Environmental Benefits and Impacts of Rooftop Greenhouses in Oakland, California

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ABSTRACT

Growing populations have led to a rise in food insecurity, and to keep up with increasing demand for food, new agricultural methods such as urban agriculture need to be assessed and implemented. Using life cycle assessments (LCA), I compared the environmental impacts of rooftop greenhouses to conventional outdoor farming methods. Using geographic information systems (GIS), I weighed socioeconomic and landscape factors to create a suitability map of Oakland, California. The main findings of this study show that rooftop greenhouses are a sustainable alternative to conventional outdoor farming. 30% of global warming potential (GWP) from rooftop greenhouses comes from the packaging life cycle stage. On average, rooftop greenhouses have a lower environmental impact in comparison to conventional outdoor farming across 5 impact categories (GWP, OD, TA, E, PO). Based on 13 total opportunity and constraint factors, Downtown Oakland South of 580 and Fruitvale are areas in Oakland most suitable and in highest need for urban agriculture spaces such as rooftop greenhouses.

KEYWORDS

life cycle assessment, urban agriculture, conventional outdoor agriculture, geographic information systems, global warming potential

INTRODUCTION

Urban agriculture (UA) - the practice of cultivating and distributing food in urban areas - is a growing method of farming that is being explored for its abilities to make cities more sustainable. With the rise of global warming, issues such as food security have become of increasing concern across the world. This poses a challenge for conventional open field farms to maintain food yield. To meet food demands of growing populations, new agricultural practices need to be explored, such as innovative urban agriculture (Thomaier et al. 2015). Modern day urban environments pose an obstacle towards sustainability due to high population densities as well as reliance on imported resources. With 70% of the world's population concentrated in cities, a significant proportion of energy is directed towards transporting and packaging foods, which increases greenhouse gas emissions (Llorach-Massana et al. 2017). To combat increasing emissions, cities are optimizing land use and creating more sustainable environments (Corcelli et al. 2019). Land is an increasingly expensive commodity and urban cities such as Oakland are working to take advantage of the untapped potential of open spaces.

Urban agriculture provides spaces for educational programs including internships, workshops and classes about nutrition and produce. Cultural programs are also offered and provide opportunities to involve local residents (Thomaier et al. 2015). Urban agriculture spaces can also increase employment rate by offering jobs to local residents including operating shops or providing consulting services. Additionally, UA's aesthetic value can increase tourism and in turn the economy, leading to more government funding to these areas (Artmann and Sartison 2018). While cities only occupy around 2% of the world's surface, they consume around 75% of its resources (Thomaier et al. 2015). It is extremely beneficial for cities like Oakland to utilize UA to grow produce for local residents. While there are many types of urban agricultural practices, rooftop greenhouses are one that is often overlooked.

Rooftop greenhouses have gained traction in recent years due to the vast amount of ecosystem services it provides to the surrounding community. Research on greenhouse technology has been increasing in popularity as food scarcity and sustainability grow in importance in society. Rooftop greenhouses utilize open space on rooftops that would otherwise be vacant and take advantage of the direct sunlight that provides optimal growing conditions (Benis et al. 2018). Urban agriculture contributes to carbon sequestration and decreasing heat island effect - when urban areas are warmer than their rural counterparts because of human activities and the cities/pavements do not reflect sunlight well (Artmann and Sartison 2018). UA can improve plant yield, economic growth, and start a movement within society to promote greener cities. Urban farming increases domestic food production and job opportunities, which decreases the reliance on imported food with a higher carbon footprint (Benis et al. 2018).

Urban rooftop greenhouses and conventional outdoor farming are two agricultural methods that have a variety of differences. Conventional farms are larger and located in rural areas whereas rooftop greenhouses are smaller and located in urban areas. The majority of crop production around the world is based around conventional farming, which consists of the widespread use of chemical fertilizers, pesticides, irrigation and tilling. Rooftop greenhouses (RTGs), though not as common, do not practice tilling and use less water and pesticides per unit area. RTGs can reduce food miles, greenhouse gas emissions, and create new green spaces (Corcelli et al. 2019). Life cycle assessment is a common tool used to compare farming strategies against one another to determine the environmental impact each method has.

The central question of my study was: Is there a net environmental benefit to transitioning from conventional agriculture to rooftop greenhouses in Oakland, CA? My sub-questions were: (1) How does the level of environmental impact of RTG change in each stage of the life cycle assessment? (2) How do rooftop greenhouses compare to conventional outdoor methods across impact categories? (3) Using GIS to analyze socioeconomic and physical landscape factors, which communities in Oakland are most suitable for urban agriculture spaces? For my research purposes, I looked at multiple impact categories while highlighting global warming potential. Out of the life cycle stages examined in this research project, infrastructure - the material used to build the structure and facility - is one that is commonly overlooked, which is why I highlighted its significance in the environmental impacts of rooftop greenhouses. In this literature synthesis, I analyzed urban farming methods such as rooftop greenhouses and conventional outdoor farming through life cycle assessments (LCA) to determine which is more energy efficient. Then, I used geographic information systems (GIS) to determine the suitability of implementing rooftop greenhouses within Oakland. Given what is seen from pre-existing literature, I hypothesized that rooftop greenhouses will have a lower environmental impact in comparison to conventional outdoor farming methods.

RESEARCH FRAMEWORK

Life cycle assessment: Environmental impacts and life cycle stages

Life cycle assessment (LCA) is a standardized tool used to measure the environmental impact of a system. One example of a life cycle is cradle-to-grave, which includes all inputs and outputs, starting from the extraction of raw materials to its disposal (Bartzas et al. 2015). LCA determines the impact of each life cycle stage and helps decision-makers improve their systems. LCA can also examine several impact categories at once including global warming potential, ozone depletion, terrestrial acidification, eutrophication, and photochemical oxidation (Bartzas et al. 2015). While there are pre-existing papers on urban agriculture, there has yet to be a meta-analysis comparing the environmental impacts of rooftop greenhouses and conventional outdoor agriculture. There is also limited research on rooftop greenhouses because it is a relatively new UA strategy.

