Proceedings of CONF-MCEE 2026 Symposium: Advances in Sustainable Aviation and Aerospace Vehicle Automation
DOI: 10.54254/2755-2721/2026.KA27936

Evaluating the Environmental Inputs and Outputs of School-Based Community Gardens through Life Cycle Assessment

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Abstract. These days, environmental stresses like stormwater runoff, the Urban Heat Island effect, and biodiversity loss have increased due to fast urbanization. By enhancing water management, cooling microclimates, and promoting social and educational advantages, community gardens provide a comprehensive solution. Life Cycle Assessment (LCA) is used in this study to examine every stage of construction for the community garden at Beijing No. 4 High School. According to the results, plant growth and the recycling of organic waste account for a net reduction of roughly 468 kg CO_2 per year. Such gardens could promote good nutrition, mental health, and civic involvement while offering practical sustainability education if they were implemented in all Beijing schools. These results show that incorporating gardens into schools is an inexpensive, effective way to promote climate action and urban resilience.

Keywords: Community Gardens, Life Cycle Assessment, Urban Sustainability

1. Introduction

Urbanization has become one of the most defining human-induced changes of the modern era, reshaping landscapes, ecosystems, and social structures at an extraordinary pace. Global urban land is now expanding at nearly twice the rate of population growth, and projections suggest that by 2030 the total urbanized area will be almost three times larger than it was at the beginning of the century [1]. This transformation is not simply a matter of more buildings and roads; it reflects a fundamental shift in how humans interact with their environment. The spread of impervious surfaces such as concrete and asphalt has fragmented habitats, reduced biodiversity, and amplified local climate challenges, most notably the Urban Heat Island (UHI) effect. The UHI effect, in which cities experience significantly higher temperatures than surrounding rural areas, increases energy demand for cooling, raises public health risks during heat waves, and intensifies greenhouse gas emissions. As cities continue to expand, the urgency of finding interventions that balance development with ecological resilience has never been greater.

One increasingly recognized intervention is the community garden. Far more than simple plots of cultivated land, community gardens represent multifunctional urban spaces that deliver ecological, social, and educational benefits. At the ecological level, these gardens help mitigate the UHI effect by providing shading, enhancing evapotranspiration, and improving soil moisture retention. Numerous studies have shown that community gardens, along with other forms of green

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infrastructure, can lower ambient air temperatures by 1–2 °C and create microclimates that reduce heat stress in vulnerable neighborhoods [2,3]. Their value extends beyond temperature regulation. In New York City, for instance, community gardens divert approximately 12 million gallons of stormwater annually, reducing the load on municipal sewer systems and minimizing flood risk [4]. Over the past decade, the combined effect of more than 10,000 gardens has been estimated to sequester nearly 190,000 tons of carbon, equivalent to offsetting a year of emissions for over 30,000 people [5]. These findings underscore the environmental relevance of gardens as decentralized, low-cost strategies for climate adaptation.

Another important ecological function of community gardens lies in their role in organic waste management and composting. Organic matter continues to dominate landfill content, with the U.S. Environmental Protection Agency reporting that over 50% of landfill waste in 2018 consisted of food scraps and other biodegradable materials [6]. Left untreated, such waste produces methane, a greenhouse gas far more potent than carbon dioxide. By contrast, community gardens provide the infrastructure and culture for composting, converting organic waste into valuable soil amendments. Sweet et al [7]. found that a single 80-cubic-yard compost pile could process around 13,000 kilograms of food waste annually, the equivalent of waste generated by more than 300 individuals. Composting not only diverts material from landfills but also closes nutrient cycles, improves soil fertility, and reduces the need for synthetic fertilizers. In this sense, gardens function as living laboratories for sustainable resource management at the neighborhood scale.

The benefits, however, extend far beyond the ecological. Community gardens play an important social role by strengthening networks, fostering civic engagement, and providing spaces for cross-cultural interaction. A survey of over 300 gardeners found that participants consistently reported improvements in their sense of belonging, perceptions of neighborhood safety, and overall satisfaction with their community [8]. These localized social bonds help build resilience, offering informal support systems that become critical during both ecological and social disturbances [9]. Moreover, gardens have been linked to health outcomes that are difficult to achieve through other urban policies. By encouraging physical activity, increasing access to fresh produce, and offering restorative spaces for reflection and leisure, community gardens contribute to both physical and mental well-being. The psychological benefits are particularly noteworthy, with gardeners frequently reporting lower levels of stress and higher levels of optimism compared to non-gardeners.

