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Shifting Gears to Sustainability: A Deep-Dive into Solar-Powered Bike Pathways

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Shifting Gears to Sustainability

A Deep-Dive into Solar-Powered Bike Pathways

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16. Abstract

This white paper evaluates the feasibility of solar-powered bike paths in California, integrating renewable energy generation with sustainable transportation. Drawing on global case studies—including Germany's solar cycle path roofing project, the Netherlands' SolaRoad, and South Korea's solar-integrated bike path—the study highlights the environmental, economic, and technical benefits of these systems. A conceptual case study along the Santa Ana River Trail in Riverside, California, modeled a 1 megawatt solar bike path capable of producing 2,022,041 kilowatt-hours (kWh) annually and offsetting 734 metric tons of carbon dioxide emissions. The analysis used advanced tools like PVWatts (a solar energy output estimation tool), System Advisor Model (SAM), and Jobs and Economic Development Impact (JEDI) to assess energy production, financial viability, and job creation. The Riverside project demonstrated a levelized cost of energy of 12.64 cents per kWh and job creation of 20.4 construction jobs and 0.2 operational jobs, confirming financial feasibility for pilot-scale projects. However, challenges such as high upfront costs, maintenance demands, and regulatory complexities must be addressed through modular designs and streamlined permitting processes. Key recommendations include leveraging public-private partnerships, prioritizing equity in project siting to benefit underserved communities, and initiating pilot projects in high-visibility areas to demonstrate feasibility and catalyze adoption. Solar bike paths represent a scalable solution to advance California's climate goals, integrating renewable energy with urban infrastructure to create a cleaner, more equitable future.

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Disclaimer

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A National Center for Sustainable Transportation White Paper

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Executive Summary

As climate change accelerates, reducing greenhouse gas (GHG) emissions in transportation is critical. Solar bike pathways offer a novel and sustainable solution by integrating renewable energy generation with active transportation infrastructure. These pathways not only encourage cycling and walking but also support clean energy goals, aligning with California's ambitious sustainability targets.

This white paper assesses their feasibility in California, examining economic, technical, and environmental factors. Drawing from global case studies, such as the Solar Highways in the Netherlands and the Healthway in India, it highlights key benefits, challenges, and lessons learned. These insights form targeted recommendations for adapting solar bike paths to California's unique climate, regulations, and infrastructure.

Key Findings

1. **Environmental Benefits**: A 1 megawatt (MW) solar bike path in Riverside could generate approximately 2,022,041 kilowatt-hours (kWh) annually, offsetting 734 metric tons of CO_2 emissions, equivalent to taking over 160 cars off the road each year.
2. **Economic Viability**: While the estimated at $3.6 million installation cost is significant, financial models suggest long-term benefits, including a levelized cost of energy (LCOE, i.e., the average cost per kilowatt-hour over a system's lifetime) of 12.64 cents per kWh and a modest internal rate of return (IRR) of 7.72%, making pilot projects feasible.
3. **Technical Feasibility**: Advances in bifacial solar panels, energy storage, and modular designs enhance efficiency and durability, but challenges such as shading, vandalism, maintenance and grid integration require strategic solutions. Security measures and proactive maintenance can enhance reliability.
4. **Social and Equity Considerations**: Solar bike paths provide shaded safer routes, mitigate urban heat islands, and support environmental justice goals by prioritizing development in underserved communities.
5. **Regulatory and Permitting Hurdles**: Complex federal, state, and local regulations necessitate streamlined permitting and early utility coordination to prevent project delays.

Lessons Learned & Recommendations

- **Optimized Design**: Implement canopy-style structures with energy storage to enhance efficiency and resilience. In areas needing sound barriers, integrating solar panels into noise-reducing walls can provide dual benefits of renewable energy generation and traffic noise reduction.
- **Funding Strategies**: Leverage federal incentives, state clean energy programs, and public-private partnerships to offset upfront costs while monitoring potential policy changes that may impact funding availability.
- **Regulatory Streamlining**: Simplify permitting and interconnection processes to accelerate deployment and reduce administrative barriers.
- **Strategic Project Siting**: Prioritize locations where high cyclist/pedestrian traffic intersects with strong solar energy generation potential, while ensuring equitable deployment in underserved communities when all other factors are equal.
- **Community Engagement & Public Awareness**: Actively engage local stakeholders and launch public information campaigns to highlight social, economic, and environmental benefits. Utilize billboards along project paths and an informational website to improve community engagement and visibility.
- **Scalability**: Begin with pilot projects in urban centers and high-traffic recreational areas, ensuring public outreach and education to build support and validate feasibility.

Conclusion

Solar bike paths integrate clean energy with sustainable transportation, offering environmental, economic, and social benefits. While challenges exist, innovative designs, collaborative funding, and streamlined regulations can make these projects a reality—positioning California as a leader in sustainable infrastructure.

Introduction

As the impacts of climate change intensify, reducing GHG emissions has become an urgent priority. While solar installations over parking lots and rooftops are well-established solutions, this study focuses on an underutilized opportunity—integrating solar panels into bike paths and active transportation infrastructure.

