SMART SURFACES COALITION

ACHIEVING URBAN COOLING, ENHANCED PUBLIC HEALTH AND EQUITY, AND LOWER CLIMATE RISK IN HOT DRY CLIMATES THROUGH SMART SURFACES:

An Indicative Case Study of Stockton, California

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1 Introduction

Much of California and the surrounding region experienced brutal heat waves, fires, and air quality challenges in 2021 that, though historically unusual, will be the norm for the coming decades. By mid-June, news of extreme heat was already dominating headlines, such as one article titled "An eighth of the US population is sweltering under a record-breaking heat dome. Climate change is making it worse."[i]

In summer 2021, cities, which are already hotter than surrounding countryside, experienced record heat and widespread heat deaths. The latest IPCC Report (AR6) advances some fundamental changes in expanding climate policy which are firmly rooted in scientific consensus and government support of this consensus: The world is on the verge of reaching irreversible climate tipping points as early as 2030—a point where, if reached, there is no return to "normal."[ii] In turn, this will increasingly worsen summer heat and health crises in cities across the country, which raises an urgent and essential question: How can cities in regions already under budget pressures due to COVID-19 reduce their heat and climate risks—and especially the increasingly deadly excess heat burden that characterizes too many of urban America's low-income and minority neighborhoods?

To answer this question, the Smart Surfaces Coalition secured a small grant through the Institute for Governance and Sustainable Development (IGSD) to estimate the potential for a highly representative city—Stockton—to deploy Smart Surfaces to cost-effectively achieve common city health, heat, air and water quality, equity, and climate objectives. Stockton, recently voted as America's most diverse city, is a mid-sized city in the middle of California's hot- and mixed-dry climate zone. Stockton is therefore a very representative city with which to evaluate the question: can Smart Surfaces effectively and cost-effectively deliver substantial cooling, health, and climate benefits to cites in hot and dry areas of California and the surrounding region?

1.1 Findings

Our findings are that city-wide adoption of Smart Surfaces by Stockton would be a very effective and cost-effective way to deliver a broad range of quality of life, equity, climate, and risk reduction outcomes. The analysis finds a 6.9:1 benefit-cost ratio from adoption of a modest set of Smart Surfaces strategies with a net present value over $777 million through 30 years of analysis. City-wide adoption of Smart Surfaces centered around Stockton's targets would also create roughly 817 full-time, well-paying jobs, reduce peak summer temperatures downtown by 2.92°F[1],[iii] and avoid 4.58 million tonnes of CO2 equivalent emissions. The largest cooling, health, and air quality benefits accrue in low-income and minority neighborhoods where there is typically less tree cover and green space, and more dark, impervious surfaces.

There are a range of substantial additional benefits that are not included in this analysis such as reduced temperatures from evapotranspiration by trees, avoided summer tourism loss due to extreme heat, many dimensions of improved public health like decreased hospital visits, and the economic benefits of enhanced walkability and enhanced city livability. If the city and state collaborated with databases, the analysis could be further detailed. Data availability and transparency were consistent barriers to efficient collaboration between air quality agencies and the community.

As such, while this analysis fully documents the cost of Smart Surfaces, the quantification of benefits is incomplete—many benefits are not included due to limited study scope and/or due to data limits. Even within these limits, this study demonstrates compelling financial, health, and climate rationale for Smart Surfaces and indicates that a full cost-benefit analysis for cities in hot- and mixed-dry climates, as with most of California and the surrounding region, would demonstrate a compelling case for city-wide Smart Surfaces adoption.

1.2 Report goals

The following document briefly frames key physical, demographic, and climate characteristics of Stockton to provide an evaluation of the potential for Smart Surfaces to effectively and cost-effectively address challenges that cities across California and the world face. These include excessive summer heat, poor air and water quality, flooding, high energy bills, structural inequality (low-income neighborhoods are generally hotter and more polluted), reduced attractiveness of outdoors that result in less livability, exercise and healthiness, and a city-wide risk from intensifying climate change. This work allows several city-wide cost-benefit analytical models to be developed and used for mapping the potential of Smart Surfaces for Stockton to address these and other issues cost-effectively. Using satellite data, we have run algorithms to estimate and characterize Stockton surfaces, providing key data to begin customizing a Stockton-specific cost-benefit surfaces model. These models and assumptions are described below along with preliminary findings. As the city provides additional city-specific data, these models can be refined and made increasingly accurate to provide city policymakers with city-specific understanding of how it can select the set of surface policy choices to best shape and ensure a healthier, cooler, more equitable, and more competitive future.

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[1] Taha et. al 2021 found that temperatures in the Sacramento Valley (adjacent to Stockton) could be reduced by up to 7 degrees Fahrenheit with a realistic but significant increase in tree cover and albedo. The temperature reduction estimated in this report is lower because the Smart Surfaces adoption plan modeled is modest.

It is also worth noting that an emphasis on job creation, environmental justice and climate change appear consistent with the objectives of Stockton's Climate Action Plan and 2040 General Plan (see section 2.2) as well as the policy priorities of the State of California (see section 3). Smart Surfaces deployment, such as tree planting or painting reflective coating onto flat roofs or parking lots, are very labor intensive—that is they quickly create many full-time jobs for each million dollars invested. By focusing these Smart Surfaces investments in low-income areas, Californian cities can help redress long-term structural inequalities that make low-income urban areas hotter, more polluted, and less livable.

This report, in addition to presenting findings, also presents a Stockton-specific cost-benefit analytical tool that the city can use to quantify the impacts of different surface decisions (see section 1.4.2). Creating a cost-benefit analytical tool for city-specific Smart Surfaces scenarios will enable policymakers to understand that implementing Smart Surfaces on a city-wide scale can help the city combat its biggest challenges around climate change and inequality, while also saving money.

The Smart Surfaces Coalition is made up of industry leading health, planning, architecture, city policy, energy, affordable housing, and other organizations dedicated to supporting expanded adoption of Smart Surfaces globally. Prior studies of potential city-wide Smart Surfaces adoption by Baltimore and El Paso, Philadelphia, and Washington D.C. demonstrated Smart Surfaces to be a cost-effective, city-wide strategy to address climate change mitigation and adaptation that would also improve equity, create jobs, and improve public health.

1.3 The need for Smart Surfaces

1.3.1 Overall need: addressing heat

More and more cities are becoming intolerably hot in the summer, and in the coming years are increasingly at risk of becoming unlivable due to more extreme summer temperatures. This is in large part because most cities are covered with dark, heat-absorbing, impervious surfaces, such as asphalt parking lots and dark roofs, resulting in higher peak temperatures, higher energy bills, worsened flooding, and increased air pollution. Summers are now commonly 9°F hotter in cities than the surrounding countryside, an effect commonly referred to as the urban heat island. The impact is usually even worse in low-income neighborhoods, which generally have more dark, impervious surfaces and fewer trees, with temperatures often 10°F hotter than wealthier neighborhoods with more trees and green space.

Climate change is making cities even hotter. Under current projections, many cities will experience a tripling of extremely hot summer days by 2050. A National Academy of Sciences report warns that the mean human-experienced temperature by 2070 will increase 13°F.[iv] Unless city policies and the pace of global warming change, many cities will become too hot in the summer for humans to survive for prolonged periods outside—or in buildings without adequate air conditioning.

In summer 2021, California experienced its hottest summer on record[v] and cities across the West Coast will continue to face serious health, infrastructure, climate, and equity risks. The heat waves engulfing these areas point to the need for cities to become more resilient to future weather challenges, not just for the health of residents, but also for economic viability. Around the world, heat is causing productivity in the workplace to slow, an effect known as heat stress. A 2016 study from the London School of Economics even suggests cities could lose almost 10% of the value of all goods and services they produce due to heat stress.[vi]

Surges in extreme heat in traditionally cool places like Seattle, Portland, and much of Canada led to hundreds of excess heat deaths in a few days and a rush to buy air conditioners where air conditioning (AC) has historically never been needed. The surge in urban AC demand raises the terrifying threat of an urban accelerating heat loop that will make urban heating and climate change even worse.

If AC does increase as projected (from 1.6 billion units now to about 5.6 billion units globally by 2050),[vii] this would increase warming by 0.5°C just from increased electricity use alone. However, the climate impact would be much larger as AC units use and leak greenhouse gasses that are potent accelerants of climate change. Large increases in air conditioners would essentially mean more AC heat ejected outside onto streets, potentially increasing city temperatures by an additional 2°F, further increasing air conditioning loads. In multi-storied buildings, ejected heat from operating AC units preheats air drawn in by AC units above, making them less efficient and in turn requiring more AC units operating at fuller capacity more of the time, in turn increasing heat rejection outside. Unfortunately, this self-reinforcing urban overheating is the future of business as usual if city-wide measures are not taken.

Extreme heat threatens the safety and health of city residents, damages valuable infrastructure via cracking, worsens the effects of systemic inequalities by making low-income areas hotter, and costs homeowners and businesses money from electricity bills/ AC use. For cities to solve these problems, they need the tools, data, and expertise to quantify the impacts of their surface decisions to fully understand how Smart Surfaces can mitigate heat in urban environments.

1.3.2 Overall need: addressing water

In addition to the risks associated with heat, the presence of impervious surfaces also means cities are prone to flooding from heavy rainfall and sea level rise. As more intense and frequent rainfall occurs due to climate change, flooding will damage infrastructure, resulting in costly repairs, and threaten the safety of residents from mold, water pollution, and storm surge.

Recent floods in Germany and Belgium[viii] showed how flooding can be ultimately linked to both the increasing threat of climate change and overwhelming presence of imperious surfaces that dominate cities. A study in the Geophysical Research Letters indicated that on average across the U.S., every time a city expands roads, sidewalks or parking lots by one percentage point, the annual flood magnitude in nearby waterways increases by 3.3 percent.[ix]

Addressing flooding in California is a major concern because nearly every county in the state has been declared a flood disaster zone on multiple occasions.[x] The Central Valley is prone to flooding from nearby waterways overflowing and counties in the South as well as areas recently burned by wildfires and communities in the desert are all vulnerable to flash floods. In California and mostly every other city, rainfall can lead to flooding in urban environments where there is inadequate drainage and impermeable surfaces, leading to economic, health, equity, and safety costs for the city. The flood maps in figure 1.1 highlight the need for more effective flood management in the state to preserve infrastructure and avoid costly repairs.

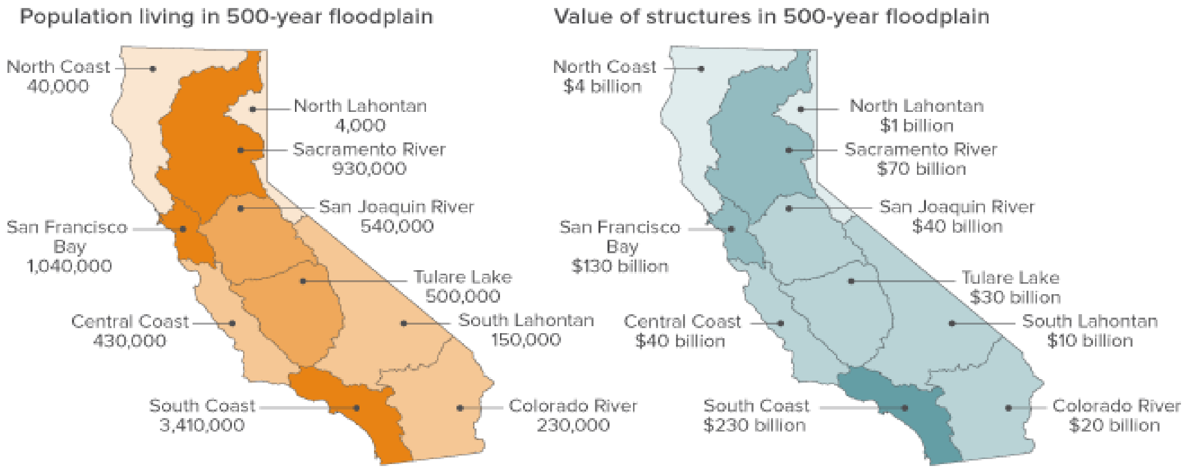


Figure 1.1 Flood zones in California versus the estimated value of structures in the area

Many cities in California have outdated flood management systems. California's climate is changing with larger winter storms, more rainfall, and more extreme high tides. These changes, along with rising sea level, will make many current flood management systems obsolete within decades, requiring major investments in new infrastructure and new approaches to reducing flood risk.[xi]

To avoid cities of the future becoming characterized by unbearable heat and regular destructive flooding, we need to adopt Smart Surfaces—surfaces that better manage urban heat and flooding such as reflective, porous, and green surfaces along with trees and solar photovoltaic panels (PV). Smart Surfaces are the only cost-effective solution available that cools cities, slows climate change, and increases flood resilience—all at the same time.

1.3.3 Need in Stockton

Stockton, the 13th-largest city in California, has a population of over 300,000 people. In 2018, Stockton residents were 42 percent Hispanic, 24 percent Asian, 19 percent non-Hispanic white and 13 percent Black,[xii] making the city the "most racially diverse large city in America," according to U.S. News.[xiii] The city is located in the San Joaquin Valley, which has some of the world's worst air quality and highest temperatures—due to the compounding effects of human-caused climate change on the Valley's topography and other existing pollution sources, and exacerbated by the dark, impervious surfaces that cover the city of Stockton.

This has led to increasingly severe heat waves, drought, and fires in recent years. But the air pollution and extreme heat that plagues Stockton does not fall equitably on the city's diverse population. Years of underinvestment in south Stockton have led to a north-south divide in the city along racial and socioeconomic lines. More Black and Hispanic residents live in the south of Stockton, and these groups have a lower median income compared to white Stockton residents who disproportionately live in the north of Stockton, as shown in data collected by Advantage Stockton. Stockton's white households have a median income of about $60,700, roughly twice the median income among Black households ($30,400) and significantly higher than among Hispanic ($43,900) and Asian households ($56,200), census data shows.[xiv] Similar disparities exist in educational attainment, unemployment, and homeownership rates.