LCA is separated by life cycle stages. A case study on orange markets looked into the carbon footprint (CF) of delivering across the US to Atlanta, Chicago, Los Angeles, and New York City; this study focused on the production, post-harvest, processing, and packaging life cycle stages (Bell and Horvath 2020) and assessed the CF through a cradle-to-market approach - following the product from birth until it reached the market (Matthews et al. 2014). These different stages are known as the item's life cycle stages. Each life cycle stage is assessed for its environmental impact. The environmental impact can be defined as a change to the environment caused by humans/facilities.

Commitment to lifting Black and Indigenous voices

Environmental problems we face are at the junction of nature and culture, and of science and society. In order to address issues of environmental justice, it is critical that Black and Indigenous communities' voices are at the forefront of these discussions. As a researcher aiming to implement rooftop greenhouses within Oakland, I believe it is important to acknowledge that these urbanized areas are on stolen land. Part of my research works to undo erasure of Indigenous knowledge and return sovereignty to grow culturally relevant crops. It is crucial to fund and support projects that allow Indigenous communities to have a prominent role in reimagining the 21st century green city; one where voices and perspectives of marginalized communities are prioritized in the decision making process. An example of an organization in the Bay Area that works with Indigenous communities to rematriate land is Sogorea Te' Land Trust. This organization's goals align with what urban agriculture aims to achieve, which is cultural revitalisation and providing the public with educational opportunities (Sogorea Te' Land Trust).

Residential segregation and redlining are often drivers of ecological outcomes in urbanized landscapes. Heat is unevenly distributed within cities, with higher surface temperatures in low-income neighborhoods due to less vegetation cover (Schell et al. 2020). Urban agriculture works to increase vegetation in areas with higher demand and combat these structural inequalities that continue to suppress marginalized communities. However, it is important to be cautious of green gentrification - when green space creation attracts wealthy white populations, leading to rises in housing costs and displacement of long term residents who are lower income and people of color. A member of UC Berkeley's ESPM department, describes a vision of a Black green city, (re)imagining a racialized urban environmentally just future (Corbin 2018). She bases this vision on Marvel's Black Panther movie, focusing on Wakanda as an example of a Black, urban, environmentally just, city that is deeply grounded in African culture. Soul Fire Farm in Grafton, New York created by Leah Penniman, a Black female farmer, is an amazing real life example of farms in urban spaces that center around African heritage (Down to Earth). The farm provides food for those with limited access to fresh produce and teaches African/Indigenous heritage to people of color in the community.

Designing cities that actively undo colonial practices that oppress marginalized communities and give land back to Indigenous communities is critical. Implementation of urban farms such as rooftop greenhouses can help advocate for marginalized communities by rematriating land and growing crops that are culturally relevant.

METHODS

Data collection

Compiling previous studies

To calculate the level of environmental impact of rooftop greenhouses across each life cycle stage, I performed a meta-analysis of past studies that used life cycle assessments (LCA). I found previous studies on rooftop greenhouses through webofknowledge.com, a site that provides databases across multiple disciplines, including but not limited to: science, social science, arts, and humanities. Originally produced by the Institute for Scientific Information, it is now maintained by Clarivate Analytics in the United States and has literature dating back to the 1900s. The home page has a search menu where I filtered my search based on topic, title, author, publication name, year published, and funding agency.

Criteria for study inclusion

While searching within the site, I used the key words “life cycle assessment, rooftop greenhouses, urban farming infrastructure” to narrow down my results. I did not limit my search to a certain location or type of crop and found case studies ranging from farms focused on oranges in California to tomatoes in Barcelona. When choosing papers to include in my data table, I used the following criteria: papers from the late 2010s that have quantitative data tables distributing environmental impacts across life cycle stages. This ensured that I had the latest research in my data tables and that I had quantitative data to average. I took notes on a separate document of all literature that I explored and transferred the relevant numbers to a larger dataset. Then, I averaged the numbers from each category to find a mean. For example: I averaged the data of global warming potential of packaging in all rooftop greenhouse literature. Impact categories included: global warming potential, ozone depletion, terrestrial acidification, eutrophication, and photochemical oxidation (Table 1). Life cycle stages included: operations, packaging, transportation, production, infrastructure, and end-of-life.

Table 1. Assessed Impact Categories

Impact Category	Acronym	Unit
Global Warming Potential	GWP	kg CO_2 eq
Ozone Depletion	OD	kg CFC 11 eq
Terrestrial Acidification	TA	kg SO_2 eq
Eutrophication	E	kg PO_4 eq
Photochemical Oxidation	PO	kg C_2H_4 eq

Data analysis

To understand how rooftop greenhouse impacts compared to conventional outdoor agriculture, I created another data table with the averages of impacts for conventional outdoor agriculture. I collected data in the same manner as rooftop greenhouses: using webofknowledge.com and using the search terms "life cycle assessment of conventional agriculture, conventional agriculture vs rooftop greenhouses LCA." Using the data from the conventional outdoor agriculture and rooftop greenhouses table, I created a bar graph comparing the impact of each agricultural system.

Compiling data layers in ArcGIS

Geographic information science (GIS) is the study of techniques to capture geographic information. On the other hand, geographic information systems, such as ArcGIS, are software tools used to analyze spatial data. Creating spatial data models by layering data into ArcGIS can help develop a stronger understanding of topology, vegetation growth rate, water quality, network systems of roads, and electrical grids.