While parking lots and rooftops are well-established surfaces for solar installation, this study was initiated to examine more complex and underutilized infrastructure—specifically, active transportation corridors such as bike paths. It is widely recognized that parking lots offer some of the lowest-cost and highest-impact opportunities for solar deployment. However, many of these areas are already saturated with solar installations or face space constraints. This study explores the potential for solar integration in less conventional areas—bike paths—where co-benefits such as transportation equity and urban cooling may justify higher upfront costs. Solar bike paths present greater technical and institutional challenges due to their elongated geometry, exposure to public use, and integration with transportation systems. Funding agencies, including Caltrans and USDOT, expressed interest in exploring these ‘harder-to-do’ opportunities to unlock new potential for renewable energy generation where conventional infrastructure is saturated or infeasible. The goal is to assess the feasibility of solar bike paths not merely as energy assets, but as multi-benefit infrastructure that advances climate, mobility, and equity objectives.

Solar bike pathways present a unique approach to sustainable mobility by combining solar energy generation with active transportation infrastructure. By integrating solar panels along bike paths, these systems not only generate clean energy but also encourage sustainable transportation, aligning with California’s climate policies, such as Senate Bill (SB) 32 [1] which mandate statewide GHG reductions, and the Low Carbon Fuel Standard (LCFS) [2], which promotes low-carbon transportation solutions.

As California intensifies efforts to meet its clean energy and climate goals, integrating renewable energy generation into transportation infrastructure represents an untapped opportunity. While solutions like rooftop and parking lot solar have gained traction, they often serve a singular purpose, energy generation, without contributing to sustainable mobility. In contrast, solar-integrated bike paths offer a dual-purpose strategy: they support active transportation while simultaneously generating clean electricity. This project addresses the need for holistic, multifunctional infrastructure that directly aligns with the state’s decarbonization targets, as outlined in California’s 2022 Scoping Plan [3] and supported by the state’s broader clean energy initiatives [4].

The value of such dual-use infrastructure is reinforced by recent projects like Project Nexus, a state-funded pilot that installs solar panels over irrigation canals to simultaneously reduce water evaporation and generate electricity [5]. Similarly, a UCLA-led feasibility study concluded that solar canal systems could offer substantial environmental and economic benefits while avoiding additional land development, making a strong case for co-located renewable infrastructure [6]. These precedents highlight the potential of solar-integrated systems to deliver compound benefits. In this context, bike paths represent an ideal surface for similar innovation, offering the opportunity to connect clean energy generation with sustainable transportation. This study explores whether such integration is feasible and impactful within California's diverse environmental and infrastructural conditions, drawing inspiration from existing work on the energy-water nexus [7].

This study focuses on evaluating the feasibility of implementing solar bike paths in California. It begins by analyzing existing studies and case examples to understand the benefits, limitations, and challenges associated with solar-integrated pathways. Building on these insights, the economic and technical feasibility of such systems is assessed with a focus on California's climatic conditions and infrastructure.. Finally, insights from stakeholders and experts help identify practical considerations, opportunities, and barriers to implementation.

The outcomes of this research are compiled into this white paper, designed to inform Caltrans' approach to integrating solar energy with transportation infrastructure. By aligning the findings with California's sustainability policies, including SB 100 [4], which mandates 100% carbon-free electricity by 2045, the study provides, evidence-based insights and recommendations to support renewable energy adoption in transportation systems while reducing emissions.

Literature Review and Case Study Analysis

The integration of solar technologies into bike paths has gained significant global attention as a dual-purpose solution for renewable energy generation and sustainable transportation. Various pilot projects and real-world implementations have demonstrated the feasibility, benefits, and challenges associated with these innovative systems. This section reviews key studies and case studies, providing a comprehensive foundation for evaluating the potential of solar bike paths in California.

The review focuses on the practical applications of solar bike paths in diverse contexts, including urban areas and transportation corridors. It highlights the environmental benefits, such as reducing GHG emissions and promoting clean energy, while also addressing challenges like high initial costs, maintenance, and regulatory hurdles. By examining successful projects, such as the SolaRoad project in the Netherlands [8] and the Healthway Solar Roof Cycle Track in Hyderabad in India [9], the analysis draws insights into design considerations, economic viability, and long-term sustainability.

Additionally, this review explores technological advancements, including the integration of bifacial solar panels that capture sunlight from both front and rear sides, microinverters (devices that convert solar panel output from DC to AC at the panel level), small devices installed on individual solar panels to optimize energy output, and power optimizers, which improve power conversion efficiency and ensure maximum performance. Energy storage solutions, such as battery systems, allow excess solar energy to be stored for use during cloudy periods or at night, improving system reliability. Lessons from these projects inform recommendations tailored to California’s unique climate, transportation policies, and sustainability priorities. This foundation aligns with California's broader objectives of reducing carbon emissions, supporting renewable energy, and enhancing sustainable urban infrastructure.

Global Practices

Pilot Projects

Pilot projects worldwide have demonstrated the potential of solar bike paths as multifunctional infrastructure that integrates renewable energy generation with urban mobility. These initiatives showcase the practicality and benefits of solar-integrated pathways in diverse urban and regional settings.

