Ficus concinna* in the overstory, *Osmanthus fragrans* as a small companion tree, and the herb *Ruellia brittoniana* below (a tree–herb structure)—stored the most carbon: 74,607.30 kg, with daily fixation of 12,677.76 g/d. The highest daily rate, 46,457.67 g/d, belonged to Community 5. Both canopy area ($r = 0.794$, $P < 0.01$) and trunk volume ($r = 0.828$, $P < 0.01$) correlated significantly with uptake, which points to tree size as the dominant control. Dense stands out-fixed moderately dense ones, and moderately dense stands out-fixed open ones. The practical implication is straightforward: infill planting that raises canopy closure can boost carbon uptake without requiring additional land.

3.2 Transpiration cooling and indirect energy conservation

Transpiration dissipates radiant energy, cooling the air and easing the cooling load on neighboring buildings. Ding et al.^[6] tracked one *Ficus concinna*, a subtropical native, through a full year in Shenzhen. Over that year the tree transpired 11,854.30 kg of water (32.48 kg/d) and absorbed 2.89×10^4 MJ of heat (79.18 MJ/d). At an air-conditioner COP of 3.5, that equals roughly 2,290 kWh in avoided electricity use per year (6.27 kWh/d); with the East China Power Grid emission factor of 627 g CO₂/kWh, it comes to about 1,442 kg of CO₂ avoided per tree per year. The same authors note

that transpiration-driven reductions elsewhere have been reported at 5–10 times the carbon fixed by photosynthesis alone. Shenzhen is not Chongqing—humidity and radiation differ, so the numbers transfer imperfectly—but *Ficus concinna* is a backbone species locally, and the Shenzhen figures give a useful first benchmark.

The cooling does not stop at the park boundary. Qiu et al.^[7] used remote sensing across 27 core Yangtze River Delta cities and found green patches an average of 2.18 K cooler than surrounding built-up surfaces; cooling of 2.9–8.3 K reached 270–450 m beyond the patch edge. Across all 27 cities, green spaces yielded 267,656.12 t of combined energy savings and carbon reduction per day—about 9,913.19 t per city. Closer to home, Hu et al.^[8] measured 2.174 °C of cooling at Huahui Garden, 1.442 °C at Shaping Park, and only 0.631 °C at University Town Central Park. They also found that tall surrounding buildings acted as “wind walls” and that extensive impervious paving choked off the spread of cool air.

Wang et al.^[9] ran a geographical detector on Landsat 8 imagery of the Chongqing metropolitan area. Within built-up areas, NDVI outperformed every other variable in explaining the heat-island pattern ($q = 0.782$), with surface elevation ($q = 0.499$) and building density ($q = 0.496$) well behind. Pairing factors pushed q to 0.50–0.82, above either factor on its own. Vegetation is therefore the single most powerful heat-island lever available, and its effect grows when terrain and building layout work with it rather than against it.

3.3 Thermal comfort improvement

Shade also changes how people behave with energy. Zhang et al.^[10] measured afternoon physiological equivalent temperature (PET) at three Chongqing riverside parks. Unshaded spots exceeded 45 °C, while positions under *Cinnamomum camphora* canopies ran 1.5–2.6 °C cooler. Beneath bridge overhangs, PET was 30.9–33.4 °C (“warm,” 23–35 °C), compared with 35–41 °C (“hot”) in tree shade and over 41 °C (“very hot”) in direct sun; the bridges blocked 59.4% and 43.8% of incoming solar radiation at the two sites. Comfortable outdoors means less time indoors with the air-conditioning on—so shade cuts energy demand from the demand side, not just the supply side.