Using ArcGIS, I created a suitability map to determine which areas within Oakland had the highest demand for urban agriculture spaces. I compiled a list of opportunity and constraint factors of the area to find which communities were in greatest need of these spaces (Table 2). Infrastructure and socioeconomic factors I considered were: employment rate, distance to AC Transit bus stops, schools, and public housing. I weighted areas with employment rates below 60% as opportunities and areas above 80% as constraints. Urban agriculture spaces further from bus stops are harder to access and limit those who can benefit from these spaces so I weighted places with a distance of over 1000m from AC transit bus stops as constraints and those within 1000m as opportunities. Similarly, closer proximity to schools was an opportunity because of the potential for educational programs to work with the farm.

Physical landscape factors I considered included: slope, flooding hotspots, and priority conservation areas close to freeways. Urban agriculture can be successful on steeper slopes; however, since flatter regions are easier to get started on, slopes < 10 degrees I weighted as opportunities. The Association of Bay Area Governments identified the 1000ft around Oakland freeways as places that need more green and park space so areas within 1000ft from freeways I considered an opportunity. Heavily forested areas with restrictions placed on it because it is government land, I weighted as a constraint. Areas within 500m of flooding hotspots I also weighted as a constraint because it could lead to expensive crop losses.

I placed a value with each opportunity and constraint so it had a weight in the suitability map. For example, the distance to AC transit bus stops that was less than 300m had a weight value of +2. The total positives and negatives were added to create a gradient across the city of Oakland, where optimal areas had the largest positive number and were represented in green, while less optimal areas were in the negative range and represented in red. To map out the functions I used within ArcGIS, I created a flow chart that detailed the tools used to create the map (Figure 1). I used a network analysis, surface analysis, and multiple buffers and queries to create the final suitability map.

Table 2. Suitability Map Factors. I chose 8 opportunities and 5 constraints to consider in the suitability map of Oakland.

Opportunities	**Constraints**
<u>**Infrastructure and Socioeconomic Opportunities**</u> **(+2) Employment Rate** < 60% **(+2) Distance to AC Transit Bus Stops** < 300m **(+1 to +3) Proximity to Schools**: - 1 min (+3), 2 min (+2), 3 min (+1) **(+1) Distance to Oakland Public Housing** < 1000m **(+2) "Environmentally Disadvantaged Communities"** - Upper 25th Percentile <u>**Physical Landscape Opportunities**</u> **(+1) Farmland Mapping & Monitoring Program** - Land Type D: "urban and build up land" **(+1) Slope** < 10 degrees **(+1) Priority Conservation Area** < 1000ft freeways	<u>**Infrastructure and Socioeconomic Constraints**</u> **(-2) Employment Rate** > 80% **(-2) Distance to AC Transit Bus Stops** >1000m **(-1 to -3) Proximity Schools**: - 4 min (-1), 5 min (-2), 6 min (-3) <u>**Physical Landscape Constraints**</u> **(-1) Farmland Mapping and Monitoring Program** - Land Type X **(-1) Distance to Flooding Hotspot** < 500m