The health disparity between racial and socioeconomic groups is exacerbated by inequitable living conditions between the north and south of Stockton. The area's lower-income, primarily Black and Hispanic communities, have higher asthma rates, lower life expectancies, and poorer overall health[xv] than those in the north and other surrounding neighborhoods. CalEPA created a tool to track community burden from pollution and vulnerability called CalEnviroScreen (CES) 3.0. When the tool is used in combination with a map of Stockton showing HOLC (Homeowner's Loans Corporation) grades of census tracts, historically D-graded, or redlined, census tracts received the highest CES scores, and thus continue to face environmental injustices.[xvi]

According to the 2016 San Joaquin County Community Health Needs Assessment, Stockton experiences "tremendous disparities in health outcomes," citing a life expectancy of 90 years in the city's wealthier areas compared to 69 years in the city's "lower-income, multi-ethnic zip codes." Poor housing quality and air pollution have worsened the link between climate change[xvii] and health-related issues, vector-borne disease, and respiratory disease.

Previous and current approaches to solving Stockton's climate-related problems and making Stockton more livable have not been successful. Dark, impervious surfaces comprise two-thirds of city areas, and in the summers, can heat cities by an average of 9°F more than surrounding countryside.

In low-income areas, the effects are even worse. Low-income neighborhoods can be 5-20°F hotter due to the lack of tree coverage[xviii] and more dark surfaces. This imposes huge health and economic burdens on those who can least afford it. As a result of our current practices, cities continue to warm, social inequities continue to widen, and climate change-related health problems continue to worsen.

Stockton is mid-sized, diverse city that suffers from socioeconomic inequality and climate related challenges like extreme heat. The city is in a hot- and mixed-dry climate, which as figure 1.2 highlights, covers most of California. Stockton's health, equity, heat, and flooding challenges parallel other cities in California and the surrounding region, making this case study on Smart Surfaces adoption regionally applicable.

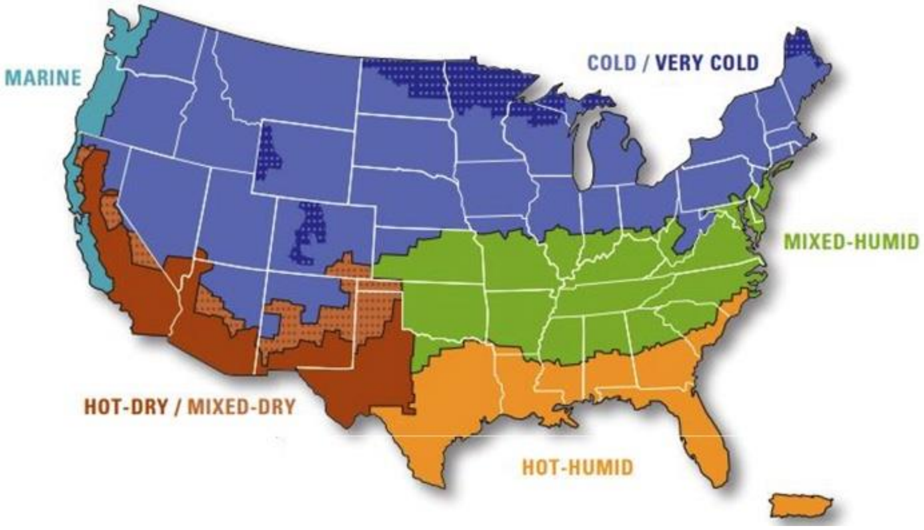


Figure 1.2 U.S climate zones[xix]

1.4 Project information

1.4.1 About the project

The project, funded by IGSD, will create a Smart Surfaces analytic engine for Stockton.

The Smart Surfaces Coalition's research and analysis, in the form of a comprehensive and adaptable model, will help policymakers, stakeholders and residents understand a highly cost-effective way to cool cities, create jobs, reduce air pollution and more—with a focus on south Stockton and environmental justice. Initial analysis indicates the following impact areas of applying Smart Surfaces in Stockton:

1. Cut smog and decrease related health problems, including asthma and respiratory illness
2. Cut building and city temperature in the summer, reducing energy bills, air pollution, and urban heating

3. Cut flooding and associated costs of water treatment and mold
4. Redress gross social and environmental injustice in cities by making low-income areas of cities cooler and more livable. (Low-income neighborhoods and communities of color generally have hotter neighborhoods with more dark, impervious surfaces—urban heat and pollution reduction provide the greatest benefits for these communities)
5. Reduce climate change – more reflective surfaces bounce sunlight and heat back into space, reducing temperature and global warming, while lowering air conditioning costs—and delivering city-wide cooling
6. Create hundreds of well-paying, full-time jobs
7. Enhance and protect city credit ratings[xx]

The Coalition has mapped surfaces and tree cover in Stockton and, using a new cost-benefit analytic engine, will run scenarios with varying levels of hypothetical implementation of Smart Surfaces in the city. Types of Smart Surfaces solutions modeled include making dark surfaces such as roofs and roads more reflective, installing solar PV, and increasing the city's tree coverage.

The Smart Surfaces adoption scenario is being developed based on a cost-benefit framework used in four other US cities to aid in policy and decision making. This analysis, in addition to valuing costs and benefits of surface implementation, will also evaluate the emissions and temperature reduction impact for a set of Smart Surfaces adoption scenarios.

Creating a cost-benefit analytical tool for city-specific Smart Surfaces scenarios will enable policymakers to understand that implementing Smart Surfaces on a city-wide scale can help the city combat its biggest challenges around climate change and inequality, while also saving money.

First Order Assessment

With limited funding, SSC conducted a comprehensive and detailed first order assessment of the surface options available to Stockton that would provide value to the city's residents, businesses, and government.

Had SSC received full funding, this project would also include training for city officials and local NGOs, a customized analytic model for specific neighborhoods, Stockton specific impact data, alternate adoption scenarios for different timelines, AC load reduction from ambient temperature reduction, other surface options like urban meadows, prevented summer tourism loss, and more. These can be quantified in future reports.

1.4.2 Analytic engine purpose and background

The Smart Surfaces analytic tool allows cities to determine the costs and benefits of Smart Surfaces adoption in their cities. The analytic engine is based on 6 years of research and development conducted in trial cities including Baltimore, MD, Washington DC, El Paso, TX, and Philadelphia, PA—the report "Delivering Urban Resilience" is the result of this work.[xxi] The detailed financial model in this report is being expanded for use in all cities with the help of Smart Surfaces Coalition partners.

The tool will allow cities to input their desired adoption level of each Smart Surface type and see all the costs and benefits associated with implementing the selected Smart Surfaces adoption mix for their city. The tool draws from climate databases, state and national databases, satellite imagery, data from partner organizations, and other industry standard sources to determine each city's unique costs and benefits of Smart Surfaces adoption. Users will also be able to drill down to see all the underlying assumptions, raw data, and other features of the model to see how specific results were calculated. Additionally, the analytic engine also allows users to adjust built-in assumptions using their own data. City officials with self-generated data can use their data as inputs to customize the cost-benefit analysis for parts of cities. A detailed walkthrough of how to use the tool can be found at the end of this report.

1.4.2.1 Example adoption scenario

Smart Surfaces for Stockton 20-Year Targets**

Smart Surface*	Coverage Target***	Albedo Target (% of solar energy reflected)
Reflective (Cool) Roofs	Low-slope roof area: 60%, Steep-slope roof area: 10%	Low-slope albedo: 0.75, Steep slope albedo: 0.4
Solar PV (3rd party financed)	Low-slope roof area: 20% Steep-slope roof area: 5%	-
Reflective Parking	Parking area: 50%	0.4
Reflective Roads	Road area: 5%	0.35
Trees	City land area: 20% (10% absolute increase)	-

*Based on Stockton's own objectives and trends in similar climates, targets were formed for city-wide Smart Surfaces adoption over 20 years.

**Both costs and benefits are still quantified an additional 10 years after the adoption scenario concludes, which means impacts are realized over 30 years.

***For this report we use a "modest" set of Smart Surfaces adoption targets, meaning that the coverage and albedo targets are conservative and could be strengthened to be more ambitious.

1.4.2.2 Example adoption scenario impacts

Smart Surfaces for Stockton 20-Year Adoption Scenario Impacts Consolidated Summary						
Smart Surface	Costs (millions, 2020$)	Benefits (millions, 2020$)	NPV (millions, 2020$, 2% Real Discount Rate)	Benefit: Cost Ratio (from 2020$)	Employment ***** (Job years created over 30-year analysis)	Peak Period Summer Temp Reduction Estimate
Reflective (Cool) Roofs – low slope	$12.60	$214.73	$198.17	17:1	440	1.39 °F
Reflective (Cool) Roofs – steep slope	$16.72	$15.52	$1.17***	0.9:1	-	-
Solar PV (3rd party financed) * – low slope	$9.58	$282.17	$267.25	29.5:1***	14,730	not included
Solar PV – steep slope	$5.15	$183.46	$174.81	35.6:1	-	not included
Reflective Parking	$16.28	$37.99	$21.28	2.3:1	179	0.4°F
Reflective Roads	$1.91	$5.56	$3.58	2.9:1	4	0.04°F
Trees****	$71.00	$186.50	$113.24	2.6:1	994	1.1°F
TOTAL ******	**$133.24**	**$925.93**	**$777.15**	**6.9:1**	**16,347 job years (817 full time jobs created)**	**2.92°F**

* Solar PV payback after year 10, this model assumes "first cost" (e.g., financing payments) are net of electricity value (electricity value is zero for first 10 years after install), and therefore first cost is zero. Third-party financiers will bear the actual first cost and Stockton system owners will not receive an electricity value benefit until year 11 after installation.

**This report takes a 10% reduction of El Paso's impact data for 3rd party financed solar PV and applies that to Stockton's surface coverage to reflect a similar difference in in direct normal irradiance during peak summer months. [xxii]

*** For cool roofs, solar PV, and urban trees this model recognizes the material benefit of reducing PM2.5 from cooling but does not include the benefit in our assumptions because California produces very little coal, an inefficient fuel combustion source that factors into PM2.5 levels.[xxiii]

****The NPV for steep-slope cool roofs is a small, but negative number. This report does not quantify AC load reduction, ambient air temperature reduction, and reduced heat-related illnesses and hospital visits for cool roofs. When these metrics are factored in, the benefits far outweigh the costs. Since these benefits are not calculated in the report due to complexity, a lack of effective studies, etc., this estimate is conservative.

***** Temperature reduction from albedo measured between 1–4pm mid-summer in downtown/central area of city. Temperature reduction from increased tree canopy is from radiative shading only. It doesn't include temperature reduction from increased evapotranspiration or reduced heat ejection into the city by air conditioners due to lower ambient temperature or from shading of buildings by trees. These are substantial additional heat reduction benefits from expanding tree coverage, meaning that cooling benefits from trees are underestimated in this model.

****** Employment (job years) and temperature reduction are not broken down by roof type. The amount of job years created, and peak summer temperature reduced is cumulative for solar PV and reflective roofs, meaning that we do not break it down by roof type. For example, there is 1.39°F of cooling from both low- and step-slope cool roofs together.

******* The total calculations may be off when adding up the numbers in the columns because calculations are rounded to the millions.

1.5 Smart Surfaces

1.5.1 What are Smart Surfaces?

This report assembles and analyzes a set of surface technologies that cities can use for roofs, roads, parking lots, sidewalks, etc., and describes these collectively with the term "Smart Surfaces."

Smart Surfaces are surfaces that more effectively manage urban heat and flooding/water runoff, such as reflective, green, and porous, surfaces, trees, and solar PV.[xxiv] Though each of these individual surfaces provide unique value on their own, Smart Surfaces are better viewed as a solution set, where the combination of these different surfaces yields much improved efficiency and cost-effectiveness. For example, solar PV, when combined with a green roof, will produce energy more efficiently while the roof simultaneously improves air quality and acts as a ballast to hold the panels in place.

1.5.2 Smart Surfaces analyzed

This report analyzes different Smart Surfaces and their impact on temperature reduction, job creation, and emissions reduction as well as on the net present value and benefit-cost ratio associated with investment.

The Smart Surfaces of focus include reflective (cool) roofs, reflective pavements for parking lots and roads, solar PV, trees, and combinations of these surfaces.

1.6 Summary of benefits of Smart Surfaces

Smart Surfaces can benefit Stockton in multiple ways, including reducing extreme summer heat, reducing emissions, creating jobs, improving equity, improving public health, and lowering energy bills.

1.6.1 Heat

Urban areas commonly experience higher temperatures than the surrounding countryside, an effect known as the urban heat island.[xxv] The urban heat island is a function of several factors, including the city's morphology, proximity to water, heat-ejecting devices like air conditioning, the area of dark surfaces, and the area of vegetation. Smart Surfaces, by increasing green space and replacing dark, heat-absorbing surfaces with more reflective ones, can reduce urban heat by several degrees.

With less heat being absorbed into the built infrastructure, the energy demand for buildings goes down, surface life of roofs and pavements are extended, heat related deaths and illnesses will be greatly reduced, and a significant amount of carbon will not be emitted.

California has experienced a series of dangerous heat waves this summer, with record breaking temperatures causing deadly levels of heat exposure.[xxvi] If Californian cities are to mitigate urban heating amid these heat waves, they must do so in an integrated, rapid, and cost-effective way, such as via Smart Surfaces adoption.

1.6.2 Emissions

Smart Surfaces reduce greenhouse gas emissions by reducing energy demand, both directly and indirectly. The former involves Smart Surfaces directly cooling individual buildings through green and cool roofs, or via shading from adjacent trees and the latter mechanism involves Smart Surfaces reducing the city's ambient air temperature. Both mechanisms cool buildings, reducing demand for air conditioning (and therefore electricity) and lowering emissions. The addition of solar PV also allows the building or city to help meet their energy demand without emitting greenhouse gases.

Smart Surfaces also reduce equivalent emissions by increasing the city's albedo (reflectivity). More reflective surfaces mean that more solar radiation is reflected into the atmosphere, which helps counter climate change via a process called negative radiative forcing.