4 Ecological safety effects

4.1 Soil and water conservation and geological safety

Steep slopes plus intense, concentrated rainfall make soil binding by vegetation a matter of slope stability, not just erosion control. Du et al.^[11] (author’s prior work) surveyed riparian zones in seven mountainous urban parks and recorded a soil erosion modulus of 186 t/(km²·a) under multi-layered tree–shrub–herb communities, against 312 t/(km²·a) under simple tree–herb stands—a 40.4% reduction. Where multi-layered cover exceeded 70%, temperatures ran 2.3 °C lower and relative humidity 8.5% higher than on bare ground. The same vegetation was thus holding soil and cooling the microclimate simultaneously.

Working on the steep slopes of Zhaomushan Forest Park, Duan et al.^[12] put forward four protection-oriented configurations using barren-tolerant species—*Robinia pseudoacacia*, *Broussonetia papyrifera*, *Erythrina variegata*, and *Ficus virens*. In the Hechuan District water-level fluctuation zone, Du et al.^[13] counted 296 vascular plant species; herbs accounted for 82.77% and wild species for 85.81%. The flora clearly had good recovery potential, but the near-absence of trees and shrubs left slope stability weak.

4.2 Biodiversity maintenance

Structurally diverse vegetation also supports more wildlife. Where wild herb cover was dense in riparian zones, Du et al. found 12 bird and 28 insect species; simplified tree–herb stands held markedly fewer. Yet Chongqing’s park riparian zones are currently dominated by cultivated species (80.57%) and tree–herb structure (57.94%), with multi-layered tree–shrub–herb communities covering only 19.31%. Monthly pruning across 70% of the area compounds the problem. Simplified structure and intensive maintenance, in short, are squeezing biodiversity from two sides.

4.3 Wildfire safety and carbon pool protection

Large pure conifer stands carry another risk: wildfire can release a stand’s stored carbon almost overnight. Yin et al.^[14] studied *Pinus massoniana* coniferous–broadleaved forest on Jinyun Mountain (96.6% cover) and put total fire-related carbon-uptake loss at 5.68 t/(km²·d) across all severity classes; severe fire alone accounted for 3.97 t/(km²·d).

Unburned stands, by comparison, sequestered carbon at $1.27 \text{ mg}/(\text{m}^2 \cdot \text{s})$. Tieshanping offers a working alternative. Liu^[15] reports that over 66.7 ha of pure *Pinus massoniana* there was converted to mixed forest—pines and firs above, fire-resistant broadleaves (*Schima superba*, *Machilus nanmu*) in the canopy, *Camellia* and *Rhododendron* in the midstory, mosses and orchids below. Since conversion, no major pest or disease outbreak has occurred; forest cover exceeds 90%, over 800 plant and animal species are present, and annual visitors top 2 million. Fire safety, carbon storage, biodiversity, and recreation all coexist on the same site.

5 Current problems

Low carbon and energy efficiency. The “lawn plus specimen tree” model, still common in some parks, carries a low leaf area index and so fixes little carbon while offering minimal transpiration cooling. Zhang et al. found daily fixation in open stands well below that in dense ones; in practice, many parks have both low canopy closure and a shortage of large, mature trees.

Over-simplified community structure. Nearly 60% of riparian zone is tree-herb, and multi-layered communities cover less than 20%. Zou^[16] found the same ranking for cooling and humidification in Chongqing: tree-shrub-herb > tree-shrub > tree-herb > shrub > lawn.

High-carbon native trees are underused. Natives such as *Ficus virens* and *Ficus concinna* have proven uptake capacity, yet some new parks continue to favor exotic ornamentals.

Mountain protection is weak. Some slopes and riparian zones still use hard revetments and large lawns in place of deep-rooted, soil-binding trees and layered protective communities. Those hard surfaces absorb and reflect heat as well, adding to local heat-island effects.

Maintenance itself generates carbon and disturbance. Pruning 70% of park area every month consumes fuel, releases carbon, and suppresses natural regeneration. Poor species matching—conflicting root depths or light requirements—further destabilizes stands, driving up replacement frequency and embodied carbon.