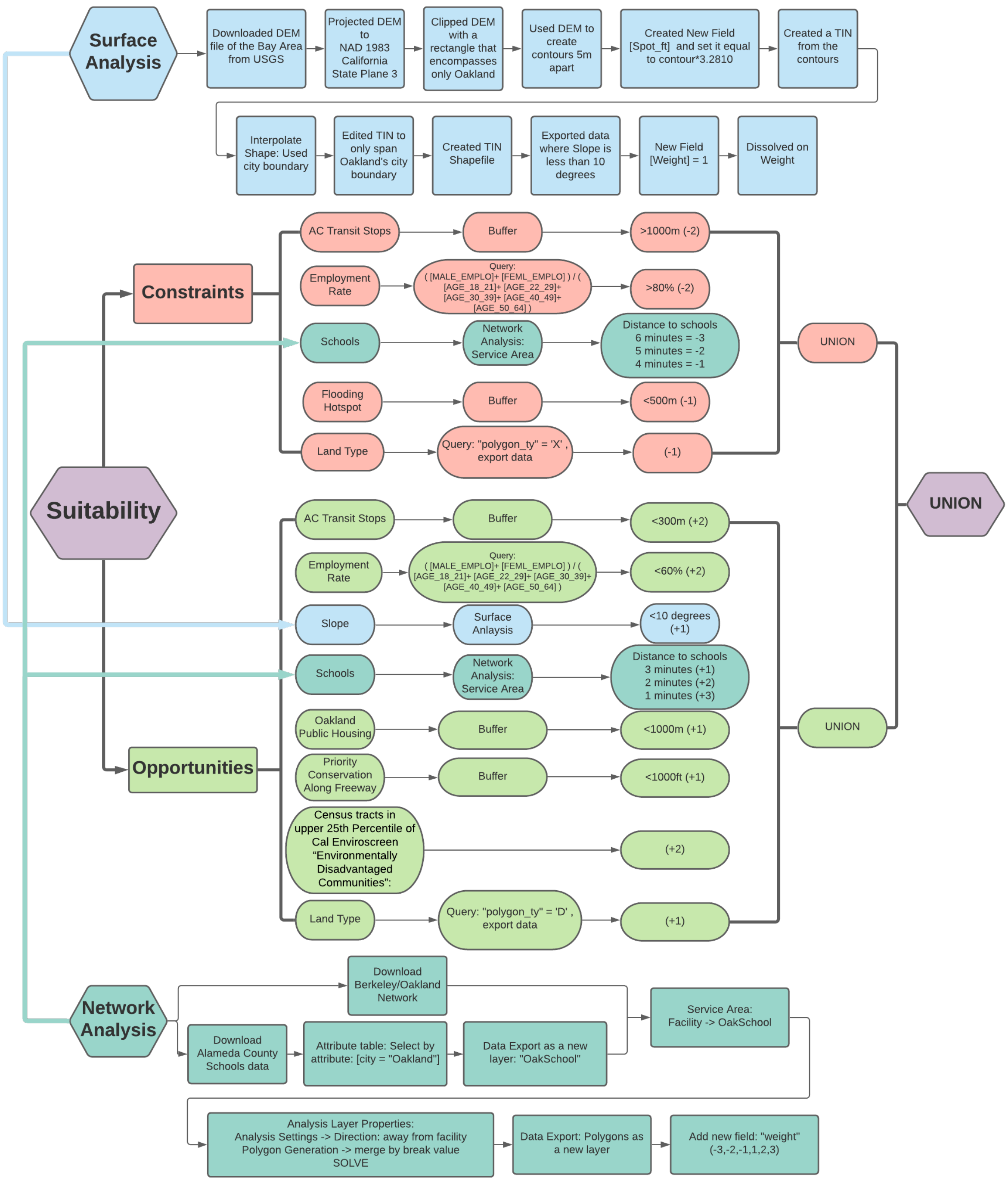

Figure 1. Flow Chart. Suitability map factors broken down into a flowchart showing the ArcGIS tools used.

RESULTS

Global warming potential of rooftop greenhouses across life cycle stages

I looked at 5 studies that from mediteranian climates that followed the life cycle of tomatoes. According to Cellura et al., building structure accounted for 18% of the total environmental impact of the greenhouse, which made it the second biggest contributor in that paper's study (Cellura et al. 2012). The first was transportation/packaging/harvest, which was 35.1% (Cellura et al. 2012). The RTG study done on tomato crops showed that the GWP of building structure included infrastructure manufacturing and installation (20.5%). This study also had the highest GWP compared to operations and transportation (Corcelli et al. 2019). In Ingram et. al. (2019), more than 60% of the CF from the outdoor shrubs were from input materials. Building structure certainly played a significant role in the GWP of indoor farming methods, and should have more research done on it. However, it may not be the most significant contributor to the environmental footprint. In Boneta et al., the highest contributor to all environmental impacts (GWP, terrestrial ecotoxicity, fossil depletion, etc) was the fertilizer used in operations (Boneta et al. 2019). The GWP of the fertilizer was calculated to be 72.7% while the building infrastructure was 18.3% (Boneta et al. 2019). For the iRTG/Tomato case study, packaging contributed the most to GWP, with a high of 65.5%, while structure accounted for 12.9% (Llorach-Massana et al. 2017). The structure was 3rd most significant in this case study because production accounted for 21.6% (Llorach-Massana et al. 2017).

After averaging the above data together, the highest contributor to global warming potential in rooftop greenhouses was the packaging life cycle stage; packaging contributed around 30% of the average kg CO_2 eq. The second and third highest contributors were infrastructure and operations at 21% and 20%. Production accounted for 13%, end of life 12%, and transportation 4% (Figure 2).

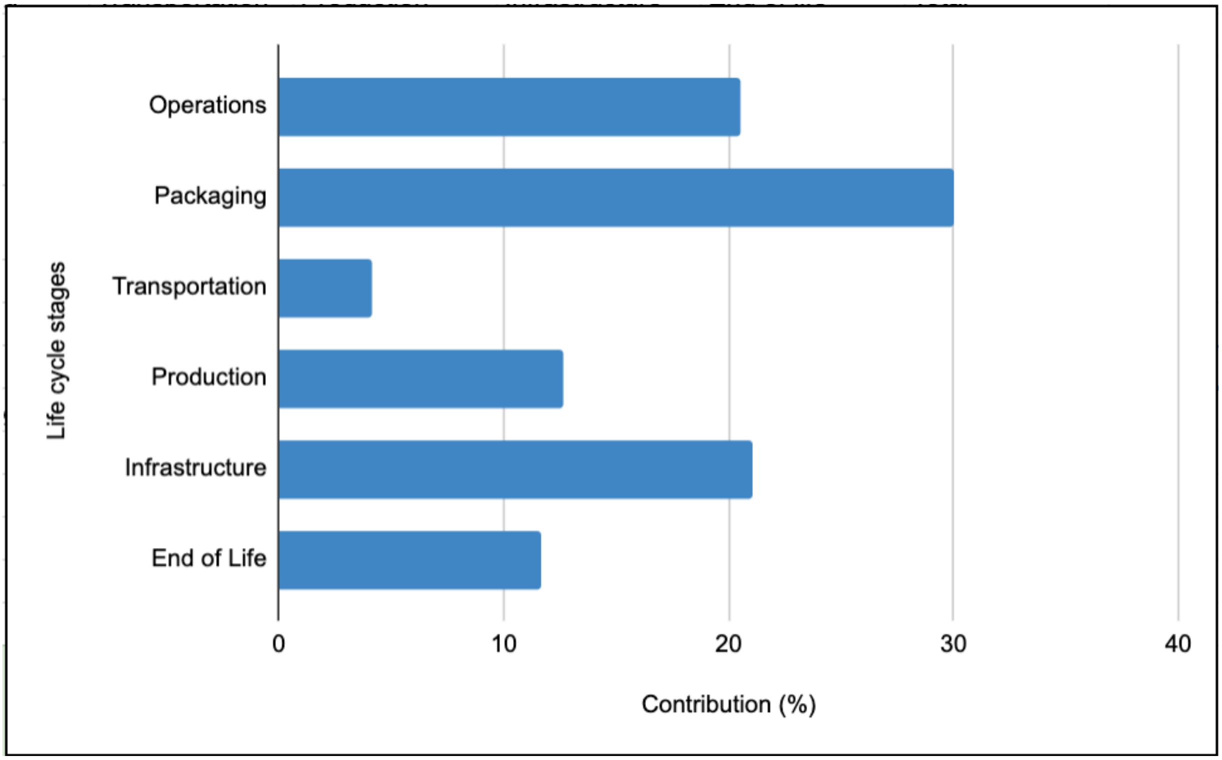

Figure 2. GWP of RTG across life cycle stages. I averaged the LCA data collected from my meta-analysis and calculated the percentage each stage contributed to GWP.