In Freiburg, Germany, a solar cycle path roofing project combines sustainability with functionality by integrating translucent solar panels over a 300-meter bike path. The project generates 280 MWh of electricity annually while providing cyclists with weather protection [10]. As shown in Figure 1, this innovative approach highlights the dual-purpose capability of solar bike paths, demonstrating their potential to support renewable energy goals while enhancing urban infrastructure.

Figure 1. Solar cycle path roofing in Freiburg, Germany.

A large-scale application in South Korea further exemplifies the potential of solar-integrated pathways [11]. The 5.5-mile-long solar bike path between Daejeon and Sejong integrates solar panels over a three-mile stretch, producing approximately 2,200 MWh of electricity annually. As illustrated in Figure 2, this infrastructure not only generates significant renewable energy but also enhances transportation connectivity. The project underscores the scalability of solar bike paths in addressing local energy demands while fostering sustainable urban development.

Figure 2. Solar-integrated transportation infrastructure in South Korea.

Case Studies

Case studies of real-world applications validate the feasibility and impact of solar-integrated pathways, providing insights into their design, implementation, and operational outcomes.

The SolaRoad project in the Netherlands is a pioneering example of a solar bike path designed to generate renewable energy while serving as a functional transportation route [8]. Since its launch in 2014, the project has produced approximately 3,000 kWh of electricity annually, enough to power multiple streetlights, charge hundreds of e-bikes, or supplement local energy demand. Despite challenges such as dirt accumulation and maintenance requirements, the project, shown in Figure 3, underscores the viability of integrating solar panels into conventional bike paths and demonstrates the potential for renewable energy solutions in urban areas.

Figure 3. The SolaRoad project in the Netherlands.

Hyderabad, India, has established a groundbreaking benchmark in sustainable urban mobility with the launch of the country's first 23-kilometer-long Solar Roof Cycle Track, known as ‘Healthway’ [9], [12]. Constructed along the Outer Ring Road, Healthway is the second project of its kind globally after South Korea’s solar-powered bike highway. With a bidirectional 4.5-meter-wide track and a total of 16,000 rooftop solar panels, it generates up to 16 MW of power, contributing clean energy directly to the grid. The track features amenities such as drinking water stations, toilets, and provisions for night cycling, and includes a green belt on both sides planted with flowers and shrubs. As shown in Figure 4, this infrastructure not only encourages active mobility and reduces carbon emissions but also shows how renewable energy can be integrated with everyday transport. Healthway is a forward-thinking initiative, built in just one year, that highlights the power of public-private collaboration and technological innovation in reshaping urban infrastructure.

Figure 4. Hyderabad's 23 km Healthway Solar Roof Cycle Track.

Feasibility Studies

Assessing the feasibility of solar bike paths requires a comprehensive evaluation of multiple factors, including economic viability, environmental impact, and stakeholder involvement. The initial costs of these projects are substantial, driven by the need for specialized materials, advanced solar technologies, and precise engineering. However, the long-term benefits, such as reduced GHG emissions, renewable energy production, and enhanced urban mobility, provide a compelling case for potential investment in this innovative infrastructure.

Economic analyses of projects like the Solar Highways in the Netherlands highlight the financial dynamics of such initiatives. This project integrates bifacial photovoltaic (PV) panels into noise barriers along highways, effectively combining renewable energy generation with infrastructure functionality. While the upfront costs are significant, as shown in Figure 5, the dual-purpose design of the Solar Highways project underscores the potential to maximize land use efficiency while enhancing financial viability, making it a replicable model for solar-integrated bike paths.

Figure 5. Bifacial PV panels integrated into noise barriers in the Solar Highways project.

Environmental impact assessments further reinforce the feasibility of solar bike paths. At scale, these systems could contribute to significant reductions in GHG emissions by offsetting energy demands with clean solar power. Additionally, they enhance urban sustainability by mitigating urban heat island effects and providing shaded areas that improve pedestrian and cyclist comfort.

Stakeholder engagement is another critical aspect of feasibility studies. Successful projects have demonstrated the importance of collaboration among public agencies, private companies, and local communities. Early engagement ensures that designs align with the needs of users, while public-private partnerships help address financial barriers. The Solar Highways project benefited from strong stakeholder collaboration, which facilitated smooth implementation and widespread support.

By integrating economic, environmental, and stakeholder considerations, feasibility studies provide a roadmap for the successful implementation of solar bike paths. These assessments highlight the transformative potential of solar-integrated infrastructure in promoting sustainable transportation and energy solutions.

Challenges and Lessons Learned

Solar bike path projects encounter several notable challenges, ranging from high initial investment costs to the technical demands of maintenance and long-term durability. For example, the SolaRoad project in the Netherlands demonstrated the critical importance of selecting materials that are not only durable under heavy use but also capable of sustaining energy efficiency despite dirt accumulation and weathering. Maintenance requirements, such as regular cleaning and inspection, add to operational costs, highlighting the need for innovative self-cleaning technologies or coatings to mitigate energy losses.