The energy-security dimension is largely absent. Cool-island effects are rarely planned together with building energy savings or grid peak shaving, so the cooling parks could provide during summer peaks is left out of demand-side energy planning.

6 Synergistic optimization strategies

6.1 Construct high-carbon energy-saving multi-layered communities

The 17 high-carbon species identified by Zhang et al. should anchor planting design, with priority given to Chongqing natives—*Ficus virens*, *Ficus concinna*, *Cinnamomum camphora*, and *Gleditsia sinensis* among them. Shade-tolerant shrubs and native groundcovers planted beneath them produce the multi-layered structure that performs best across functions. Open stands below 70% closure can be brought to 70%–90% by interplanting large native trees. Where parks face buildings upwind or border high-activity areas, broad-canopy, high-transpiration species should lead, so that cool air spills off the park and into surrounding buildings. Pairing fast-growing species (quick early carbon gains) with long-lived slow-growing ones (durable carbon pools) spreads the benefit over time.

6.2 Strengthen mountain ecological protection

On slopes steeper than 25° and in water-level fluctuation zones, deep-rooted, poor-soil-tolerant species should lead—*Robinia pseudoacacia*, *Broussonetia papyrifera*, and *Ficus virens*—supplemented by flood-tolerant species: *Pterocarya stenoptera* (15–30 days of flooding; 92% survival under 3 m fluctuation), *Vitex negundo* (5–10 days), and *Leersia hexandra* (10–15 days). Mixing deep and shallow roots in layered stands gives more stable protection than either alone. Existing hard revetments can then be softened incrementally with vegetated buffer strips.

6.3 Create native near-natural communities

The balance should shift toward native species and away from cultivated varieties and high-maintenance lawns. The Tieshanping experience suggests inserting fire-resistant broadleaves—*Schima superba*, *Machilus nanmu*—into pure conifer stands, which reduces fire risk while adding carbon storage and habitat. Wild herb strips should be retained or sown, and pruning reduced from monthly to 2–3 times yearly; this cuts maintenance emissions and gives insects and

birds both food and cover.

6.4 Optimize spatial layout for cool island and disaster prevention

Green corridors should be aligned with prevailing winds and valley breeze paths, connecting parks to surrounding built-up areas rather than letting buildings seal them off behind “wind walls.” Inside parks, shaded plazas and emergency open spaces should be distributed across the site—broad-canopy natives where people gather, open ground kept clear for earthquake and fire evacuation. Cooling and disaster prevention then share the same space instead of competing for it.

7 Conclusions

Chongqing’s park vegetation reduces carbon along two routes simultaneously. One *Ficus concinna* tree can save roughly 2,290 kWh/year and avoid about 1,442 kg/year of indirect CO₂ emissions, and these indirect savings may run 5–10 times higher than direct photosynthetic fixation. The strongest communities fix up to 12,677.76 g/d and hold 74,607.30 kg of carbon, while NDVI is the most powerful single heat-island mitigation factor ($q = 0.782$).

Ecologically, multi-layered stands reduce the soil erosion modulus by 40.4% and support richer wildlife (12 bird species, 28 insect species). Converting pure conifer plantations to mixed coniferous–broadleaved forest can likewise deliver fire safety, carbon storage, and biodiversity on the same ground.

The principal shortcomings are low carbon–energy efficiency, over-simplified stands (tree–herb communities account for 57.94%), weak slope protection, excessive maintenance, and the absence of an energy–security lens. Four strategies address these jointly: high-carbon energy-saving communities, stronger mountain ecological protection, native near-natural stands, and optimized spatial layout. Pursued together, they advance energy conservation, carbon reduction, and ecological safety rather than trading one off against another.

Two limitations should be kept in mind. The *Ficus concinna* energy-saving figures come from Shenzhen and require validation against long-term, in situ measurements in Chongqing. Future work should also test how cool-island effects vary with park size, surrounding building density, and meteorological conditions.

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