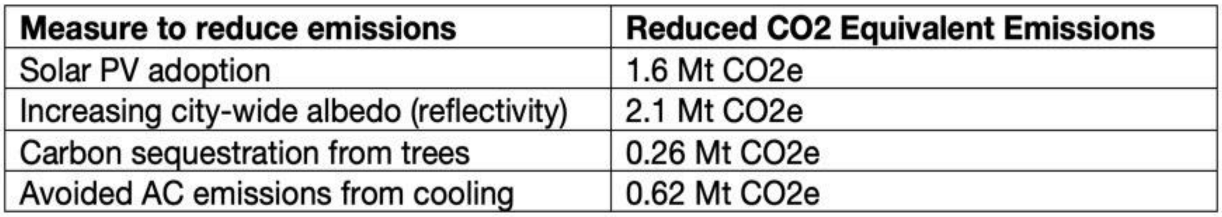
California is taking a lead on reducing emissions globally by setting ambitious climate targets. AB 32, the Global Warming Solutions Act of 2006, required California to reduce GHG emissions to 1990 levels by 2020, which was achieved in 2016, 4 years ahead of schedule.[xxvii] However, the state will "fall short of meeting the 2030 goal" of a 40% reduction in greenhouse gas emissions from 1990 levels by 2030 "unless emissions reductions occur at a faster pace."[xxviii]

By adopting Smart Surfaces state-wide, California can continue to be a leader in decarbonization, meet their climate objectives on time, improve air quality and public health, and advance equity.

1.6.2.1 CO2/GHG equivalent reduction impact for Stockton

As Smart Surfaces are deployed at scale, more and more cities will realize major impacts on health, equity, urban cooling, flood mitigation, jobs, and city-wide resilience. By adopting the host of surface solutions discussed in this report, Stockton can effectively cool itself, increase reflectivity, reduce building energy demand, and reap the many benefits of an expanded tree canopy, which all contribute to a reduction in greenhouse gas emissions for the city.

This report finds that Stockton can avoid a total of 4.58 million tonnes of CO2 equivalent emissions over 30 years. This is a conservative estimate, and only includes emissions reductions impacts from solar PV adoption, carbon sequestration from urban trees, city-wide albedo increase, and reduced air conditioning demand. These impacts are broken down Figure 1.3.



Measure to reduce emissions	Reduced CO2 Equivalent Emissions
Solar PV adoption	1.6 Mt CO2e
Increasing city-wide albedo (reflectivity)	2.1 Mt CO2e
Carbon sequestration from trees	0.26 Mt CO2e
Avoided AC emissions from cooling	0.62 Mt CO2e

Figure 1.3 CO2 equivalent reduction from Smart Surfaces by mechanism

One mechanism by which Smart Surfaces can lower emissions is by reducing the demand for electricity from the grid via solar PV adoption. This clean, non-carbon emitting energy generation offsets “dirty” energy generated from non-renewable sources like coal and natural gas. To calculate the emissions reductions associated with meeting the defined solar PV adoption goals, we assume that Stockton would implement solar linearly each year to reach its 20-year adoption goal, and that the emissions intensity of California’s grid would decline 3% per year. Data on current emissions from California’s electricity grid was derived from the California Air Resources Board.[xxix]

To calculate the emissions reduction associated with reduced air conditioning use, this report uses a model that quantifies the relationship between changes in average city-wide temperature during cooling hours and electricity demand.[2] We modeled the AC reduction associated with 1.45°F reduction, which is roughly half of the projected downtown summer peak temperature reduction identified in this report, to ensure our results were conservative. Given that in the first few years the cooling benefits of urban trees and cool roofs would be

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[2] Cooling hours are all periods of the day where AC is used to cool buildings, which is assumed to be temperatures over 67°F.

less significant (due to less implementation and trees being in earlier stage of development), we did not model the emissions reduction impact of cooling through the first 10 years. To include savings related to direct cooling (e.g. light bounces off a reflective roof, thereby cooling a building), we assume that direct energy savings outweigh indirect energy savings by a ratio of 3:1; this ratio was documented in the Smart Surfaces for Baltimore report. We again assume that the California grid's emissions intensity will decline 3% each year. This report conservatively estimates the carbon equivalent emissions reduction impact of reduced AC demand to be 615,000 tonnes.

To calculate the emissions reductions associated with increasing city-wide albedo, this report uses Akbari et al. (2009) and Menon et al. (2010).[xxx]

To calculate carbon sequestration from urban trees, we use the i-Tree Planting Calculator.[xxxi] We input a blend of four tree species approved in Stockton's tree inventory, assumed half the trees needed will be planted in year 1 and the other half in year 20 to essentially average out planting throughout the 30-year analysis, and presumed that urban trees in "excellent condition" will experience 10% mortality. This target scenario yields roughly 336,000 Mt CO2e reduced over 30 years. When we use a similar, more conservative set of inputs, which models urban trees in "good condition" and with an expected 15% mortality rate, we estimate that 176,000 MT CO2e will be reduced from sequestration. Therefore, carbon sequestration from trees in Stockton will range between 176,000 and 336,000 MT CO2e over 30 years. For simplicity, this report assumes the average of the range, which is 256,000 MT CO2e reduced.

There are several other mechanisms by which Smart Surfaces can reduce emissions that are not modeled in this report. For example, cooler summer temperatures and more greenery can lead to an increase in non-car commuting. Smart Surfaces also lower temperature during the hottest times of the day when the grid is the dirtiest. Due to lack of available data, these emissions reduction impacts were not included.

Adopting Smart Surfaces would enable Californian cities to critically reduce their CO2/ GHG equivalent emissions and save residents and businesses money on energy bills.

1.6.3 Jobs

In January 2021, the unemployment rate in Stockton was 10%[xxxii] while the national unemployment rate in the same month was 6.3%.[xxxiii] Smart Surfaces can reduce the city's unemployment level because installing a number of these surfaces are labor intensive and provide good jobs. Investments in Smart Surfaces, such as planting trees, resurfacing roads, coating roofs in reflective materials, or installing green roofs or solar panels, create more jobs than installing and managing conventional surfaces like black asphalt.

Smart Surface jobs are also more distributed and typically pay above average wages, at over $15/hour. According to U.S. News & World Report, solar photovoltaic installers made a median salary of $44,890 in 2019.[xxxiv] According to the same analysis, the median salary for painters is $40,280. In the US, tree planters make an average salary of $32,803 per year, equal to $16 per hour.[xxxv] A recent Federal study found that employees in the renewable energy sector earned an average of $48,000 annually, equal to an hourly wage of $23.89.[xxxvi] This is above the national median hourly wage of $19.14 (in 2019), equal to an annual salary of $38,000.

Shifting funding in Stockton to Smart Surfaces would create significant jobs on a net basis. The number of jobs created from different Smart Surfaces varies, as discussed later in this report, but Smart Surfaces are on average three times as job intensive as the economy.[xxxvii]

This report finds that Smart Surfaces adoption could create 817 full time jobs (see section 1.2.2.2) over the 30-year analysis period. According to our modeling, about 778 full time jobs will be created in the first 20 years of adoption whereas only about 5% of jobs will be created in years 20 to 30 (39 full time jobs).

1.6.4 Equity

Smart Surfaces are an essential, cost-effective environmental justice solution. The largest cooling, health, and air quality benefits accrue in low-income and minority neighborhoods where there is typically less tree cover and green space, and more dark, impervious surfaces. Our past studies have shown that lower-income areas of cities are often 10°F hotter on summer days than wealthier, tree-lined areas of the same city. Lower-income areas of cities, in addition to experiencing higher temperatures, often experience more frequent and severe flooding, worse air quality, and higher energy burdens.

There is a strong correlation between urban heat and a lower socioeconomic status, brought about by a history of redlining, underinvestment in green space, and lack of tree planting.[xxxviii] This trend is no different in California either as previous studies show low-income neighborhoods in Southern California can be on average 7°F warmer than higher income communities.[xxxix]

These are negative impacts, exacerbated by dark, impervious surfaces, and deploying Smart Surfaces can help redress longstanding structural inequalities that have jeopardized the upward mobility of much of urban America. Investing in Smart Surfaces can keep communities of color and low-income neighborhoods safer from potentially deadly temperatures.[xl]

1.6.5 Health

Smart Surfaces improve public health in myriad ways. Green Smart Surfaces, such as green roofs and urban trees, directly capture particulate matter, an air pollutant that causes respiratory issues. Reflective Smart Surfaces cool buildings and city-air, reducing the demand for air conditioning and the need to run nearby power plants, which also emit air-polluting particulates. Air pollution, among other factors, can also cause or worsen asthma symptoms. One study from the Asthma and Allergy Foundation of America showed that adults were more likely to visit the emergency room for asthma-related breathing issues when summer air pollution was high. Another study from the same organization even found that young people were 40% more likely to have acute asthma episodes during high pollution summer days.[xli] According to a recent study from Toronto, green space structures can protect those aged 0–19 years from high risk of developing asthma and protect older city residents from worsening their asthma conditions.[xlii]The cooling effect of Smart Surfaces also reduces urban smog, which causes additional health issues, as well as reduces extreme summer heat, which exacerbates a variety of existing health conditions and causes fatalities in of itself.

Perhaps most significantly, Smart Surfaces make communities more livable. More walkable, livable communities bring people outside, enabling more active lifestyles and preventing a whole range of health issues. There are also large benefits for mental health of Smart Surface adoption. The presence of trees, green walls and roofs, and open green space for community engagement all have been shown to contribute to a reduction in psychiatric disorders for children.[xliii] Smart Surfaces adoption in a city like Stockton can improve the physical as well as mental health of its residents.

The American Lung Association maintains a list of cities and towns with the worst air quality, rating 25 cities in three categories: ozone, year-round particle pollution, and short-term particle pollution. In 2019, Californian cities were collectively listed as the worst air in all three categories.[xliv] Smart Surfaces adoption in California would greatly improve air quality, support outdoors activity, reduce temperatures, and mitigate the health impacts of flooding, all while improving public health across the state.

This report quantifies the impact of reduced ozone, PM2.5, and heat related mortality and morbidity, but does not include other metrics like decreased hospital visits due to lack of data, effective studies, and a limited budget.

1.6.6 Energy

Smart Surfaces save city residents money because they reduce energy bills. Reflective and cool roofs as well as urban trees directly cool individual buildings, reducing the demand for AC and other plug-in cooling methods like fans. Smart Surfaces cool buildings, thereby saving building operators and homeowners money on energy bills. This would also decrease energy burdens in low-income areas, which would enable underserved families to use more of their income for other vital expenditures.

Smart Surfaces, when deployed at scale, could also reduce city-wide ambient temperature, further decreasing the need for air conditioning. Preliminary modeling of Smart Surfaces for Stockton shows that residents would save tens of millions of dollars on lower energy bills annually, likely amounting to hundreds of dollars saved per resident per year.

A recent report from UC Berkley's Haas School of Business found that Californians are paying two to three times more for electricity than it costs utilities to provide, which could push customers to use appliances powered by fossil fuels instead.[xlv] Rates are expected to grow over the next decade, incentivizing reduced electricity consumption, despite knowing that greater electrification will reduce pollution and other emissions. Smart Surfaces adoption can greatly reduce electricity costs for residents and businesses by reducing a building's energy demand.

1.7 Why Smart Surfaces now?

In nearly all Californian cities, future objectives include better livability, enhanced water and air quality, environmental justice, increased employment, greater attractiveness for tourism, expansion of good jobs, and reducing its contribution to climate change. Smart Surfaces can play a major role in enabling Stockton and other cities in the state to achieve these multiple objectives cost-effectively.

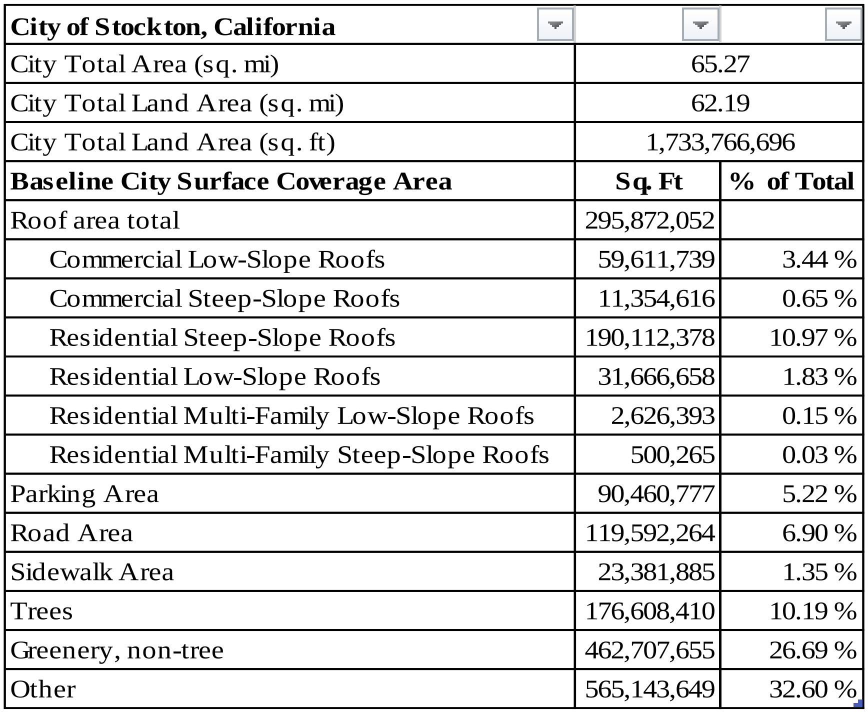
Smart Surfaces can mitigate rapidly mounting climate risks, thereby protecting the economy. Smart Surfaces are well-proven and widely available solutions, and if deployed city-wide would make a city like Stockton cooler, more livable and financially stronger despite climate change. In contrast, business as usual (dark, impervious surfaces) is a far riskier and much more financially fraught pathway.

There is a compelling financial, ethical, and risk-based case for rapid adoption of Smart Surface solutions city-wide as the standard, baseline city policy.

2 Background on Stockton

2.1 Current surface cover

The Coalition uses an array of algorithms to analyze satellite imagery of the city to estimate the areas of city baseline surfaces to establish where, how much, and what type of Smart Surfaces can reasonably be adopted in a given timeframe. This allows for cost-benefit analysis to be conducted on a per square foot basis, using city-specific goals. Figure 2.1 below shows the breakdown of surface area in Stockton.