Public and regulatory acceptance remains another critical hurdle. Transparent and early engagement with stakeholders, including local communities, public agencies, and private partners, has been essential in successful implementations. Addressing concerns about safety, aesthetics, and cost through proactive communication fosters trust and secures public support. Projects like the Solar Highways in the Netherlands underscore the value of collaborative frameworks, where clear objectives and aligned stakeholder interests reduce friction and enhance project outcomes.

Opportunities for California

The lessons learned from global solar bike path projects offer California a robust roadmap for implementation. Addressing the state’s specific climate conditions, such as frequent dust accumulation in arid regions or shading challenges in urban environments, requires tailored solutions. Advanced designs, such as bifacial PV panels and modular systems, can mitigate these obstacles while maximizing energy efficiency and functionality.

Integrating solar bike paths into California's broader urban planning initiatives aligns with the state's ambitious renewable energy targets and climate action goals. By combining renewable energy generation with sustainable transportation networks, California can significantly reduce GHG and improve urban mobility. Additionally, these projects provide an opportunity to address equity concerns by prioritizing development in underserved communities, thereby ensuring broader access to sustainable infrastructure.

Public-private partnerships, leveraging lessons from projects like the Healthway Project in India, can help alleviate financial barriers and accelerate adoption. These collaborations not only distribute costs but also bring in technical expertise and innovative funding models, such as Power Purchase Agreements (PPAs), to make solar bike paths economically viable.

Conclusion

The review of global practices, feasibility studies, and real-world applications underscores the transformative potential of solar-integrated bike paths. While challenges such as high costs, maintenance demands, and regulatory complexities remain, the opportunities for renewable energy generation, environmental sustainability, and enhanced urban infrastructure make these challenges worth addressing.

California stands at the forefront of this innovation, with the chance to adopt and refine global best practices to suit its unique landscape and energy goals. The insights gathered in this chapter lay a strong foundation for further analyses, including detailed cost evaluations and technical feasibility studies. These findings aim to provide actionable recommendations for decision-makers, ensuring that solar bike paths become a practical and impactful component of California’s sustainable development strategy.

Economic and Feasibility Analysis

This section examines the feasibility of solar bike paths as a sustainable infrastructure solution, focusing on key elements like energy production, cost-effectiveness, financial performance, and job creation. Riverside, California, was chosen as a hypothetical case study due to its abundant solar resources and the availability of detailed geographic data for precise spatial analysis, and its designation as a Disadvantaged Community and Low-Income Community. This status highlights the potential for equitable investment in clean energy infrastructure to enhance local sustainability, economic benefits, and environmental justice.

To evaluate the project, advanced tools were employed to simulate its various components. ArcGIS provided accurate spatial measurements for a segment of the Santa Ana River Trail [13], while the PVWatts (a solar energy output estimation tool from NREL) calculated potential energy production based on local solar irradiance and weather data [14]. Financial feasibility was assessed using the System Advisor Model (SAM, a performance and financial simulation tool), which analyzed project costs, energy pricing, and potential returns [15]. The broader economic impacts, including job creation and regional economic benefits, were evaluated through the Jobs and Economic Development Impact (JEDI) model (Jobs and Economic Development Impact) [16]. These tools together offered a detailed understanding of the practicality and potential impact of integrating solar energy with bike paths.

The analysis adopted a structured approach, combining reliable data sources with robust analytical techniques. This methodology encompassed all critical aspects, including site selection, energy modeling, financial evaluation, and compliance with regulatory requirements. By addressing both opportunities and challenges, this analysis provides a clear picture of the potential for solar bike paths to contribute to California's sustainability goals.

Energy Production and Environmental Impact

Based on the specifications of the selected solar modules and the total system size, the energy generation potential of the solar bike path project was estimated using the PVWatts tool, which calculates solar power output based on local sunlight levels and weather conditions. This tool integrates location-specific data, such as solar irradiance and weather conditions, to provide accurate projections of energy output. The dimensions of the selected segment of the Santa Ana River Trail, determined through ArcGIS analysis, played a key role in this estimation. As shown in Figure 6 and detailed in Figure A1, the analysis includes a detailed inset highlighting an 11-foot-wide measurement of the bike path and an outset providing a broader view of the 1-mile trail segment. Figure A1 is based on existing bikeway data from the City of Riverside's ArcGIS online database [17], developed as part of the Riverside Bicycle Master Plan (2007) [18]. The total available area for solar panel installation was calculated to be approximately 58,080 square feet.

Given the site's characteristics, careful consideration of infrastructure security and durability is necessary. Where solar panel structures provide elevated surfaces or enclosed spaces, design strategies should mitigate unintended use, ensuring structural integrity while maintaining accessibility. Incorporating reinforced materials, tamper-resistant designs, and community engagement efforts can help preserve the project's long-term functionality and sustainability.

Further details about the site specifications and system configuration are provided in Table B1, which outlines key parameters such as the assumed module size (89.72 x 44.64 x 1.38 inches), the total number of solar panels (2,087), and the overall system size (1,147.85 kW). The initial system size of 1,146.75 kW was determined based on the number of modules and their power rating (550 W per module). These assumptions and measurements served as inputs for the PVWatts simulation to estimate energy output.

Figure 6. Proposed 1-mile solar bike path along the Santa Ana River Trail in Riverside, with inset showing 11 ft path width and selected project area.