Rooftop greenhouses and conventional outdoor agriculture impacts

RTG had a lower percentage contribution to all 5 impact categories (global warming potential, ozone depletion, terrestrial acidification, eutrophication, photochemical oxidation). Global warming potential had the largest percent difference at 52.78%. Ozone depletion of RTG was 64.92% that of conventional agriculture, terrestrial acidification was 69.48%, eutrophication was 74.3%, and photochemical oxidation was 61.71% (Figure 3).

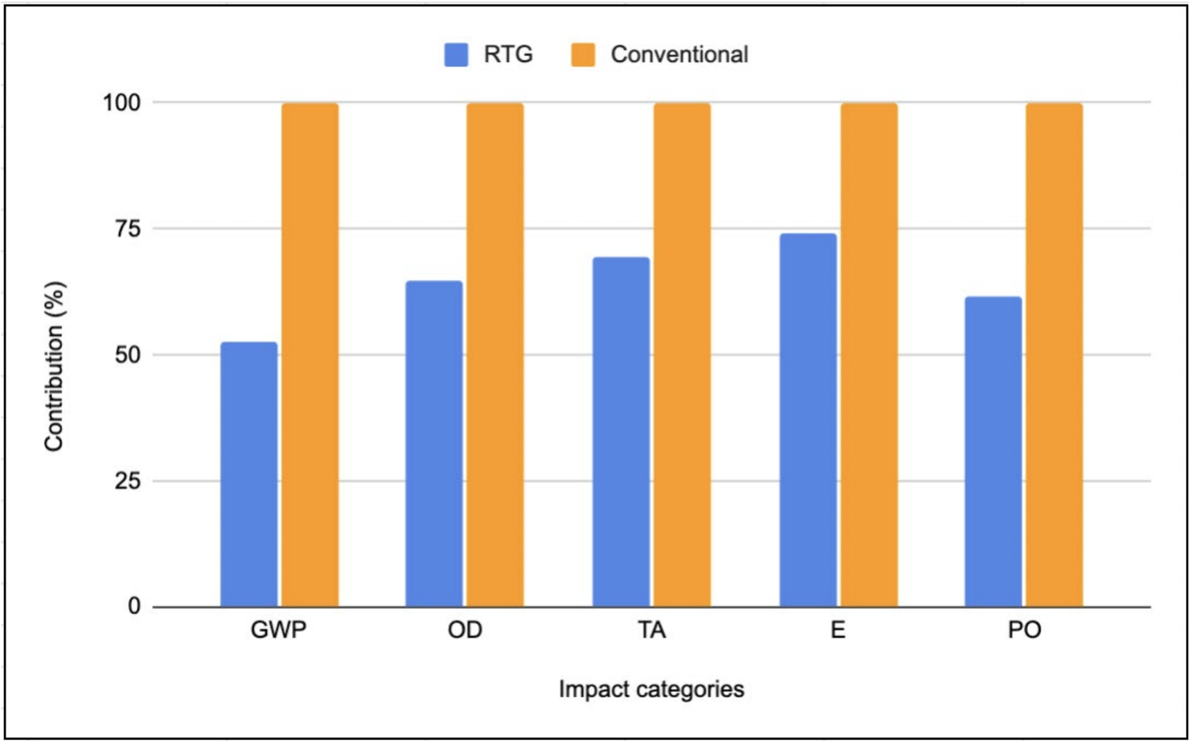

Figure 3. Comparison of impact categories between rooftop greenhouses and conventional outdoor agriculture. GWP = Global warming potential, OD = Ozone depletion, TA = Terrestrial Acidification, E = Eutrophication, PO = Photochemical oxidation

Using GIS to find urban agriculture opportunities in Oakland, CA

I found that areas in the city of Oakland with lower employment rates, closer proximity to schools, bus stops, public housing, and their status as environmentally disadvantaged communities were closer to the center of the city (Figure 4) whereas areas with more constraints laid on the edge of the city's border (Figure 5). The two optimal locations with highest weighted opportunities are circled in Figure 6's suitability map: Downtown Oakland South of 580 and Fruitvale.