City of Stockton, California		
City Total Area (sq. mi)	65.27	
City Total Land Area (sq. mi)	62.19	
City Total Land Area (sq. ft)	1,733,766,696	
Baseline City Surface Coverage Area	**Sq. Ft**	**% of Total**
Roof area total	295,872,052	
Commercial Low-Slope Roofs	59,611,739	3.44 %
Commercial Steep-Slope Roofs	11,354,616	0.65 %
Residential Steep-Slope Roofs	190,112,378	10.97 %
Residential Low-Slope Roofs	31,666,658	1.83 %
Residential Multi-Family Low-Slope Roofs	2,626,393	0.15 %
Residential Multi-Family Steep-Slope Roofs	500,265	0.03 %
Parking Area	90,460,777	5.22 %
Road Area	119,592,264	6.90 %
Sidewalk Area	23,381,885	1.35 %
Trees	176,608,410	10.19 %
Greenery, non-tree	462,707,655	26.69 %
Other	565,143,649	32.60 %

Figure 2.1 Surface area in Stockton, California

2.2 Existing sustainability goals

The city of Stockton completed their Climate Action Plan (CAP)[xlvi] in 2014 for the purpose of collecting an inventory of greenhouse gas (GHG) emissions and recommended strategies to prevent future emissions. Under CAP, the city sought to reduce GHG gas emissions by 15% of 2005 levels by 2020, until another target was to be set in FY2021–2022, to reflect the need to address both economic development and climate change. In the plan, the city expanded their urban forestry program to plant 500 new trees per year, which is roughly 0.5% tree canopy increase per year, and 10% increase over 20 years.[xlvii]

In 2018, the city created the 2040 General Plan[xlviii], containing many goals, policies, and actions that address five main topics more broadly: downtowns, public health, environmental justice, air quality, and climate change.

In that same year, Stockton also completed their Sustainable Neighborhood Plan,[xlix] which offered perspectives from the city's residents on what their sustainable framework should look like. 12 goals were formed by prioritizing the input and recommendations of vulnerable populations on the frontlines of climate change. Among these goals were objectives to promote public health and equity, improve air and water quality, strengthen the economy, adapt to climate change, advance the targets of CAP, and promote community resilience and engagement.

Most recently (July 2021), the California Air Resources Board approved a Community Emissions Reduction Program (CERP) under AB617, which will require direct community involvement to identify, monitor and reduce air pollutants of specific corner for the local population.[l]

San Joaquin Valley is also currently in non-attainment of both national and state ambient air quality standards[li] and has put in place an Ozone Attainment Plan[lii] and PM2.5 Attainment Plan,[liii] the goals of which would be furthered by adoption of Smart Surfaces valley-wide.

Adopting the host of policy and surface recommendations in this report would simultaneously allow Stockton to accomplish their climate objectives while creating jobs and garnering city-wide resilience. This would create a healthier, more resilient, equitable, economically viable, and adaptive Stockton.

2.3 Current temperature

Stockton has a moderate climate, with hot, arid summers and cold, cloudy winters. The city gets an average of 257 sunny days per year, compared to the U.S average of 205.[liv] While average daily highs reach roughly 84°F, average summer highs are typically around 93°F. There is also an average of 74.4 "hot days" days where the temperature is above 90°F, per year, making it warmer than most places in California. According to the same data, the most pleasant days, where temperatures are between 70–85°F, are during October, May, and April, all of which fall just before or just after peak tourism season.[lv]

Stockton currently has about 32 days above 90°F and that number is projected to increase to 98 days by 2100 if emissions are not cut moderately. By 2050, Stockton is projected to have 62 days above 95°F.[lvi] Current temperature projections highlight the need for heat mitigation to support community resilience, improve public health, and advance equity.

2.4 Current energy use

California is regarded as a leader in energy efficiency. In fact, it is ranked as the third lowest state in terms of energy use per capita, which is roughly 197 million Btu per person, much less than the average per capita consumption rate in the U.S of 348.7 million Btu.[lvii] Two thirds of all homes in California have air conditioners, which results in 585 million metric tons of CO2 to be released in the atmosphere every year.[lviii] Though AC use in Stockton is not well documented, the city's energy use is on par with that of California. San Joaquin County residents collectively consumed nearly 1.9 million kilowatts of electricity in 2019.[lix]

Stockton's electricity rates are even with average rates in California, apart from the industrial sector. Commercial electricity in Stockton is about $14.08 ¢/kWh compared to the state average of 13.41¢/kWh and residential electricity has a rate of 15.59¢/kWh compared to the state average of 15.34¢/kWh, only a 5% and 1% increase in price respectively. However, the average industrial rate in Stockton is 8.98¢/kWh compared to California's average of 10.49¢/kWh, which is 14.39% cheaper of a rate.[lx] The cheaper industrial rates likely reflect the high levels of production and scale of electricity in the industrial sector.

Though AC use in Stockton has not been effectively researched and reported on, the city's AC use can be approximated because it is in a hot- and mixed-dry climate. As of 2015, the households in cities and towns within that climate zone, such as most of California, parts of Arizona, New Mexico, and West Texas, have an average AC expenditure of 17%.[lxi] Smart Surfaces adoption can reduce AC use, cut emissions from summertime cooling, and save Stockton's residents money.

2.5 Managing sun in Stockton

Like many cities in California, Stockton, in a hot-summer Mediterranean climate, suffers from extreme heat. The overwhelming presence of dark, impervious surfaces absorb most of the heat into the built environment and makes cities even hotter.[lxii]

The hottest days in Stockton range from early June to late September with average daily high temperatures above 86°F.[lxiii] According to Weather Spark's tourism score, the best time to visit is between June and September, which are the hottest days of the year. As climate change leads to more intense, regular summer heat waves, summer tourism across the country will be impacted. The Los Angeles Times notes that heat disproportionately affects elderly people and those with preexisting health conditions, which means that with malls, libraries, movie theatres, and mostly all air-conditioned public spaces being closed from the COVID-19 pandemic, people are less inclined to leave their homes for public attractions and tourist destinations.[lxiv] In Europe, research shows that heat is already a factor drives tourists away from certain destinations.[lxv]

Recent heat waves have caused the city to already begin to think about measures to ensure the safety of residents when temperatures surge. In July, Stockton opened cooling zones for residents to escape the heat.[lxvi] While opening cooling zones is a temporary heat adaptation solution, Stockton will need to think about long-term, holistic solutions to reduce urban heat so that residents can be healthier and safer, especially in lower-income communities.

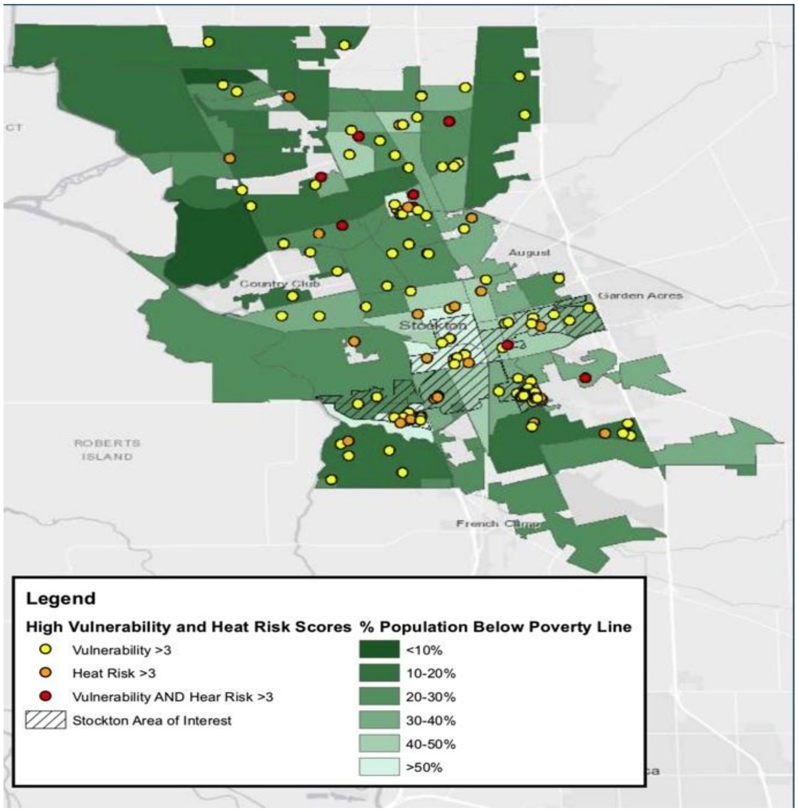


Figure 2.2 Overlay map of income distribution, heat risk, and house vulnerability risk[lxvii]

Figure 2.2 shows that low-income communities face the largest threats of extreme heat in Stockton. The household vulnerability score represents residents of disabled, senior, Hispanic, African American, low-income, and non-English speaking households, while the heat risk score is based off a home's access to air conditioning, shade, and other cooling sources. Low-income communities often have less green space and tree cover, with more dark, impervious surfaces, making them much hotter than surrounding areas.[lxviii] The figure reflects the direct correlation between heat and income distribution in most cities in the U.S.

In the San Joaquin County Local Hazard Mitigation Plan of 2017, heat was identified as a major source of health problems for residents and the county continually recognizes the need to couple new development with greening methods and other measures that reduce the urban heat island.[lxix] Many Californian cities already issue heat warnings when necessary and have trained professionals at hospitals who can assist over the phone and in person with heat-specific hospitalizations. While heat warnings and other small measures are again temporary solutions to avoid urban heat, Smart Surfaces adoption is a cost-effective solution that can cool cities, both in the short and long term.

2.6 Managing rain in Stockton

The climate in Stockton is moderate, with hot, arid, and mostly clear summers coupled with short, cold, and cloudy winters. The wetter season, in which there is greater than a 14%

chance everyday of it being a wet day (at least 0.04 inches of liquid precipitation), lasts 5.1 months between November and April, accounting for 80% of total precipitation.[lxx] Between the months of May to September, there is very little rainfall, but during the wet season, Stockton is severely prone to flooding. For instance, San Joaquin County, where Stockton is located, has annual flood damages of roughly $11.8 million and the number of properties at risk is projected to increase dramatically over the next 30 years.[lxxi] There are currently approximately 137,945 properties already at risk of flooding.[lxxii] Following a storm in January, unrelentless rain toppled several trees, which led city residents to complain about the lack of preparedness before the storm hit.[lxxiii]

Since Stockton gets all its rain at once in a shorter season, the intense sudden flooding can cause the city to both lose a significant amount of money on rebuilding infrastructure and jeopardize the safety and livelihood of its residents.

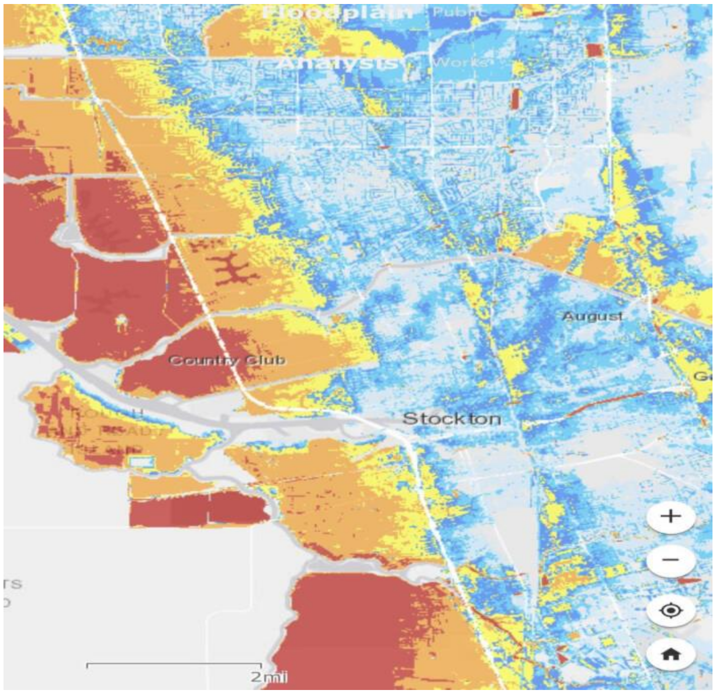


Figure 2.3 Stockton flood danger map[lxxiv]

Figure 2.3 highlights the urgency of flood mitigation measures Stockton needs to take if it is to remain protected from nearby waterways and storm surge. However, most flooding in Stockton is the result of overflowing rivers and waterways as opposed to from rainfall. Since Smart Surfaces are more effective in addressing rain runoff and catching the first few inches of flooding, surfaces such as porous pavements, trees, and bioswales likely won't be preferred solutions for fully mitigating flooding in Stockton. As a result, this report focusses more on heat mitigation, but flood control measures will be further analyzed in future reports.

3 A review of climate policy in California

The State of California has established itself as a leader in sustainability and combating climate change in the United States. Particularly, California has created one of the most comprehensive and responsive climate landscapes in the world, as seen in achieving the goal of Assembly Bill (AB) 32 Global Warming Solutions Act of 2006, which sought to reduce emissions to 1990 levels by 2020, 4 years ahead of schedule in 2016.[lxxv] The ambitious climate policy goals passed by the State of California set the standard for the decisions that local project developers and managers carry out to actively achieve the State's goals around health, heat, risk reduction, equity, worker safety, flood mitigation, and economic performance.

California has a multitude of different climate programs (Cap and Trade, Green Building Standards, GHG Emission Inventory, 60% Renewable Portfolio Standard by 2030, etc.), regulating authorities (California Energy Commission, Air Resources Board, State Transportation Agency, Strategic Growth Council, CalRecyle, etc.), and ambitious climate policies that guide state action.[lxxvi] Moreover, so far, 49 cities and counting in California have adopted building codes that reduce their reliance on gas and support energy efficient design.[lxxvii] California even organized the Global Climate Action Summit in 2018 to gather leaders of all expertise for a call to climate action.[lxxviii]

However, an audit from the California Air Resources Board estimated that the State will fall short of meeting the 2030 goal of a 40% reduction in greenhouse gas emissions from 1990 levels by 2030 "unless emissions reductions occur at a faster pace."[lxxix] Even with statewide support for climate action, ambitious targets set by policymakers, a position as a leader in sustainability, and with an abundance of climate regulators, California still needs to think creatively and holistically to address risk, equity, health, heating, flooding, and the other issues outlined in their climate targets cost-effectively.