The PVWatts simulation incorporated these specifications alongside detailed input parameters to project energy output. As summarized in Table B2, key inputs included an array tilt of 20° (the upward angle of the solar panels from horizontal), an azimuth angle of

180° (the compass direction the panels face, with 180° corresponding to true south in the Northern Hemisphere), a DC-to-AC ratio of 1.2 (the ratio of solar panel capacity to inverter capacity), and system losses of 11.08%. The simulation also included an albedo factor (surface reflectivity, which affects the amount of sunlight reflected onto the panels), derived from the site-specific weather file. These parameters were chosen to reflect realistic system design considerations for this project.

Since PVWatts does not explicitly model elevated canopy structures, assumptions about the array tilt and orientation were made based on best practices for maximizing solar energy generation while ensuring cyclist and pedestrian usability. The 20° tilt was selected to optimize solar exposure, accounting for potential shading effects and structural feasibility. This approach provides a reasonable estimate of expected performance, even though actual energy generation may vary based on final canopy design, height, and structural configuration.

The PVWatts simulation projected an annual energy output of approximately 2,022,343 kWh under optimal conditions with minimal shading. This level of production represents a substantial contribution to renewable energy goals. Additionally, the project's environmental impact was evaluated by estimating the reduction in CO_2 emissions. Using California's grid emission factor of 4.17×10^{-4} metric tons of CO_2 per kWh, the analysis calculated that the system could offset approximately 734.58 metric tons of CO_2 annually [19]. A 1.15 MW system could offset approximately 844 metric tons of CO_2 annually, with larger installations(10 MW or 50 MW systems) achieving proportionally greater reductions, as shown in Table 1.

Table 1. Estimated energy production and carbon dioxide (CO_2) emissions reductions for different system sizes.

System Size (MW)	Annual Energy (MWh)	Annual CO_2 Abated (metric tons)
1.15	2,026.80	844.18
10	17,615.90	7,345.83
50	88,079.50	36,729.15

Table 1 shows that larger installations can deliver substantial CO_2 reductions, supporting scalability for emissions mitigation under California's climate goals

These results demonstrate the scalability of the project, highlighting its potential to significantly reduce GHG emissions at larger scales while contributing to California's renewable energy goals.

Financial Feasibility and Cost Analysis

The financial feasibility of the solar bike path project was assessed using the SAM, a comprehensive tool for analyzing renewable energy systems. The analysis incorporated site-specific parameters for Riverside, including solar irradiance, module specifications, and regional cost factors. Detailed results from the SAM analysis, including financial and performance metrics, are provided in Figure A2 for further reference.

The proposed system configuration was normalized to 1 MW from an initial size of 1,146.75 kW to provide a standardized basis for analysis. This adjustment resulted in 1,830 monocrystalline modules arranged in portrait orientation, achieving a DC capacity of 1,007.72 kW with a DC-to-AC ratio of 1.25. While the minimum theoretical requirement is 1,818 modules, 1,830 was chosen to ensure a buffer for efficiency and a proper electrical configuration. This allowed for 61 full strings, each containing 30 modules, preventing partial strings that could cause electrical imbalances.

Key technical specifications, including module count, voltage limits, and system design, are detailed in Table 2.

Table 2. Parameters and values for normalized 1 MW solar system.

Parameter	Value (1 MW)
Module	550W
Number of Module Required	1830 modules
V_{oc} of Module	49.70V (~ 50 V)
V_{dcmax} of Inverter	1500 V
Max No. of Module in Series	30 modules (1500 V/50 V)
Number of Parallel Strings	61 (1830 modules/30 modules/string)

The total installation cost was estimated at $3.36 per watt, based on SAM analysis (Figure A3) resulting in a total project cost of $3,635,603. This estimate includes equipment costs, balance of system (BOS) components, and labor, providing a comprehensive view of the project's capital requirements.

When considering the combined implementation of both a Class I bikeway and solar infrastructure, the cost analysis must also account for bikeway construction expenses. The estimated cost for a Class I bikeway is approximately $1 million per mile, while the solar integration adds approximately $3.6 million per mile, bringing the total estimated cost of a solar-integrated Class I bikeway to $4.6 million per mile. This highlights the financial scale of such projects and underscores the importance of leveraging funding opportunities and optimizing design efficiencies to enhance economic viability.

Financial metrics derived from SAM offer detailed insights into the project's economic viability. The LCOE, a measure of the average cost of generating electricity over the project's lifetime, was calculated at 15.83 cents per kWh nominally and 12.64 cents per kWh in real terms. While higher than utility-scale solar PPAs, this LCOE is reasonable for a distributed solar project and remains competitive with California's retail electricity rates, particularly when energy is utilized for on-site applications such as e-bike charging stations or public infrastructure.

The Net Present Value (NPV) was estimated at $60,570, indicating its potential to generate long-term value, while the Internal Rate of Return (IRR), a metric that measures how profitable the investment is compared to other options, was 7.72%, reflecting a modest but positive return on investment. However, given the potential for multiple agencies to provide funding, the distribution of returns may differ depending on funding mechanisms. Public sector contributions through grants or subsidies may not yield direct financial returns but could generate broader public benefits, including urban cooling, shaded cycling infrastructure, and transportation electrification. If agencies participate through public-private partnerships (PPPs) or investment-based mechanisms, structuring cost-sharing models, revenue sources (e.g., energy sales, charging fees), or long-term financial incentives would be essential for financial sustainability.