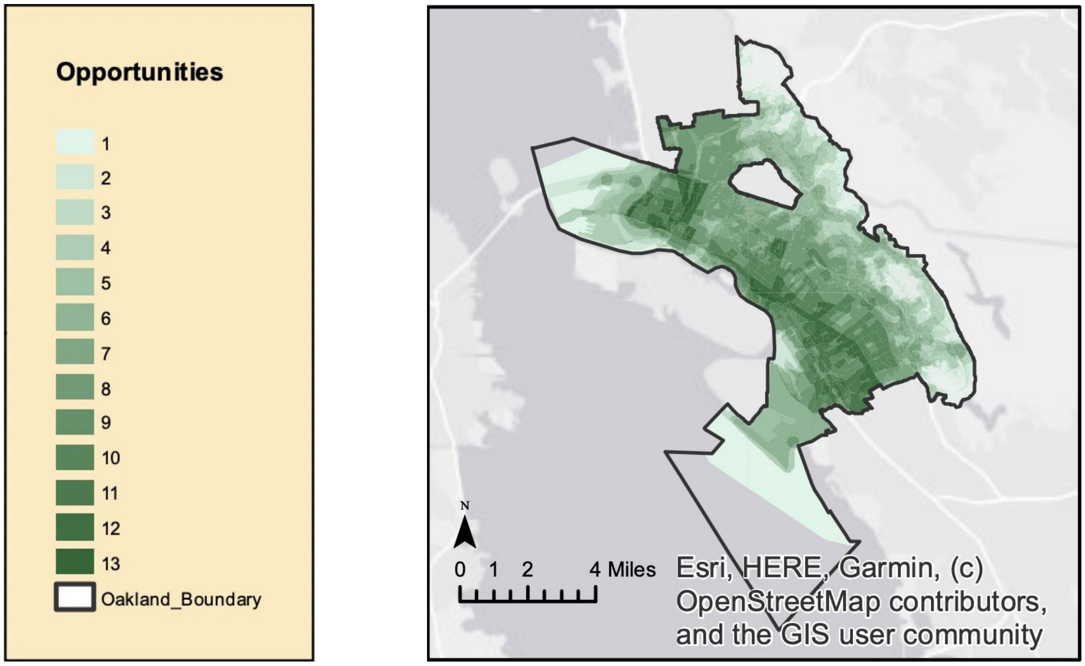

Figure 4. Opportunity Factor Map. This shows the opportunity factors of implementing urban agriculture in the city of Oakland, CA.

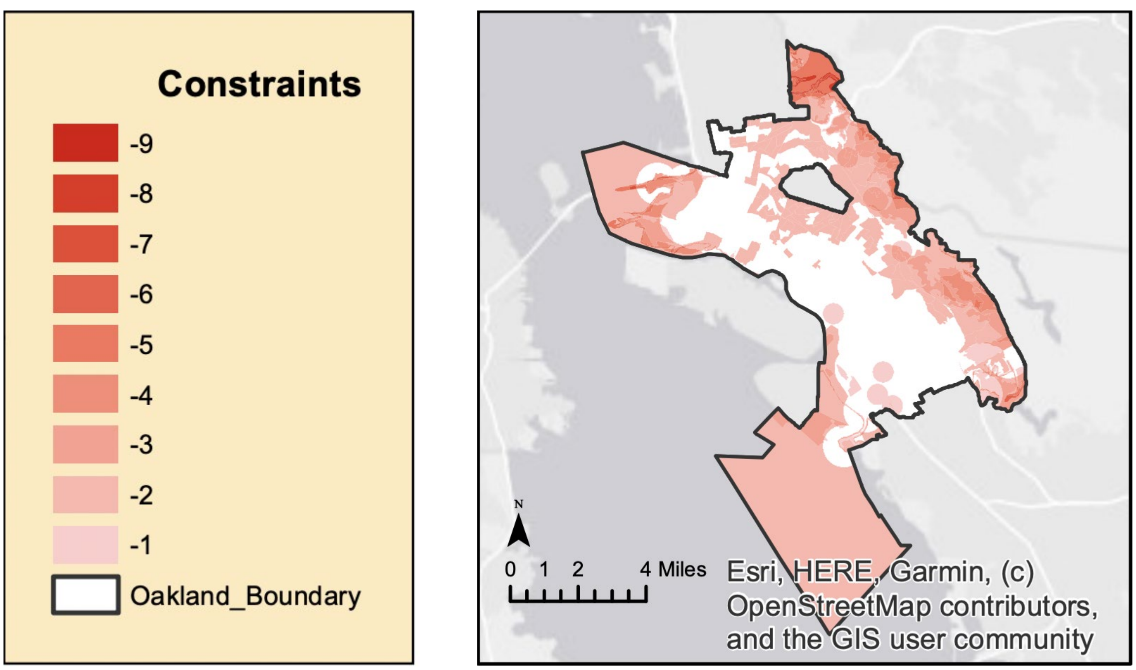

Figure 5. Constraint Factor Map. This shows the constraint factors of implementing urban agriculture in the city of Oakland, CA.