Retaining its position as a global climate leader means California must move faster to electrify buildings and decarbonize large industry than other states. By adopting Smart Surfaces state-wide, California can continue to be a leader in decarbonization, meet their climate objectives on time, improve air quality and public health, stabilize the grid, and advance equity, all doing so cost-effectively.

To ensure that California's resources are allocated most effectively, State policies must include "Smart Surfaces" (surfaces that better manage heat and rain runoff) into their legislation to influence the decisions of local project managers and city agencies that handle infrastructure decisions. Without a clear definition of Smart Surfaces, cities will revert to the traditional strategies of deploying surfaces with the lowest initial/first cost such as dark, impervious surfaces for these projects. City departments must work together to consider the wide array of benefits of adopting greener, more reflective, and more porous surfaces, such as extensions of surface life, improvement of public health and air quality, reduction of extreme heat in underserved communities, and overall improvement of the livelihood of Californians struggling to combat extreme heat. We cannot repeat the same mistakes when developing projects to address and improve the climate and livability of California. We know this, and Californians are tired of experiencing this every day.

4 Summary of Smart Surfaces analyzed

4.1 Reflective surfaces

Reflective Smart Surfaces include cool roofs, roads, and parking lots.

4.1.1 Cool roofs

Cool roofs have higher solar reflectance (often called albedo) than conventional dark roofs, which have a low solar reflectance. Solar reflectance, or albedo, indicates the fraction of solar energy that an object reflects. It ranges from 0 to 1, with 0 meaning an object reflects no solar energy and 1 meaning an object reflects all solar energy. (High albedo helps keep the areas such snow or ice cool). Because of their higher solar reflectance, cool roofs reflect more sunlight and absorb less solar radiation than conventional, dark roofs. This means that cool roofs do not get as hot, reducing heat transfer to the building below and to the urban environment.

Cool roofs typically reflect most of the solar radiation that reaches their surface—much of which is reflected into space—and thus remain cooler throughout the day while reducing global warming. In contrast, dark roofs absorb most of the solar radiation, and their surface gets much hotter than that of a cool roof.

4.1.1.1 Costs of cool roofs

Cool roof installation and maintenance costs presented in this report are based on recent literature and on guidance from roofing professionals.[lxxx] Roof replacement, rather than restoration, is the norm when a roof needs repair.[lxxxi] Low slope cool roofs have been around long enough that they typically are the same or only marginally higher cost than their conventional equivalent.[lxxxii]

Based on literature review and industry discussions, we assume a cost per square foot of $0.23 for low slope cool roofs and $0.83 for steep slow cool roofs. There is typically a higher cost premium for steep slope cool roofs. Maintenance requirements for cool roofs are like those for conventional roofs, but cool roofs can be washed to maintain a higher albedo. There are two cleaning options for cool roofs: power washing and mop cleaning (or equivalent) to restore the albedo of a surface.

4.1.1.2 Benefits of cool roofs

The surface temperature of a cool roof is lower than that of a conventional roof, which means that less heat is transferred to the building and to the air above. This means that a building with a cool roof requires less energy for cooling in the summer but can require somewhat more energy for heating in the winter. However, since there is a lower sun position and shorter days in the winter, the reduced solar heat gain in the winter (called the "heating penalty") is still less than the cooling energy saving. If Stockton made the switch from conventional, dark roofs to cool roofs, there would be a substantial impact on urban summer air temperature, leading to city-wide net energy savings. This report assumes a benefit per square foot assumption of $4.24 for commercial low slope cool roofs and $0.77 for residential steep slope cool roofs.

The major benefits of cool roofs include ambient cooling, reduced energy use for cooling, reduced greenhouse gas emissions and global cooling, improved air quality, extended surface life (due to less thermal expansion and contraction) and reduced heat-related mortality. Other benefits include potential downwind cooling, and reduced stormwater runoff temperature.

4.1.1.3 Adoption of cool roofs

This report assumes that 70% of available roofs would be a cool roof. Cool roof adoption in Stockton would have roughly a 17:1 benefit-cost ratio for low slope roofs, but a benefit-cost ratio of 0.9:1 for steep slope roofs. Despite steep slope cool roofs having a negative net present value, these surfaces greatly cool the city and its residents, preventing risk of heat related illnesses and death. When factoring in the ambient air temperature reduction, reduced hospital visits from overheating, and other health impacts of steep slope cool roofs, the benefits far outweigh the costs. Since many of these assumptions are left out due to complexity, this estimate is conservative. Cool roofs provide a significant return on investment for the city, while reducing energy bills, cutting greenhouse gas emissions, improving air quality and public health.

Although cool roofs have been successfully used for years, there can be problems with moisture such as ponding or mold build up. However, Stockton and most of California is in the third climate zone, which as the Department of Energy notes, is a zone where cool roofs are recommended most strongly.[lxxxiii] Due to a hotter, more arid climate, Californian cities and towns are well suited for the adoption of cool roofs, especially as summers continue to get hotter.

4.1.2 Reflective roads/ parking

Reflective roads or pavements work like reflective (cool) roofs. They have a higher solar reflectance than conventional pavements meaning that they reflect more solar energy, reducing the amount of heat gain and reducing urban surface temperatures. As with cool roofs, some of the reflected solar energy is reflected to space, helping to slow climate change. Reflected solar energy may also impact nearby buildings and pedestrians.

The most cost-effective way to increase existing road and parking lot reflectivity is through surface treatments or overlays, essentially adding a thin reflective layer to the existing pavement surface.[lxxxiv] This is because the better that application of reflective pavements can fit into existing pavement installation and maintenance practices, the less expensive reflective pavements are, and the more likely they are to be adopted at scale. Thinner pavement layers are also less expensive because they require less material.[lxxxv] This report focuses on changing the albedo of only the pavement layer exposed to the sun. For pavements that support car traffic (i.e., roads and parking lots) this means applying surface treatments to increase albedo.

4.1.2.1 Costs of reflective roads/ parking

This report focusses on reflective surface treatments–essentially changing the reflectivity of the topmost pavement layer when it is already scheduled and budgeted for resurfacing.

The standard, conventional preservation surface treatment for a street or parking lot is a slurry seal, which is a traditional dark pavement coating used for maintenance. During each instance of preservation, this analysis assumes the added cost of a cool pavement coating is the difference in cost between the unit costs of the cool pavement coating and the standard dark surface coating like a slurry seal, chip seal, or fog seal (i.e., $0.20 per square yard, $0.02 per square foot). This makes sense because the city would be applying a dark pavement coating for maintenance regardless of reflectivity, so it will only pay for the extra cost, or the cost premium, of the reflective layer. This report assumes a $0.32 cost per square foot assumption for reflective roads and $0.45 for reflective parking.

Maintenance consists of minor repairs and can happen as often as annually or biannually. Maintenance also includes preservation techniques. Surface treatments are a common preservation technique for asphalt pavements and include techniques like chip seals, asphalt emulsion sealcoats, slurry seals, fog seal, and bituminous crack sealants.[lxxxvi]

4.1.2.2 Benefits of reflective roads/ parking

Since conventional surfaces like black asphalt expand during the day and contract at night, they often have reduced surface lives from cracking whereas reflective roads can have roughly a 20-40% surface life extension.[lxxxvii] Reflective roads or reflective surface coatings do not face this problem because they absorb much less of incoming radiation. This report assumes a benefit per square foot of $0.93 for reflective roads and $1.05 for reflective parking.

The major benefits of reflective pavements include ambient cooling, reduced cooling energy use, reduced greenhouse gas emissions, global cooling, and improved air quality and reduced heat-related mortality. Other benefits include a potential increase in pavement life, reduced street lighting requirements, downwind cooling, and reduced stormwater runoff temperature.

4.1.2.3 Adoption of reflective roads/ parking (Stockton specific)

Reflective roads, like cool roofs, have a substantial benefit-cost ratio of roughly 2:9:1 and reflective parking has benefit-cost ratio of roughly 2.3:1, both of which would greatly extend the surface life of pavements and provide other health and economic benefits. This report assumes that 50% of parking and 5% of road coverage would have a reflective coating on the surface. In other California cities, research shows that raising the albedo of all paved surfaces can reduce outdoor summertime air temperature in California cities by about 0.2 to 0.9°F depending on the city.[lxxxviii] The installation of reflective pavements has been quite effective in other California cities like Berkeley, Elk Grove, and Davis because they can be 5-20°F cooler than conventional pavements.[lxxxix] Stockton would significantly benefit from reflective pavements as a long- and short-term solution for urban heat and associated health risks.

4.2 Solar PV

Solar PV converts sunlight into electricity. Combined with an inverter and other hardware (e.g., racking), solar PV panels provide electricity to the grid or to homes and buildings and offset electricity purchases from the grid.

There are three commonly cited PV sectors: residential, commercial, and utility scale. Utility-scale consists of large-scale PV power plants and is typically the least expensive on a unit basis due to economies of scale. Commercial and residential PV are considered distributed generation, meaning they produce electricity at the point of consumption, reducing line losses and providing shading to roofs. Distributed generation is typically located on rooftops (especially in cities where land is expensive), while utility-scale is typically ground-mounted and generally not near the point of consumption. This report focuses on PV on buildings.

This report assumes that all solar PV is third party financed considering the readily available financial services that enable cheap and less risky system install around the country, and specifically in California.

4.2.1 Costs of solar PV

The standard measure for estimating PV system install cost is cost per watt. The costs to install a system have come down dramatically in the last decade and are expected to continue to fall. This report assumes a cost per square foot over 20 years of $0.51 for residential low and steep slope, commercial low and steep slope, and for multifamily and single-family homes.

Because we are assuming all new solar in Stockton is third-party financed, the first ten years of electricity generation benefits accrue to the financier, and only the last 20 years of electricity generation accrue to the residential or commercial property.

Accounting for trends in PV durability and longevity improvements, this report assumes a system life of 30 years for direct purchase PV systems with 20% PV efficiency.

4.2.2 Benefits of solar PV

Deploying solar PV on one building would generate electricity and thus reduce its energy demand. The use of solar PV would thus reduce greenhouse gas emissions and improve air quality, thereby allowing a city to meet their climate objectives. This report assumes a benefit per square foot of $20.28 for steep slope residential surfaces and $15.70 for low slope commercial surfaces.

Solar panels can also provide shading benefits for pedestrians and public spaces. They can also contribute to a greater reduction of the urban heat island because the heat is being conducted away from roof. A modeling study of the sensible heat flux from black roofs, white roofs, green roofs, and these three roof types with added PV panels found that putting PV panels on black roofs slightly reduces the contribution of black roofs to the UHI because total heat conduction away from the roof decreases.[xc]

4.2.3 Adoption of solar PV (Stockton-specific)

Solar PV adoption in Stockton would be quite valuable in reducing emissions, improving air quality, and cutting energy bills. This report assumes that 25% of viable roof options for panels use solar PV and the Stockton cost-benefit analytic calculator allows the user to alter the amount of direct versus third party purchasing agreements. California is by far the state with the most solar capacity and production with over 21,000 megawatts (MW) of installed solar capacity; the next top state is North Carolina at just over 4,300 MW of capacity installed.[xci] Californian cities are well situated to adopt solar PV across municipalities and can create value for residents, businesses, and the government alike. The benefit-cost ratio for Solar PV in Stockton can range between 29.5:1 and 35.6:1 for low and steep slope roofs respectively, assuming all solar is third party financed.

4.3 Urban trees

Urban trees provide direct and indirect benefits. Direct benefits include energy savings due to shading of adjacent buildings and windbreak. Urban trees also sequester CO2, remove harmful pollutants from the air, and reduce stormwater runoff. Indirect benefits of urban trees include ambient cooling through evapotranspiration and shading (which reduces cooling energy use city-wide), reduced ambient ozone concentrations and related health costs, and heat-related mortality. Urban trees also indirectly achieve pollution reductions (e.g., CO2, ozone precursors, PM2.5 and PM2.5 precursors) by reducing demand for electricity. Akbari et al., EPA, and Casey Trees provide excellent descriptions of the benefits of urban trees.[xcii] Potential drawbacks are relatively small and include potential in some circumstances for increased humidity, increased emissions of biological volatile organic compounds, increased heating needs due to winter shading, and increased pollen production (increasing contribution to allergies).

4.3.1 Costs of urban trees

The initial cost of planting a tree includes purchasing the tree and the cost of planting. There is a wide range of estimates for tree planting costs. For Stockton, this report assumes $283 per tree, based on discussions with American Forests, TPL, Casey Trees, and the US Forest Service. In addition, we assume 2% of new trees planted will not survive and need to be replaced. There are also costs for maintaining trees including pruning, pest and disease control, irrigation, program administration, liability issues, root damage repair (e.g., to sidewalks), and stump removal.[xciii] A regional summary of the costs and benefits of trees by the U.S. Forest Service, and discussion with American Forests and Casey Trees, leads this report to assume maintenance costs for trees in Baltimore of $0.47 per square foot of tree canopy per year. This report assumes a cost per square foot of $2.01 for urban trees.

4.3.2 Benefits of urban trees

Major benefits from urban trees include ambient cooling, reduced energy use due to lower need for building cooling, reduced greenhouse gas emissions and global cooling, improved air quality, reduced heat-related mortality, and reduced stormwater runoff. Other benefits include downwind cooling, reduced stormwater runoff temperature, increased property value and aesthetic value, and increased biodiversity. This report assumes a benefit per square foot of $5.28.

4.3.3 Adoption of urban trees (Stockton-specific)

Urban trees provide a lot of value for a city and many of the external benefits to physical and mental well-being, hospital recovery times, and work productivity are not quantified or valued. In California, the hot dry climate means that urban trees are not as effective as other moister climates. The benefit-cost ratio for trees is roughly 2.6:1, and as a result this report only assumes a 10% absolute increase of Stockton's urban tree canopy. The city plants around 2,500 trees per year and the recently adopted 2040 general plan calls for an increase of that number by about 500-900 trees annually.[xciv] Considering nonprofits and community groups also engage in tree planting programs, the 10% absolute increase of tree cover is a conservative target.[xcv] Trees provide shade, sequester carbon, look aesthetically pleasing, and can contribute to a reduction in the amount of stormwater runoff and pollutants that reach local waters to a certain degree. Though urban trees are not most effective in Stockton year-round, they are still beneficial and provide great value for a city in terms of health, air quality, heat, aesthetics, flooding, and jobs.