Although there is a wealth of international literature on community gardens, there is still not much information available about their development in China. There are very few official government-led community gardening programs in the nation, despite the growing urban population and urgent food security issues. In reality, the majority of Chinese city dwellers who grow plants do so primarily for aesthetic or decorative reasons, paying little attention to ecosystem services or food production. However, pilot projects have gradually emerged in recent years, particularly in educational institutions. Schools in Wuhan, Shanghai, and Beijing have started experimenting with incorporating gardens into their curricula and campus culture. Beijing 101 Middle School, for example, incorporates edible plants alongside small livestock such as geese and alpacas, while Haidian Foreign Language Experimental School has invested in an intelligent multi-span greenhouse that integrates vertical farming and automated drip irrigation. At Shanghai Jiaotong University, rooftop gardens provide students with hands-on opportunities to grow and harvest crops. These early experiments suggest that schools may offer an especially promising context for scaling community garden initiatives in China.

The educational dimension of community gardens deserves particular attention. Schools provide a setting where environmental education and social learning can intersect in meaningful ways.

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Participation in gardening instills responsibility, patience, and teamwork among students, while also exposing them to practical knowledge of agricultural practices such as soil management, irrigation, and composting. These experiences enrich classroom learning by providing tangible, hands-on applications of abstract concepts in science, health, and sustainability. Importantly, the influence of school gardens often extends beyond the students themselves. By sharing what they learn with families and communities, students act as multipliers, spreading sustainable practices into wider social networks. This ripple effect positions school gardens not only as educational tools but also as catalysts for cultural change toward sustainability.

In light of this, the current study uses the Beijing No. 4 High School community garden as a case study to assess the social and environmental effects of school-based community gardens. In particular, the study uses the Life Cycle Assessment (LCA) methodology to measure the garden's carbon footprint throughout its entire system boundaries, from planting and building to harvesting, operating, and cleaning up. In addition to identifying possible hotspots where improvements could result in the biggest reductions, life cycle assessment (LCA) enables a systematic accounting of greenhouse gas emissions. However, this analysis also takes into account wider social benefits like better mental health, closer community ties, and improved learning outcomes for students. The dual perspective—environmental and social—offers a more comprehensive understanding of the role community gardens can play in sustainable urban development. By framing school gardens as both ecological infrastructure and educational assets, this paper seeks to contribute evidence and guidance that may inform policy, encourage adoption across additional institutions, and ultimately promote more resilient and sustainable cities.

2. Methodology

Community gardens are a form of urban agriculture where participants share responsibilities for maintaining the space and distributing the produce [10]. This study examines the Beijing No.4 High School community garden, covering five phases: container construction, seeding, operation and maintenance, harvesting, and clean-up. Emission factors were measured across each phase to calculate the carbon footprint.

The methodology, which includes goal and scope definition, inventory analysis, impact assessment, and interpretation, complies with ISO 14044 standards for Life Cycle Assessment. To ensure comparability with other urban agriculture studies, the functional unit is defined as one square meter of garden per year, with additional results expressed per kilogram of vegetables.

While secondary data were gathered from reputable databases and literature, primary data were gathered directly during each life cycle phase through measurement and observation. Accuracy and representativeness are guaranteed by this dual strategy.

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Table 1. Life Cycle Inventory of community garden.

Construction			Amount	Unit	Emission factor) kgCO2/kg	Source
Seeding	Vegetable bed	Plastic	5	kg	1.44	Climateiq
		Screw driver	0.5	kg	1.73	SEFR https://www.climatiq.io/data/emission-factor/ba711e53-e650-4248-aad4-a7bc337a5026
		Soil	150	kg	0.59	EPA [11] https://www.climatiq.io/data/emission-factor/67f8e782-6b93-47ed-aced-2034e686a562
		Cotton Gloves	0.3	kg	1.30	IFEU: Environmental footprints of cotton fibres [11]
		coriander seed	0.01	kg	0.51	Estimate
		rapeseed seed	0.01	kg	1.61	Climateiq EF entry
		cumin seed	0.01	kg	1.04	CarbonCloud
		Shovel	4	kg	0.27	Climateiq
Operation	Water	Water	80	L/week * 32 weeks = 2560 L	0.21	China water supply EF
		Plastic Kettle	2	kg	8	The Chinese Academy of Environmental Planning (CAEP)
Clean-up		Dry biomass	0.9	kg	1.7	The Climate Registry, 2023 [12]
Harvesting		Harvested vegetable and plants(output)	283	kg	-1.65	Bernhardt et al. 2020 [13]

Emission calculations were conducted using the formula: Carbon Emissions = Σ (input amount × emission factor).Carbon removals were estimated as: Carbon Removal = vegetable amount × carbon content × (CO_2 molecular weight / C molecular weight).