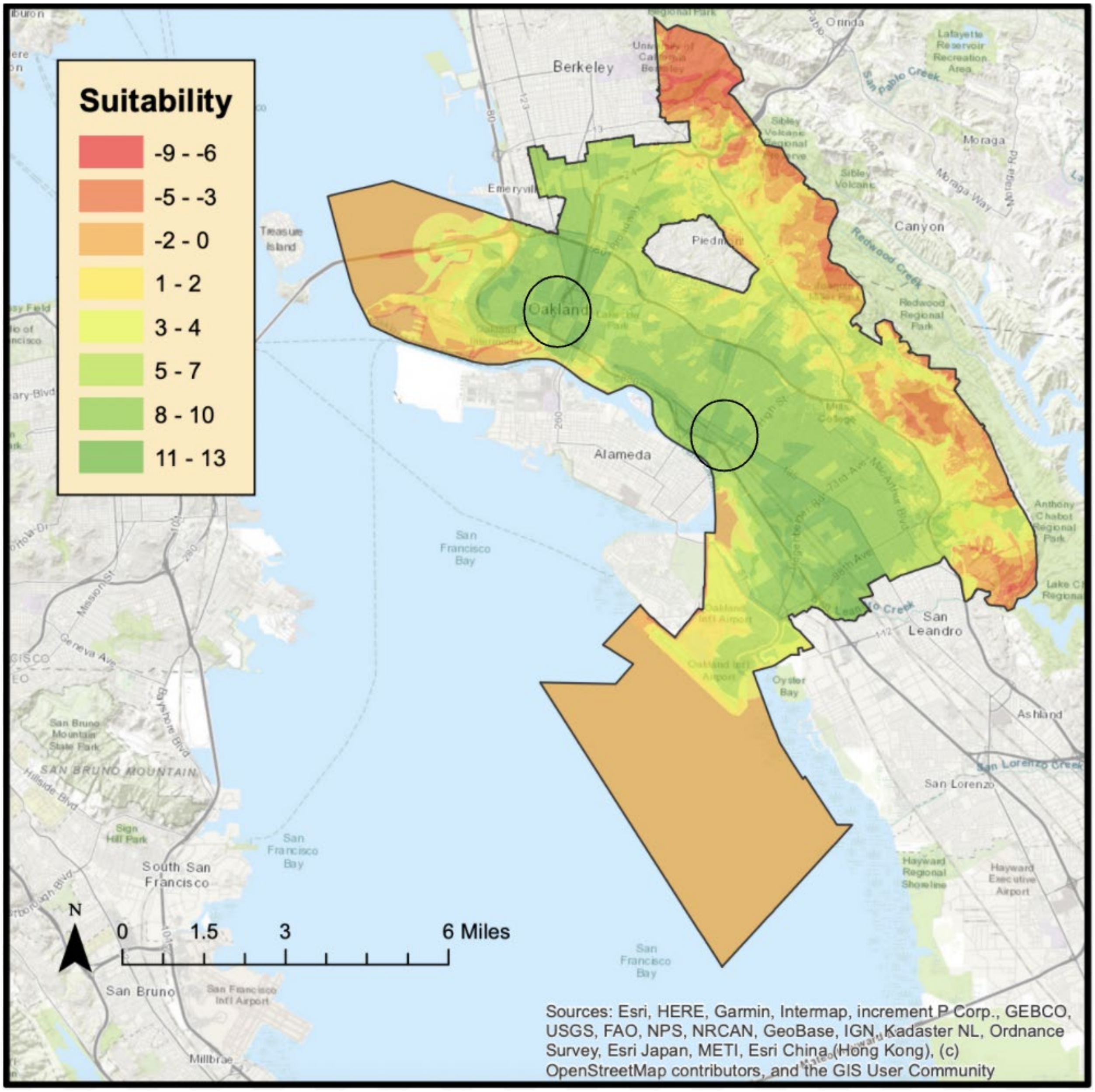

Figure 6. Suitability Map. This combines the opportunity and constraint maps and shows suitability of urban agriculture in the city of Oakland, CA.

DISCUSSION

Rooftop greenhouses had lower environmental impacts in comparison to conventional outdoor agriculture. Global warming potential of RTG was 52.78% that of conventional outdoor agriculture. RTG also had additional educational, environmental, and economic opportunities that served as great potential for our local Oakland community. I assessed the suitability of building an urban agriculture space in the city of Oakland and optimal locations found were Downtown Oakland South of 580 and Fruitvale. Rooftop greenhouses pose a potential alternative to conventional outdoor agriculture within the city of Oakland.

Global warming potential of rooftop greenhouses across life cycle stages

The environmental impact of rooftop greenhouses was greatest in the packaging stage and lowest in the transportation stage. This could be explained by the immense amount of materials and resources used in the packaging stage. Since rooftop greenhouses are a local source of crops and for the neighboring community, there is a lower need to transport the produce further distances. My study found that infrastructure contributed around 21% to the overall impact of global warming potential of RTG. Similarly, Corcelli et al. found that infrastructure can be an environmental hotspot for rooftop greenhouses, contributing between 16-63% of impacts of photochemical oxidation, ozone depletion, global warming potential, fossil depletion, and metal depletion and 2-10% of the impacts on the remaining categories (Corcelli et al. 2019).

Other literature shows that RTG is a promising agriculture method to utilize in the future for its practical land-use (Benis et al. 2018). Transforming urban underused rooftops into productive spaces can improve the urban metabolism by producing or collecting local resources such as energy, greening, food or water (Corcelli et al. 2019). RTG is also beneficial because it allows for year-round production and works with its host building to use 80-90% of rainwater for crops, and utilizes the heat of the building (Rufí-Salís et al. 2020). In order to prevent exhausting our planet's finite resources, sustainable urban planning is essential. I assessed the global warming potential of RTG and then compared those to conventional outdoor agriculture methods.

Rooftop greenhouses and conventional outdoor agriculture impacts

Rooftop greenhouses had a lower total percent impact across all 5 impact categories compared to conventional outdoor agriculture. According to my study, rooftop greenhouses had 52.78% less impact in global warming potential compared to conventional outdoor agriculture. Additionally, RTG was 64.92% lower in ozone depletion, 69.48% lower in terrestrial acidification, 74.3% lower in eutrophication, and 61.71% lower in photochemical oxidation. Previous literature synthesis supports these results as well. Studies of urban RTG showed these systems can provide lower environmental burdens relative to traditional supply chains (Goldstein et al. 2016). Goldstein's study on RTG tomatoes in Barcelona showed a 33% reduction in carbon emissions in comparison to conventional supply chains. In Mediterranean climates such as Barcelona, indoor heating requirements were reduced by 79% through heat recovery from RTG (Goldstein et al. 2016). According to Sanyé-Mengual et al., RTG can also benefit the US by reducing both packaging and food waste (Sanyé-Mengual et al. 2012).

RTG even shows lower environmental impacts in comparison to other urban agriculture methods such as greenhouses. A sustainability study in South Korea showed that tomato production in RTG had 43% less global warming potential, 45% less cumulative energy demand and abiotic depletion, 37% less photochemical oxidation and acidification, and 27% less eutrophication in comparison to greenhouses (Torres et al. 2020). This is due to the decreased energy load, elimination of transportation, storage, and handling losses during the distribution stage. The reduction in lower impact categories is a logical consequence of low food-miles and is important in reducing environmental impacts. Implementing lower environmental impact agriculture methods such as rooftop greenhouses in urban cities is the next step.