4.4 Smart Surfaces not quantified in this report

4.4.1 Porous/permeable surfaces

Permeable pavements are pervious surfaces that allow for stormwater infiltration and storage, as compared to conventional, impervious surfaces. Porous surfaces can be either permeable surfaces or impermeable surfaces with added drainage capacity such as a parking lot that drains into adjacent bioretention areas or a tree trench that manages stormwater runoff.

Permeable pavements can reduce the total and peak stormwater runoff volumes by more slowly conveying water to conventional stormwater systems. This is done by allowing stormwater to gradually infiltrate the soil below the pavement, and marginally through evaporation of water from the surface layer of the pavement. It is worth noting that pervious pavement often requires a different base than what's used in standard road or parking lot construction to enable infiltration of water without damaging the subsurface. There can be considerable subsurface costs to converting an existing road or parking lot to one that is pervious.

Major benefits of permeable surfaces include reduced stormwater runoff and flooding and reduced salt use due to less ice buildup. Other impacts which warrant further study include ambient cooling, which leads to reduced cooling energy use, reduced greenhouse gas emissions, improved air quality and reduced heat-related mortality, increased thermal comfort, and improved water quality. Though porous surfaces would help reduce flooding in Stockton's rainy season, it can be costly considering that most rainfall only comes in one season and flooding is typically the result of waterway overflow as opposed to rain runoff. Stockton gets only 17 inches of rainfall annually compared to the average city in the U.S, which gets around 38 inches.[xcvi] Therefore, for this report we assume no permeable surface increase.

Stockton is at flood risk from sea level rise, which means pervious surfaces—e.g., ground water recharge to slow settling—along with additional water flooding management should be part of a larger analysis.

4.4.2 Bioswale-managed roofs and parking

Bioswales, bio retaining parking lots or roofs, and rain gardens can manage stormwater runoff from adjacent roofs or parking lots. Often found along curbs and in parking lots, bioswales use vegetation or mulch to slow and filter stormwater flows.[xcvii]A small area of bioswale or tree trench can manage the water runoff of a much larger hard surface. Benefits of bioswale managed roofs and parking lots include stormwater retention, improved air quality, biodiversity, and aesthetic value.

These surfaces, though greatly impactful for stormwater runoff, are not calculated in this report due to limited rainfall for much of the year but will be quantified and modeled in future reports.

4.4.3 Urban meadows

Urban meadows are natural, self-sustaining ecosystems that add greenery to a dense, urban landscape. Much of traditional landscapes or greenery in urban areas relies heavily on maintenance of plants,[xcviii] but urban meadows are composed of plants best suited for rainfall patterns, temperatures, drainage patters, sunlight, wind, and soil of the area. If vacant lots, packed dirt, old homes, or any area of a city not being used can turn into urban meadows, residents would benefit significantly. Some major benefits of urban meadows include improvement of local air quality, biodiversity, aesthetic beauty, and stormwater runoff.[xcix] Not to mention there is potential for community engagement, improvement of wellbeing, and learning opportunities for students. As a study from the Harvard Design Magazine shows, urban meadows require the right seed species, site preparation, seed sowing, and management of the plot every year or half year,[c] which all influence the cost of installation and maintenance as well as the benefits. While urban meadows are a terrific and creative solution for cities to add greenery to a city and improve biodiversity, they are not included in this report for simplicity. Future studies will incorporate these calculations.

4.4.4 Green roofs

Put simply, a green roof is a vegetative layer on a rooftop. More specifically, green roofs typically consist of drainage layer and soil layer on top of conventional roofing and waterproofing systems.[ci]

Major benefits of green roofs include reduced cooling and heating energy use, reduced greenhouse gas emissions, improved air quality and reduced heat-related mortality, reduced stormwater runoff, and reduced water pollution. Other benefits include downwind cooling, reduced stormwater runoff temperature, increased amenity and aesthetic value, and increased biodiversity. Potential drawbacks for some climates include increased humidity.

Though green roofs are beneficial for cities in a variety of ways (I.e., stormwater management, heat mitigation, air quality, etc.), they are not included in this report because they can be costly and when there is very little water for much of the year like in Stockton, it does not make economic sense to adopt this surface regularly. Green roofs are therefore not quantified in this report but could be analyzed in future assessments.

5 Low-income areas and Smart Surfaces

Low-income neighborhoods and communities of color often suffer from an increased presence of dark, impervious surfaces, resulting in higher temperatures, heightened energy burdens, increased health risk, and more pollution.

5.1 Urban heat island effect

Due to the use of lowest first cost, dark, and impervious surfaces as the standard surfacing solutions, Stockton and other cities experience what is called the urban heat island (UHI) effect. The UHI effect results in substantially higher summer temperatures—about 9 degrees F—and worse air pollution in cities than the surrounding suburban and rural areas. Low-income areas tend to have lower coverage of greenery and higher coverage of dark, impervious surfaces. As a result, urban low-income residents suffer disproportionately from the urban heat island effect.

The combination of impervious surfaces, anthropogenic climate change, and the scarcity of heat-ameliorating features such as trees and reflective surfaces results in increasingly dangerous urban summer temperatures.[cii] Asphalt in particular has very high surface temperature, heat storage potential, and heat emission capacity relative to other surfaces.[ciii] These elements contribute to high and rising urban temperatures and hurt lower-income neighborhoods disproportionately.[civ] A study conducted by the University of Maryland and Portland State University highlights the inequitable heat distribution between lower-income and high-income neighborhoods. The study found that formerly redlined areas relative to their non-redlined neighborhoods vary in land surface temperature by as much as 7°C.[cv]

Dark, impervious surfaces impose high nighttime temperatures and associated health risks.[cvi] By implementing more reflective surfaces, less heat is absorbed during the day and re-radiated at night, contributing to nighttime cooling and greatly reducing negative health impacts.

5.2 Health

The damage and cost of increased temperature and air pollution are particularly acute for urban low-income areas. The publication *Environmental Health Perspectives* has noted that, "Substantial scientific evidence gained in the past decade has shown that various aspects of the built environment can have profound, directly measurable effects on both physical and mental health outcomes, particularly adding to the burden of illness among ethnic minority populations and low-income communities."[cvii] Increased green space and gardens has been demonstrated to have a positive correlation with reductions in asthma hospitalization.[cviii]

Healthcare costs pose a significantly larger financial burden on low-income urban residents than higher-income residents, which Smart Surfaces can help redress.

Smart Surfaces are the only viable strategy available to reduce or even reverse climate change and UHI-driven excess urban heat. Utilizing greenspace to reduce heat can also help mitigate heat-related illnesses and heat-related emergency calls—which are most common in low-income areas.[cix] Increasing urban greenspace and cooling streets can also result in increased walking and exercise, yielding health benefits associated with greater physical activity.[cx] If Stockton reshapes its outdoors to make its neighborhoods cooler, less polluted and more shaded, this will increase outdoor activity and exercise, strengthen community and reduce crime. And, as the great Jane Jacobs noted in her seminal book, *The Death and Life of Great American Cities*, having "eyes on the street" is central to making communities safe and vibrant places to raise families and grow strong community. Smart Surfaces results in more "eyes on the street" and enables more active outdoor lives and more vibrant communities. In our analysis, we can quantify many benefits, but we do not yet have data to fully value the creation of more livable, healthy places and communities.

5.3 Address systemic inequity and energy

Energy costs make up a higher percentage of expenses for lower-income residents. Research from the Joint Center for Housing Studies of Harvard University, for example, shows that for the lowest-income renters, tenant-paid household energy costs represent approximately 15% of income, while energy costs make up about 1% of total income for the highest-income renters.[cxi] As a consequence, the impact of energy bill reductions is proportionally far larger for affordable housing properties. Roofs in low-income city areas also generally have low solar reflectance, meaning they absorb most of the sunlight, which greatly increases the heat gain on the top floor of buildings, increasing the risk of heat death—and contributing to higher urban temperatures. In addition, urban low-income residents are more likely to live in areas with no tree canopy and/or greater than 50% impervious area.[cxii]

The September 2020 ACEEE Report[cxiii], "How High Are Household Energy Burdens? An Assessment of National and Metropolitan Energy Burden across the United States," illustrates this disproportionate burden of energy bills on low-income residents and people of color.

The ACEEE report found that "across the 25 municipalities studied, low-income households experience energy burdens at least two times higher than the average household in all cities. In all metro areas studied, Black and Hispanic households experience higher energy burdens than non-Hispanic white households. In addition to the negative physical and mental health outcomes associated with high energy burdens, "households with high energy burdens are more likely to stay caught in cycles of poverty," according to the report.

In addition, low-income schools, neighborhoods, workplaces, and homes are more likely to experience different forms of discomfort and productivity loss due to higher temperatures than wealthier and cooler neighborhoods. A New York Times editorial entitled

“Temperatures Rise, and We’re Cooked” summarizes findings that “students who take New York State Residents exam on a 90-degree day have a 12 percent greater chance of failing than when the temperature is 72 degrees”, and that in auto factories, “a week of six days above 90 degrees reduces production by 8 percent”.[cxiv]

6 Cost-benefit analytic engine walkthrough

The Stockton-specific online cost-benefit analytic engine will allow a user to create scenarios based on adoption of various Smart Surfaces and different Smart Surfaces options. The calculator uses the adoption mix as an input to determine the adoption scenario’s net financial benefit, temperature reduction impact, job years created, and CO2-equivalent reduction.

1 Where
2 When
3 Roofing
4 Parking Lots
5 Streets and Sidewalks
6 Trees

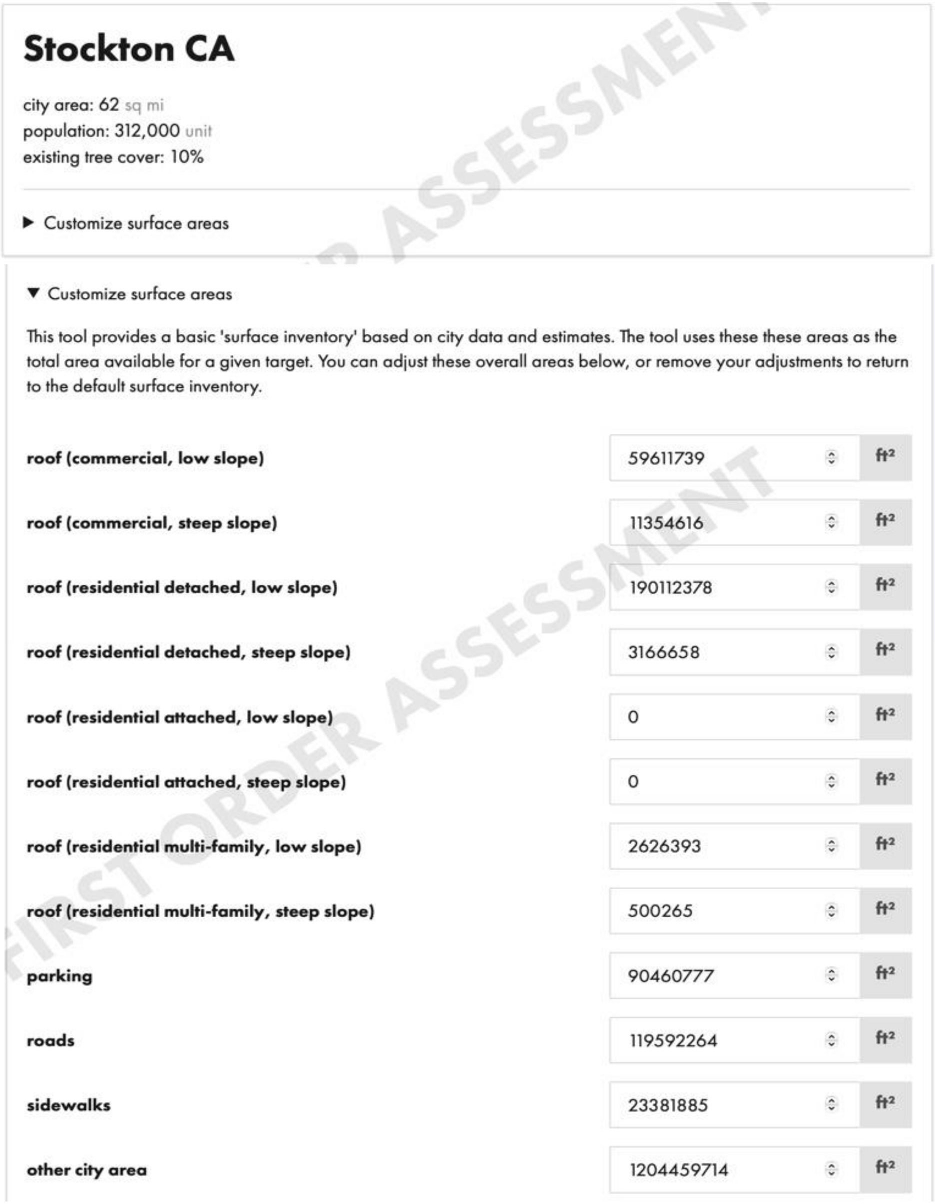
Figure 6.1. The six main categories available to users in the Smart Surfaces Coalition’s online cost-benefit analytic engine.

6.1 Location selection

In the first category titled “where” the engine user will have Stockton pre-selected because the tool was built to run city-wide Smart Surfaces adoption scenarios.

After selecting Stockton as the city of focus, the user has the option to customize surface area assumptions. The tool provides a basic ‘surface inventory’ based on city data and estimates. The tool uses these areas as the total area available for a given target. This calculator has been built using Stockton's existing total surface areas of roofing, paving, and trees; how much of each can potentially be upgraded with smart surface measures; and data about local policies, incentives, population, and climate.

The preliminary/first-order assessment of the net financial costs and benefits are based on comparable figures for El Paso, TX, taken from the Smart Surfaces Coalition's detailed financial model [Delivering Urban Resilience](#).