The overall carbon footprint equals emissions minus removals. By quantifying emissions and removals, this study identifies high-impact stages and provides recommendations for reducing the carbon intensity of urban gardening practices.

3. Results

The Life Cycle Inventory of the community garden showed that construction and operation contributed the majority of emissions, while harvesting provided significant removals. Table 2 summarizes the carbon footprint across phases.

Table 2. Carbon footprint of community garden.

	Carbon footprint (kgCO2)
Construction	96.93
Seeding	1.54
Operation	17.07
Clean-up	1.53
Harvesting	-468

According to the case study of the Beijing No. 4 High School Community Garden, the implementation of a moderately sized community garden can reduce the annual carbon footprint by

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approximately 468 kg CO_2. Educational institutes, ranging from preschools to higher-education institutions, provide an ideal platform for the adoption of community gardens, as these initiatives not only contribute to environmental benefits but also foster community cohesion, promote environmental awareness, and instill responsibility in students. As of fiscal year 2025, Beijing hosts a total of 3,744 educational institutes, including 2,109 preschools, 709 primary schools, 789 middle schools, 27 special schools, and 110 higher-education institutions. Based on interviews and field investigations, the community garden at Beijing No. 4 High School represents a moderately low level in terms of garden size; therefore, its carbon footprint reduction can serve as a conservative estimate for other schools with similarly sized gardens.

Extrapolating this value, if all educational institutes were to adopt community gardens, the potential annual reduction in carbon footprint could reach approximately 1,751 metric tons of CO_2. In a moderate adoption scenario, assuming only one-third of schools implement such gardens, the estimated annual carbon footprint reduction would still amount to roughly 584 metric tons of CO_2, which is equivalent to the annual greenhouse gas emissions from 126 passenger vehicles and the amount sequestered by 7,000 tree seedlings grown for 10 years, according to the U.S. Environmental Protection Agency's Greenhouse Gas Equivalencies Calculator. By comparison, conventional industrial agriculture typically generates 0.3–1.5 kg CO_2 per kilogram of vegetables produced, depending on inputs such as synthetic fertilizers, mechanized irrigation, and transport [14]. This indicates that even small-scale school community gardens produce substantially lower carbon emissions per kilogram of produce while providing local food and social benefits.

Beyond their environmental contributions, school-based community gardens provide significant social and educational benefits. Schools are uniquely positioned to offer children opportunities to engage with nature, as they reach nearly all young people, provide space for practical skill-building, and are guided by educators who emphasize learning. Research shows that fostering gardens in schools can increase fruit and vegetable consumption while delivering essential lessons in nutrition and sustainable food practices. For instance, one study found that 17% of overweight or obese children improved their BMI after participating in a school garden, while all children with a normal BMI maintained their classification [12]. These gardens also contribute to mental health: students involved in community gardening report higher levels of subjective well-being, resilience, and optimism compared to those in home gardening or other outdoor activities.

Taking part in school gardens fosters the virtues of accountability and tenacity. The work involved in caring for plants reinforces life lessons that go beyond the garden by showing students that consistent effort yields observable benefits. Additionally, cultivating teamwork improves peer relationships, fostering cooperation and a feeling of community within the school. Students are introduced to agricultural practices like soil care, crop rotation, composting, and water conservation through hands-on engagement, which provides experiences that classroom instruction cannot match. One student demonstrated how knowledge learned in school can have a positive impact on families and communities by stating that gardening taught them new techniques to manage kitchen waste through composting, which they could then implement at home.

These lessons motivate students to explore agriculture more deeply while nurturing a greater respect for the natural world and its resources. By linking healthy eating, sustainability, and community-building, school gardens promote not only environmental awareness but also long-term lifestyle changes. The influence extends beyond students themselves, shaping healthier habits within families and strengthening the educational institution's role in preparing young people to live responsibly in a changing world.

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4. Conclusion

This study applied Life Cycle Assessment to the Beijing No.4 High School community garden and demonstrated that even a modest garden can reduce emissions by about 468 kg CO_2 annually. Scaled citywide, reductions could reach 1,751 metric tons annually.

School gardens also provide co-benefits, including healthier diets, stronger community bonds, and increased environmental awareness. These contributions highlight their value beyond simple carbon reductions.

Although this study is limited to one site and did not capture all indirect emissions, it offers a conservative estimate of impacts. Future research should expand to gardens of different sizes and settings, with attention to economic outcomes and long-term behavioral changes.

Overall, school community gardens represent a low-cost, high-value strategy that integrates sustainability, education, and health. Their benefits extend well beyond the school environment, positioning them as a promising model for climate action and community development.

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