These key financial metrics are summarized in Table 3.

Table 3. Financial metrics for solar bike path project, demonstrating cost-effectiveness and long-term viability.

Metric	Value
LCOE Nominal	15.83 cents per kWh
LCOE Real	12.64 cents per kWh
NPV	$60,570
IRR	7.72%
Net capital cost	$3,635,603

Table 3 summarizes the project's financial performance; a 12.64¢/kWh real LCOE and 7.72% IRR suggest moderate feasibility for demonstration-scale projects.

The LCOE values indicate a competitive cost structure, particularly when compared to typical electricity rates in California, which tend to be higher. While the IRR of 7.72% may be lower than that of larger commercial projects, the positive NPV and cost benefits suggest that solar-integrated bike paths could be financially viable under the right conditions.

The financial viability of solar bike paths strongly depends on securing end uses that capture near-retail value of electricity. Unlike residential solar systems where generation offsets on-site consumption, solar generation from bike paths risks being undervalued if exported at wholesale rates (~$0.02/kWh). To address this, on-site applications such as e-bike or EV charging stations, pedestrian-scale lighting, and adjacent public facility electrification should be prioritized to increase avoided-cost savings and improve project economics. Additionally, integrating solar bike paths into community solar programs—where credits are shared with local residents or public facilities—offers another mechanism for monetizing energy at closer to retail value, while advancing equity goals. Without these use cases, the modest IRR and NPV reported here may be insufficient to attract private investment or justify public capital.

While the financial metrics suggest limited immediate returns, they support the feasibility of this project as a demonstration initiative. Such pilots can help validate the concept, refine value capture strategies, and inform broader implementation efforts. The analysis highlights the potential for scalability and broader adoption, positioning the project as a steppingstone for integrating solar energy into urban infrastructure effectively.

These types of on-site uses are critical to achieving a financially viable model, especially when LCOE exceeds wholesale compensation rates. Without these high-value applications, the project risks being limited to wholesale export rates (~$0.02/kWh), which are significantly lower than the estimated LCOE. Establishing these co-located demand sources is key to making the project financially sustainable and policy-relevant.

Job Creation and Economic Impact

The JEDI model was utilized to evaluate the broader economic implications of the conceptual solar bike path project in Riverside, California. This tool provided detailed insights into the direct, indirect, and induced employment opportunities associated with both the construction and operational phases of the project. The analysis incorporated input parameters outlined in Table B3, including the project's location (California), a system size of 1 MW, and construction scheduled for 2030. These inputs ensured accurate modeling of job creation and economic output.

During the construction and installation phase, the analysis estimated that approximately 20.4 jobs would be created as detailed in Table B4. These positions include roles in project development, onsite labor, and supply chain activities. Onsite labor encompasses tasks such as solar panel installation, electrical work, and site preparation, while supply chain activities involve manufacturing and transporting materials. The project development phase also creates opportunities for engineers, designers, and project managers, contributing to the local economy by generating demand for professional and technical expertise.

The operational phase of the project, while less labor-intensive, is expected to support 0.2 full-time equivalent (FTE) jobs annually, as shown in Table B5. This means that the maintenance tasks such as routine inspections, cleaning of solar panels, and minor repairs would require about 8 hours of work per week throughout the year. Instead of needing a full-time position, this workload could be handled by a part-time worker or distributed among existing maintenance staff. Although fewer jobs are created during this phase, these roles are essential for maintaining the performance and reliability of the solar infrastructure, ensuring its long-term contribution to the local economy.

The employment impacts are summarized in Table 4, emphasizing the distinction between the initial surge in job creation during construction and the ongoing opportunities during operation.

Table 4. Job creation estimates for the solar bike path project, illustrating the short-term impact of construction and the ongoing maintenance roles required for long-term sustainability.

Phase	Jobs Created	Annual Jobs (Ongoing)	Description
Construction and Installation	20.4 jobs	N/A	Jobs include project development, onsite labor, and supply chain activities.
Operational Phase	N/A	0.2 jobs	Primarily maintenance-related jobs contributing to long-term economic stability.

Table 4 highlights that the project supports short-term construction jobs and modest ongoing employment, demonstrating localized economic benefits.

The JEDI model also highlights the indirect and induced economic benefits of the project. Table B4 provides a breakdown of these impacts during the construction and installation phase, where indirect effects stem from increased demand in sectors supporting the project, such as manufacturing, logistics, and professional services. Induced impacts arise from the spending of wages earned by workers employed during both phases, which boosts local businesses such as retail and services.

During the operational phase, the economic benefits continue at a smaller scale, as outlined in Table B5, where induced impacts from maintenance activities contribute to local economic activity.

Overall, the solar bike path project demonstrates its potential to contribute to the local economy by creating jobs, fostering professional growth, and stimulating broader economic activity. These employment benefits, coupled with the project's environmental and financial advantages, reinforce its role as a model for sustainable urban infrastructure initiatives.