Stockton CA

city area: 62 sq mi
population: 312,000 unit
existing tree cover: 10%

This tool provides a basic 'surface inventory' based on city data and estimates. The tool uses these these areas as the total area available for a given target. You can adjust these overall areas below, or remove your adjustments to return to the default surface inventory.

roof (commercial, low slope)	59611739	ft²
roof (commercial, steep slope)	11354616	ft²
roof (residential detached, low slope)	190112378	ft²
roof (residential detached, steep slope)	3166658	ft²
roof (residential attached, low slope)	0	ft²
roof (residential attached, steep slope)	0	ft²
roof (residential multi-family, low slope)	2626393	ft²
roof (residential multi-family, steep slope)	500265	ft²
parking	90460777	ft²
roads	119592264	ft²
sidewalks	23381885	ft²
other city area	1204459714	ft²

Figure 6.2. Surface area measured in feet squared for roofs, parking, roads, sidewalks, and other city area that can be adjusted in the cost-benefit tool. Current numbers are based on city data and estimates.

6.2 Time frame selection

The section labeled “when” allows the user to select a time frame for adoption of Smart Surfaces. The overall target areas will be held constant. Estimate the time frame over which you expect the city to be transformed to meet your smart surface targets. The overall target areas will be held constant. As replacement timelines get shorter, the time value of money will mean that all benefits and costs will rise in today's dollars. This also determines how long to account for benefits and costs that accrue annually. The timeline for adoption can also be adjusted manually to select any time frame between 5 and 30 years.

Over 10 years

Achieve your targets by incrementally replacing existing surfaces over 10 years: from 2020 through 2030. Observe their costs and ongoing benefits in 2040.

Over 20 years

Achieve your targets by incrementally replacing existing surfaces over 20 years: from 2020 through 2040. Observe their costs and ongoing benefits in 2050.

Over 30 years

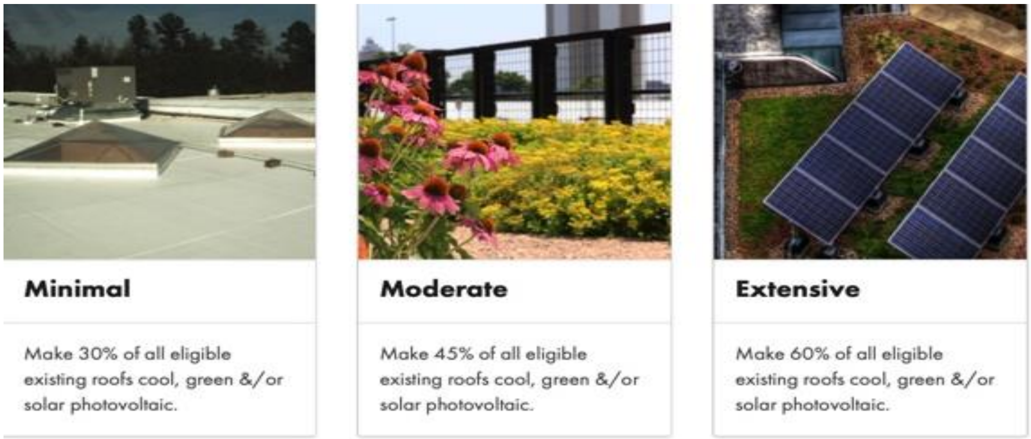
Achieve your targets by incrementally replacing existing surfaces over 30 years: from 2020 through 2050. Observe their costs and ongoing benefits in 2060.

Figure 6.3. Three available options for time frame targets. Note that costs and benefits accrue for an additional ten years after adoption has concluded.

6.3 Roofing selection

The third section titled “roofing” allows the user to determine how much of the city’s roofs will be converted to include cool roofs, cool roofs with rainwater harvesting, green roofs, and photovoltaic panels.

Users can select a target commitment from three percentage-based choices – minimal, moderate, and extensive roof upgrades. These will translate into total areas of specific roofing surfaces to be upgraded over your selected time frame. The impact of those selections will be evident in the first + operational costs, but more critically in the 10, 20 and 30 year returns on investments. Cool roofs and solar PV will be able to be applied to both low- and steep-slope roofs, which have varying costs.



Minimal

Make 30% of all eligible existing roofs cool, green &/or solar photovoltaic.

Moderate

Make 45% of all eligible existing roofs cool, green &/or solar photovoltaic.

Extensive

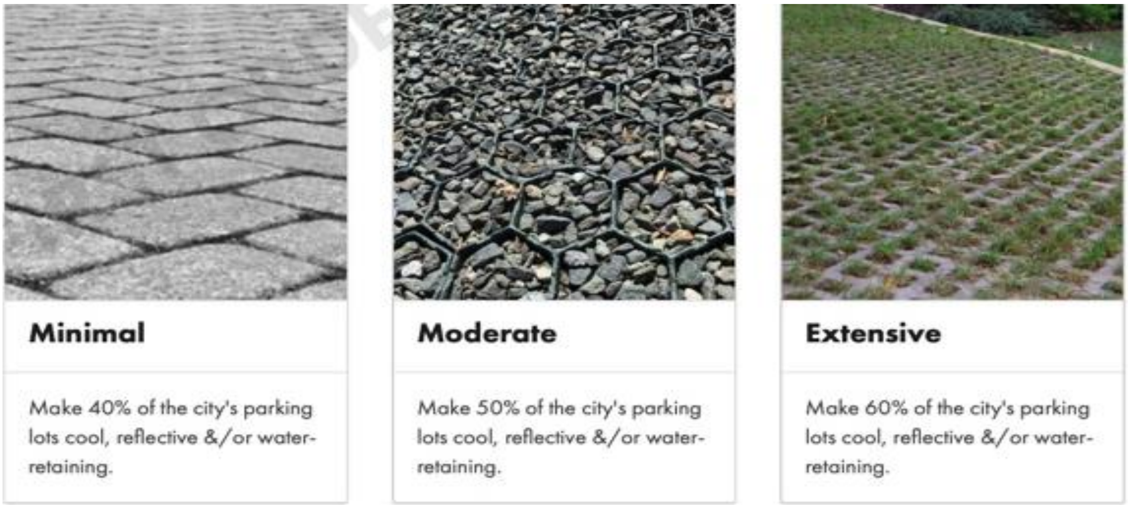
Make 60% of all eligible existing roofs cool, green &/or solar photovoltaic.

Figure 6.4 Three categories of roofing options include minimal, moderate, or extensive roofing for cool roofs, green and/or solar PV solutions on eligible and existing roofs.

After selection of a roofing option, the analytic engine offers a possible breakdown of how to meet established targets. This breakdown is customizable using drop-down sliders adjustable by % of existing surface eligible to be converted to each Smart Surface. This percentage is then broken into feet squared of each Smart Surface option. The user has the option to select either “adjust altogether”, which adjusts coverage equally across all roofs or “adjust individually”, which allows for greater customization of coverage targets based on each roof type (i.e., 60% of low-slope commercial cool roofs, 10% of steep-slope residential cool roofs).

6.4 Parking lot selection

The fourth section titled “parking lots” estimates how much of the city’s parking lots are converted to Smart Surfaces. The user can select a minimal, moderate, or extensive target commitment from these percentage-based choices for improving parking lots for managing heat and rain.



Minimal

Make 40% of the city's parking lots cool, reflective &/or water-retaining.

Moderate

Make 50% of the city's parking lots cool, reflective &/or water-retaining.

Extensive

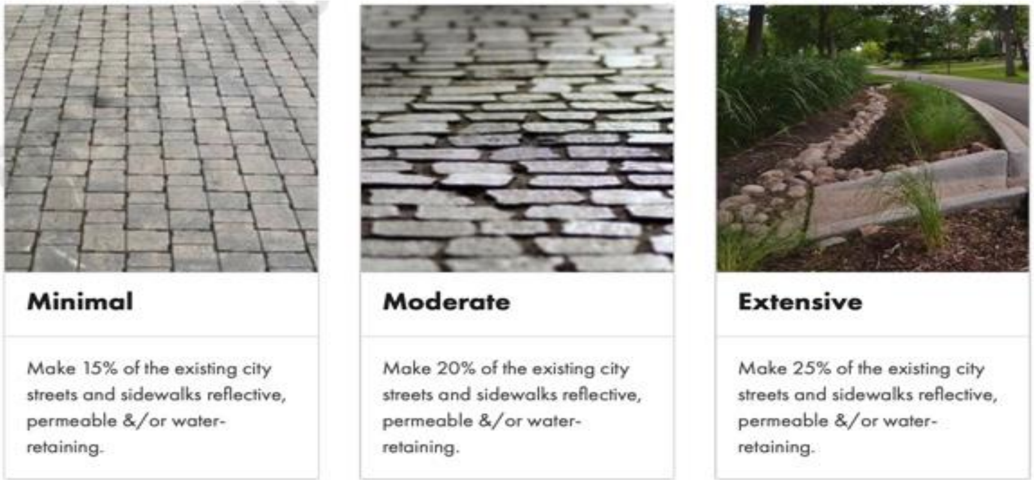
Make 60% of the city's parking lots cool, reflective &/or water-retaining.

Figure 6.5. Three categories of parking lot options include minimal, moderate, or extensive surfacing for cool, reflective, and/or water-retaining solutions. Each pre-set surface goal is fully adjustable using drop-down sliders.

This target group determines how much of the city's parking lots will be converted to include reflective pavements and rainwater permeable and storage solutions, as well as the addition of photovoltaic canopies over reflective pavements. This report assumes no increase in permeable parking but does assume an increase of reflective parking given the climate in Stockton.

6.5 Streets and sidewalks selection

This fifth section titled "streets and sidewalks" determines how much of the city's streets and sidewalks will be converted to include reflective pavements and rainwater permeable and storage solutions. The user can select a minimal, moderate, or extensive target commitment from these percentage-based choices for improving streets and sidewalks for managing heat and rain.


Minimal

Make 15% of the existing city streets and sidewalks reflective, permeable &/or water-retaining.

Moderate

Make 20% of the existing city streets and sidewalks reflective, permeable &/or water-retaining.

Extensive

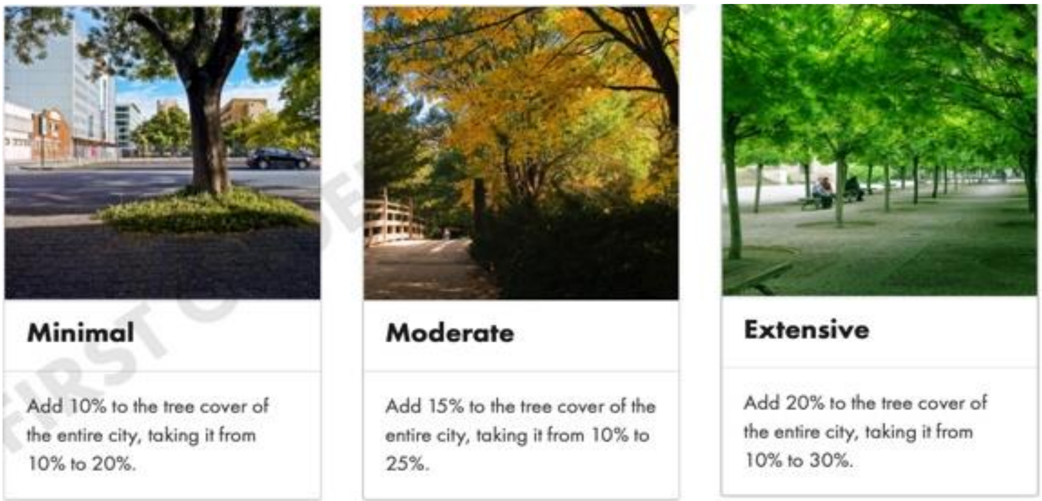
Make 25% of the existing city streets and sidewalks reflective, permeable &/or water-retaining.

Figure 6.6. Three categories of city streets and sidewalk options include minimal, moderate, or extensive surfacing for reflective, permeable, and/or water-retaining solutions.

For reasons concerning pedestrian safety and glare, we have not included reflective or water-retaining solutions for sidewalks. We do however assume an increase of reflective streets.

6.6 Tree canopy selection

The sixth section in the engine is titled "trees" and determines how much of Stockton will be add trees. The user can select a target commitment for these choices for urban trees from the minimal, moderate, or extensive percentage-based choices.


Minimal

Add 10% to the tree cover of the entire city, taking it from 10% to 20%.

Moderate

Add 15% to the tree cover of the entire city, taking it from 10% to 25%.

Extensive

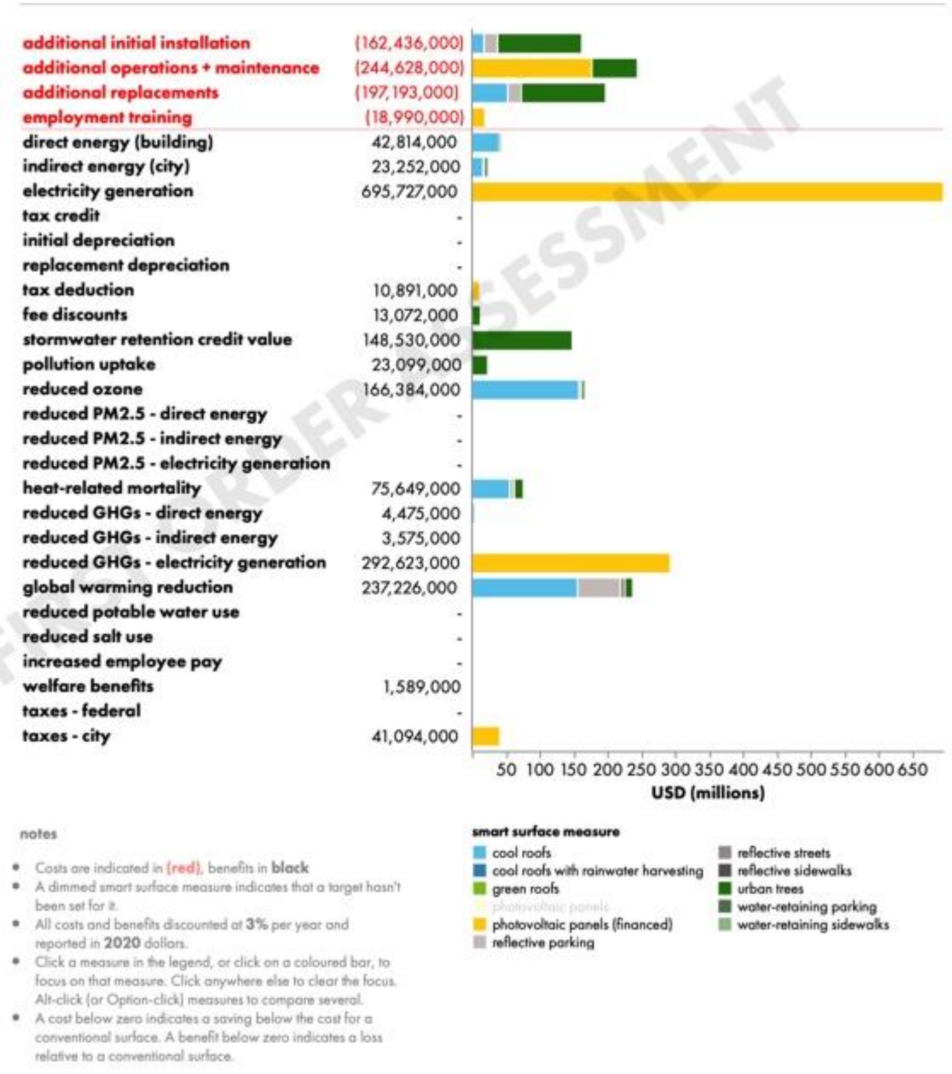
Add 20% to the tree cover of the entire city, taking it from 10% to 30%.