Urban agriculture opportunities in Oakland, CA

Downtown Oakland South of 580 and Fruitvale are the two optimal locations for the city of Oakland to consider building urban agriculture spaces in. Greener areas that represent more suitable areas are all within the center of the city. Darker red areas tend to lie along the border of the city, where there are more constraints. This is likely due to the fact that there are more bus stops and schools in the center of the city and those factors were weighted as opportunities. The two darkest green areas are Downtown Oakland South of 580 and Fruitvale. These areas are close to schools, bus stops and public housing. Both communities are in the upper 25th percentile of environmentally disadvantaged census tracts according to CalEnvrioScreen2.0. Existing studies used similar factors to create suitability maps.

Moniruzzaman et al. uses GIS to quantify the change in land-use cover and runoff due to urbanization (Moniruzzaman et al. 2020). Using remote sensing, flow charts, and maps, Moniruzzaman et al. found a 13.1%, 4.8%, and 7.8% reduction in agricultural land, green spaces, and water bodies. In the face of rapid urbanization, agricultural land is scarce. Abd El Karim et al. uses GIS to recommend areas most suitable for urban development (Abd El Karim et al. 2020). They built a suitability map based on opportunities and constraints to find an ideal location for urban development. Kang et al. designed a suitability assessment of urban land use in Dailin, China and categorized areas as "most suitable," "suitable," and "normal" (Kang et al. 2021).

Smith and Miller created their suitability map with factors including poverty levels, housing values, air quality, and other environmental indicators (Smith and Miller 2013). Another study divided their spatial suitability map into categories; areas with gentler slopes were considered of higher suitability and areas with steeper slopes were of low suitability (Abd El Karim et al. 2020). This is similar to the factors I used in my map where I identified slopes below 10 degrees as an opportunity. Both studies also created an opportunity and constraint map before showing the final suitability map. This helped provide a breakdown of what factors were considered towards the recommended areas for urban development. With the optimal locations within the city of Oakland in mind, I wanted to determine if RTG is a method that can be applicable to the city.

Implementation of RTG into Oakland

RTG is an urban agriculture method that the city of Oakland can consider adopting into their urban planning in the future. RTG is shown to have lower impacts in impact categories including global warming potential, ozone depletion, terrestrial acidification, eutrophication, and photochemical oxidation in comparison to conventional outdoor agriculture. Non Profit organizations that practice urban agriculture in Oakland such as Planting Justice work with residents to provide employment and community ownership in order to enable long-term residents to resist displacement (Alkon and Moore 2019). Other social benefits of urban agriculture include increased access to food, positive health impacts, and connections to broader social change efforts (Horst and Hoey 2017). The sustainability aspect of RTG is highly supported with the life cycle assessment (LCA).

Suitability of these areas in Oakland for RTG are not as clear. While these areas in Oakland have high needs for urban agriculture, feasibility of implementation of RTG is uncertain. Alkon and Moore's study on food movements such as urban agriculture suggest that it may have unintended consequences which harm the low-income communities of color that food justice advocates seek to serve (Alkon and Moore 2019). Options including employing long-term residents in well-paying jobs are not enough to keep up with rising rent, so policy oriented change is required as well; for example, community development block grants, inclusionary zoning, linkage fees, and community land trusts are just a few. Sanyé-Mengual et al. counter argues that RTG can provide economic, social, and environmental opportunities to the local community through efficient food production (Sanyé-Mengual et al. 2016). While the results are relatively promising, there are certain limitations to the scope of the project that should be addressed.

Limitations

Additional LCA on RTG can be continuously added to my data tables to create a stronger meta-analysis as well as adding additional opportunity and constraint factors for a more comprehensive suitability assessment of Oakland. The meta-analysis data I averaged were all from Mediterranean climates but not all from the exact same location, so there may be slight variations in the resources needed for the system or other confounding variables. There was also limited data on RTG so only a few studies were used. In the data layering process in ArcGIS, I used 8 opportunities and 5 constraints with the data sources I was able to find for the suitability assessment. For a more comprehensive understanding of where in Oakland has the highest need and highest suitability, more factors could be considered. It is also difficult to conclude that the 13 factors I did consider gives a full perspective of what locations would be best suitable for urban agriculture. As I keep in mind these limitations and reflect on my results, I am able to consider what I would do differently or would like to add to my study in the future.

Future directions

The future direction I would like to take my study is to continue adding to my database of LCA comparing RTG and conventional outdoor agriculture and also work with Oakland organizations to bring our urban agriculture plans to fruition. In ArcGIS, I would like to increase the opportunities and constraint factors I consider when creating the suitability map within

Oakland, CA. I could consider current open-field areas that could be converted to community gardens. Researchers in this field should continue working with organizations in the Bay Area to implement urban agriculture systems within the areas most suitable. Organizations such as Planting Justice, an SF Bay Area Food Justice Organization that builds gardens, works with high schools to develop food justice curriculum, and creates jobs for folks transitioning from prison. Given the time and funding, researchers can develop a larger dataset on RTG LCAs and collect the quantitative data across each life cycle stage and impact category to get a better understanding of the agricultural method. They can also use the current data as a means/argument to support the shift in agriculture towards urban agricultural methods including rooftop greenhouses, for its sustainable advantages and utilization of land. In order to fund RTG projects in the future, participation of research institutes, private initiatives, and administration can help lift barriers and create concrete RTG projects. My next steps are to use my results to further the movement of transitioning towards urban agriculture methods as well as working with local organizations such as Planting Justice to create these farms in the city of Oakland.

Broader implications

Urban farming methods can serve as an opportunity for us to grow economically while also providing environmental benefits for the local community. As Sanyé-Mengual et al. says, RTG is an innovative way of producing food within city limits by using unused space on buildings (Sanyé-Mengual et al. 2016). I hope the meta-analysis of life cycle assessments of RTG and conventional agriculture applied to a city such as Oakland sheds light on the benefits UA can give to the local community. There is great potential for urban farming methods such as rooftop greenhouses within Mediterannean climates such as the city of Oakland to benefit local residents.

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