Permitting, Regulations, and Compliance

The successful implementation of the solar bike path requires navigating federal, state, and local regulations to ensure compliance with environmental, energy, and transportation policies. While California has strong sustainability policies, federal policy shifts can impact project feasibility through funding availability, incentive structures, and regulatory changes.

Federal Policy Considerations

Several federal policies and programs directly impact the financial and regulatory landscape for solar bike path initiatives:

- **Inflation Reduction Act (IRA, 2022)**: Administered by the U.S. Department of the Treasury and the Environmental Protection Agency (EPA), provides Investment Tax Credits (ITC) of up to 30% for solar energy projects through at least 2025, reducing capital costs for integrating solar panels into bike path infrastructure. However, future modifications to the IRA could affect long-term incentive structures.
- **Fixing America's Surface Transportation (FAST) Act**: This federal program overseen by the Federal Highway Administration (FHWA) funds transportation projects—including bicycle and pedestrian infrastructure, through grants like the Surface Transportation Block Grant Program (STBG). Solar bike paths may qualify for funding under multimodal transportation categories.
- **Bipartisan Infrastructure Law (BIL, 2021):** Administered by the U.S. Department of Transportation (DOT), the BIL allocates $108 billion for public transportation and supports innovative infrastructure solutions, including the integration of renewable energy into transportation networks.
- **Advanced Transportation and Congestion Management Technologies Deployment (ATCMTD) Program**: Administered by the U.S. Department of Transportation (USDOT), the ATCMTD program funds technology-driven transportation projects that improve mobility, safety, and environmental outcomes. It has supported initiatives led by agencies such as Caltrans and regional planning organizations like the Southern California Association of Governments (SCAG) and the Metropolitan Transportation Commission (MTC).

While the Inflation Reduction Act and Bipartisan Infrastructure Law currently provide strong incentives for clean energy and infrastructure development, recent executive actions have introduced uncertainty into their long-term implementation. For example, presidential orders issued in 2024 and 2025 have called for reviews of certain climate-related spending provisions and adjustments to agency guidance, which may affect the scope and timeline of available funding. These shifts—particularly those affecting tax credits or discretionary grant allocations—could impact project viability and planning horizons. To mitigate these risks, state and local agencies should engage with federal partners, closely monitor regulatory changes, and develop contingency plans that incorporate diversified or alternative funding pathways.

State and Local Regulations

Several state and local policies directly influence the permitting, funding, and regulatory framework for solar bike path projects in California:

- **California Environmental Quality Act (CEQA)**: Requires environmental impact assessments (EIAs) for infrastructure projects to evaluate potential effects on land use, ecosystems, and GHG emissions. Compliance ensures alignment with California's sustainability goals.

- **California Public Utilities Commission (CPUC) Interconnection Policies**: Regulates grid interconnection and energy distribution for solar energy projects. Solar bike paths exporting electricity must comply with Net Energy Metering (NEM) agreements and interconnection requirements.
- **California Active Transportation Program (ATP)**: Provides funding for bike and pedestrian infrastructure, potentially supporting solar-integrated pathways.
- **Title 24 Building Energy Efficiency Standards**: Mandates energy efficiency requirements for new construction, which may impact solar canopy designs, electrical systems, and lighting in bike path projects.
- **Building and Electrical Permits**: Issued by county and municipal authorities, these permits ensure compliance with local safety codes, zoning laws, and construction standards for solar installations.
- **Utility Interconnection Policies**: Local utilities oversee grid connection approvals, interconnection agreements, and capacity studies to ensure safe integration of solar energy.
- **Land Use and Zoning Regulations**: Municipal zoning ordinances dictate where solar bike paths can be installed. Some jurisdictions may require special use permits or modifications to existing land-use plans.
- **Community and Stakeholder Engagement**: Early coordination with agencies and local communities is crucial to address concerns such as construction impacts, vandalism risks, and long-term maintenance. Public meetings and outreach efforts can help build support and streamline approvals.

While California has established regulatory frameworks to guide the development of solar-integrated infrastructure, permitting challenges can create delays. Streamlining approval processes such as establishing expedited permitting pathways for low-impact projects or developing standardized design templates could enhance project feasibility and reduce administrative burdens. Collaboration between state agencies, such as the CPUC, CEC, and Caltrans, may further support regulatory efficiency for future solar bike path initiatives.

Table 5 summarizes the key agencies involved in the permitting process and their respective roles.

Table 5. Summary of agencies involved in permitting and compliance.