Figure 6.7. Three categories of tree coverage options include minimal, moderate, and extensive.

Given Stockton's goal to increase tree canopy by 0.5% in the future, this report assumes a 10% absolute increase of tree canopy (from 10% urban tree canopy to 20%).

6.7 Results

Once the user has specified the scenario they wish to test, they can click the "calculate" button to run the analysis to get the corresponding impact and financial results. The engine will present a net cost or benefit that is broken down by category, and it is also possible to isolate the costs and benefits breakdown for each individual Smart Surface technology. See figure 6.8 for a rough estimate of the results of the online analytic engine.



additional initial installation	(162,436,000)
additional operations + maintenance	(244,628,000)
additional replacements	(197,193,000)
employment training	(18,990,000)
direct energy (building)	42,814,000
indirect energy (city)	23,252,000
electricity generation	695,727,000
tax credit	-
initial depreciation	-
replacement depreciation	-
tax deduction	10,891,000
fee discounts	13,072,000
stormwater retention credit value	148,530,000
pollution uptake	23,099,000
reduced ozone	166,384,000
reduced PM2.5 - direct energy	-
reduced PM2.5 - indirect energy	-
reduced PM2.5 - electricity generation	-
heat-related mortality	75,649,000
reduced GHGs - direct energy	4,475,000
reduced GHGs - indirect energy	3,575,000
reduced GHGs - electricity generation	292,623,000
global warming reduction	237,226,000
reduced potable water use	-
reduced salt use	-
increased employee pay	-
welfare benefits	1,589,000
taxes - federal	-
taxes - city	41,094,000

notes

- Costs are indicated in (red), benefits in black
- A dimmed smart surface measure indicates that a target hasn't been set for it.
- All costs and benefits discounted at 3% per year and reported in 2020 dollars.
- Click a measure in the legend, or click on a coloured bar, to focus on that measure. Click anywhere else to clear the focus. Alt-click (or Option-click) measures to compare several.
- A cost below zero indicates a saving below the cost for a conventional surface. A benefit below zero indicates a loss relative to a conventional surface.

Figure 6.8 Stockton-specific results when using modest targets for roofs, parking lots, streets, and trees.

The costs (red) and benefits (black) of Smart Surface investments can be found in the key. All costs and benefits are broken down by surface, and each surface has a specific color that can be found in the key. Benefits include direct and indirect energy savings, health benefits, ozone and PM2.5 pollution levels, heat-related mortality, greenhouse gas emissions, and more.

The findings from the report draw from Stockton surface coverage and El Paso and Baltimore impact data, for which we ran detailed cost-benefit quantifications in the past. Given the budget constraints of this project, this can be viewed as a first order assessment of Smart Surface adoption for Stockton. Therefore, the results in the online cost-benefit analytic engine, though conservative, are still accurate and highlight the economic rationale for continued investment in city-wide Smart Surface adoption.

These numbers have been built into an analytic engine that, using hundreds of data points that link city attributes to monetary benefits, create a reliable cost-benefit analysis of various levels of smart surface implementation in Stockton.

7 Implications

7.1 For Stockton

Stockton's climactic, economic, demographic, and environmental profiles all suggest the city has great opportunity to benefit, on multiple levels including the municipal, commercial, and individual levels, from Smart Surfaces adoption. And considering the health of low-income communities, the current COVID-19 pandemic has highlighted that communities with higher poverty levels tend to have a higher mortality rate from the virus.[cxv] Living in a low-income area, which is very likely to endure higher pollution rates and worse hear, can also increase the mortality rate of its residents. COVID-19 has had worse effects on Black and Hispanic populations—a large percentage of Stockton residents.[cxvi] Smart Surfaces cost-effectively reshapes infrastructure to reduce urban heat and pollution, while reducing environmental injustice and inequity.

7.2 For California

Although this report is focused on the potential of Smart Surfaces for Stockton, its findings hold lessons for cities across much of California. Many of the characteristics that make Smart Surfaces so necessary for livability of Stockton—a pronounced urban heat island,[cxvii] air quality problems (see Figure 7.1), high energy burdens,[cxviii] and structural inequities—exist in cities throughout California's central valley, the Los Angeles Basin, and the San Francisco Bay Area. Despite these challenges, California can enable its cities to prosper socially, economically, and environmentally through broad adoption of Smart Surfaces.

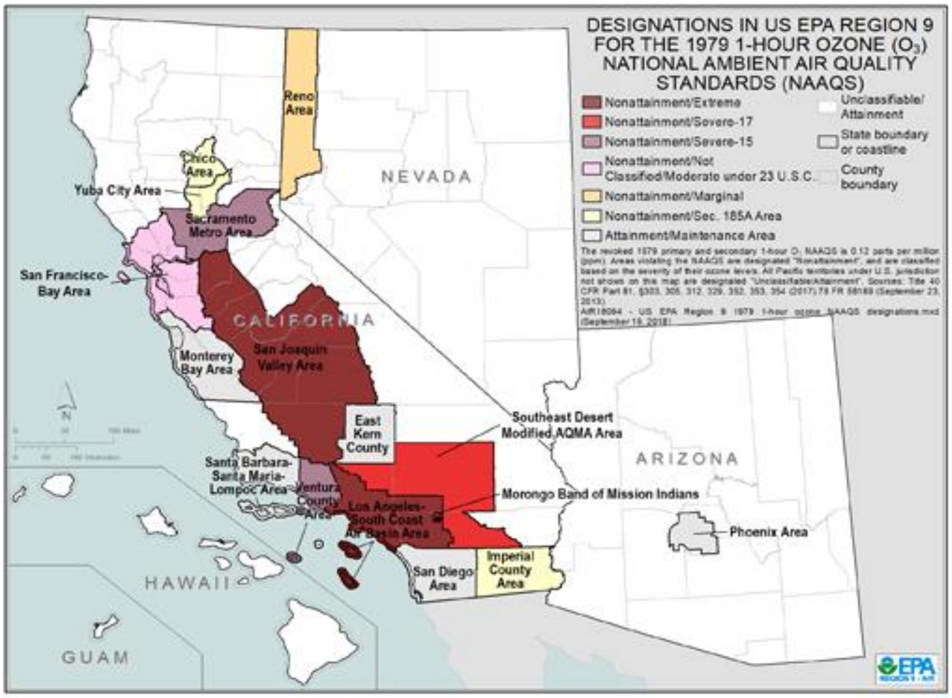


Figure 7.1 Map of California’s ozone nonattainment zones in 2018

Further, when deployed across a region-wide scale (e.g., a larger urban region), the benefit-cost ratio of Smart Surfaces increases. For example, region-wide adoption would deliver larger temperature reduction, air quality and risk reduction benefits. Cities like Los Angeles and San Francisco are already leaders in several individual Smart Surfaces measures, such as reflective roofs and roofs and tree planting programs. California can and should build on this leadership. Smart Surfaces is a large and cost-effective climate mitigation, adaptation, and equity solution. Smart Surfaces should be considered as a central solution in California’s policy options moving forward.

7.3 For the world

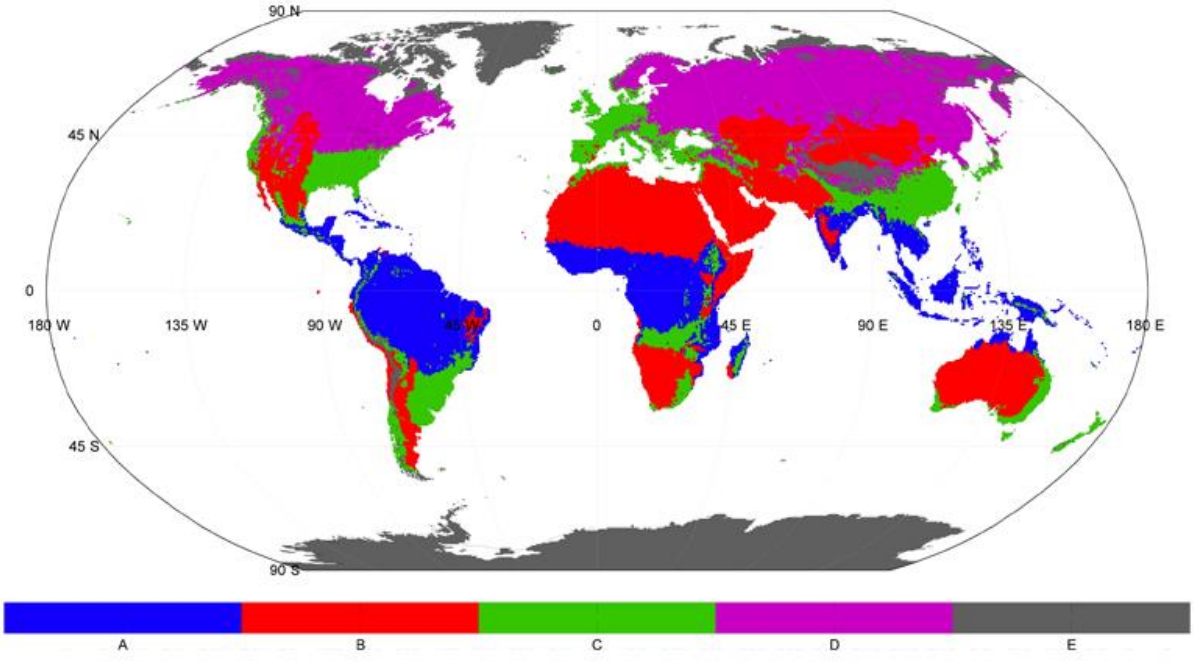


Figure 7.2 Major Köppen climate classifications[cxix]

Though this report seeks to frame the case for Stockton to adopt Smart Surfaces city-wide, the findings can be applied globally. As seen in figure 7.2, Stockton's climate falls in the major Köppen type "c", which experiences similar environmental conditions as places in South America, much of Europe, India, Southeast Asia, Africa, and Australia. Stockton is mid-sized, diverse city in a hot- and mixed-dry climate that suffers from socioeconomic inequality and climate related challenges like extreme heat and flooding. Stockton's health, equity, heat, and flooding challenges parallel many other cities globally such as Kolkata or New Delhi in India or Santiago in Chile for example. By adopting Smart Surfaces at scale, cities around the world can simultaneously cool themselves, advance equity, improve public health, reduce flooding, and both adapt to and mitigate the effects of climate change.

8 Conclusion

In summer 2021, cities, which are already hotter than surrounding countryside, experienced record heat and widespread heat deaths. If scientific consensus tells us that this represents our future summers, imposing increasingly worse summer heat/health crises in cities across much of California and the surrounding region from dark, impervious surfaces is a step in the wrong direction. This report seeks to answer the question: Do Smart Surfaces provide an effective and cost-effective way for can cities in hot dry regions to cut heat, address equity, and recue climate risk cost-effectively?

To answer this question, the Smart Surfaces Coalition estimated the potential for a highly representative city—Stockton—to deploy Smart Surfaces to achieve important health, heat, air and water quality, equity and environmental justice, climate, and risk reduction objectives. The report finds that Smart Surfaces can cost-effectively deliver substantial cooling, health, and climate benefits to cities in hot dry areas of California. This report shows that even with modest targets and assumptions that Smart Surfaces adoption can cool Stockton by 2.92°F[cxx], create 817 full-time, well-paying jobs, and reduce 4.58 million tonnes of CO2 equivalent emissions over 30 years, all while having a net present value of $777 million and a benefit-cost ratio of 6.9:1 (see section 1.2.2.2). 2.92°F peak summer downtown cooling from a modest Smart Surfaces effort would provide about ten times more cooling than the projected warming from climate change through 2050. The largest cooling, air quality, and health benefits would accrue in low-income and minority neighborhoods, providing a major and effective step toward delivering environmental justice.

Stockton, and other cities in California, can reduce their summer temperature as the world warms and can mitigate flooding even as sea level rises. In so doing, the city can build on already strong water management and tree planting policies to enhance livability, support economic growth, protect its vital tourism industry, and become more equitable and cooler. Many of the physical inequalities that characterize, and disadvantage low-income areas can be redressed with Smart Surfaces—and as demonstrated in this report—would provide large net financial returns to all its citizens.

But this requires that cities make design decisions for their surfaces differently, shifting from lowest first cost, dark, and impervious surfaces to lower total cost, reflective, porous, and green Smart Surfaces. It is important to note that piecemeal solutions to many of the issues discussed in this report already exist. Cities across California are already deploying solutions like cool roofs or tree planting programs to address specific needs, one solution at a time. However, this approach is woefully insufficient if cities and towns are to meet the scale and severity of the problem that is the climate crisis.

The case with Stockton, as with Smart Surfaces analysis of other cities, demonstrates that by deliberately reshaping their surfaces to better manage its sun and rain, cities in hot- and mixed-dry regions can ensure that their communities become cooler, healthier, more livable, and vibrant for coming generations.

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