Agency	Roles
FHWA	Oversees compliance with federal regulations under Title 23 CFR, including environmental reviews under NEPA.
NEPA	Requires an environmental review for projects involving federal funding or federal land use to assess potential ecological and social impacts.
CEQA	Mandates EIAs for infrastructure projects to evaluate potential effects on land use, ecosystems, and GHG emissions.
CPUC	Regulates grid interconnection and energy policies; oversees NEM agreements, power distribution, and compliance with renewable energy programs.
CEC	Ensures projects align with state renewable energy goals, including compliance with Title 24 Building Energy Efficiency Standards for energy-efficient infrastructure.
Local Building and Safety Departments	Issue building and electrical permits for solar-integrated bike paths, ensuring compliance with local safety codes, zoning laws, and construction standards.
Municipal or Regional Utility Providers	Manage grid connection applications, interconnection agreements, and capacity studies for projects feeding solar energy into the local grid.
City and County Planning Departments	Enforce land use and zoning regulations; may require special use permits or amendments to accommodate solar-integrated bike paths.
Local Transportation Agencies	Oversee integration with existing transportation infrastructure and ensure compliance with multimodal transportation policies.
Community and Stakeholder Groups	Involved in public engagement and project approvals; may include HOAs, local advocacy groups, and planning commissions.

Conclusion

The economic and feasibility analysis of the solar bike path project in Riverside, California, demonstrates the potential of integrating renewable energy into urban infrastructure. Through tools such as PVWatts, SAM, and JEDI, the project analysis highlighted its capacity to generate clean energy, provide financial returns, and create jobs. Additionally, the environmental impact assessment revealed significant reductions in greenhouse gas emissions, contributing to California's broader sustainability goals.

While challenges such as high initial costs, regulatory complexity, and integration with existing infrastructure remain, the benefits of the project—including renewable energy generation, economic growth, and enhanced urban mobility—underscore its viability. The permitting and compliance processes further ensure the project's alignment with legal, environmental, and community standards.

As a pilot initiative, this project provides a conceptual case study for scaling solar bike paths across California and beyond. Its success could serve as a blueprint for similar sustainable infrastructure projects, driving the transition to a low-carbon, resilient future.

Stakeholder Perspectives

The integration of stakeholder perspectives is a cornerstone in evaluating the feasibility, challenges, and opportunities of implementing solar bike paths in California. By engaging with stakeholders and industry experts, the project gained valuable insights into practical, real-world considerations that shape the development of such infrastructure. These perspectives highlight critical themes such as technical barriers, economic challenges, and regulatory complexities while offering strategies to align with California's sustainability and transportation goals.

Stakeholders, representing various sectors as outlined in Table B6, contributed expertise in areas such as renewable energy solutions, engineering, and project development. Their input emphasized the need for tailored solutions to overcome challenges such as voltage drops, vandalism, an issue expected to occur rapidly, as seen in recent cases of public infrastructure damage. Discussions also highlighted the importance of integrating solar bike paths with existing transportation and energy systems to ensure compatibility and maximize benefits.

Conversations guided by the questions listed in Appendix B-1, provided valuable insights into enhancing public engagement, securing financial viability through innovative funding mechanisms, and ensuring equitable benefits for underserved communities. These diverse perspectives not only inform the project's technical design but also shape its broader social, economic, and environmental impact. By addressing stakeholder feedback, solar bike paths can evolve into a sustainable and practical infrastructure solution that advances California's renewable energy and transportation goals.

Stakeholder Insights

Opportunities and Challenges

Stakeholders emphasized the potential of solar bike paths to advance clean energy and sustainable transportation goals. These projects were recognized for their dual benefits: generating renewable energy and enhancing urban infrastructure. Participants highlighted their compatibility with California's broader sustainability objectives, particularly in reducing GHG emissions and supporting renewable energy generation. Opportunities to integrate e-bike charging infrastructure were identified to encourage green transportation and expand user adoption. Additionally, stakeholders noted that utilizing solar power for pedestrian- and cyclist-scale lighting could improve safety and comfort, particularly in low-visibility areas or during nighttime use.

However, significant challenges were identified, including high installation costs, maintenance requirements, and risks of vandalism and theft. Stakeholders stressed the importance of selecting sites with high visibility and consistent monitoring to reduce these risks. Incorporating tamper-resistant designs and robust materials was recommended to enhance durability and security. Financial constraints were a recurring concern, with participants suggesting the need for innovative funding models, such as leveraging state and federal incentives or forming public-private partnerships, to ensure project viability.

Environmental and Social Impacts

Participants underlined the role of solar bike paths in reducing carbon emissions by promoting cycling and generating clean energy. The shading provided by solar structures was recognized for mitigating urban heat island effects, enhancing rider comfort and encouraging year-round bike path usage.

From a social equity perspective, stakeholders emphasized the importance of ensuring these projects benefit underserved communities. Integrating solar bike paths with community solar programs was seen as an effective approach to make clean energy accessible to disadvantaged populations. Participants also recommended prioritizing development in areas with limited transportation options, which could address equity concerns by improving access to sustainable infrastructure. This targeted approach was viewed as critical for aligning solar bike paths with California's environmental justice goals.

Engagement with Key Stakeholders

The success of solar bike path projects was consistently linked to effective stakeholder engagement. Early collaboration with local governments, transportation agencies, utility companies, and community organizations was deemed essential for addressing regulatory, technical, and social considerations. Stakeholders noted that consulting cyclists during the design phase is particularly important to ensure that the infrastructure meets safety and usability needs.

Participants highlighted the value of involving schools and community programs, such as Safe Routes to Schools, to align projects with local priorities and promote their benefits. Proactive public outreach and education campaigns were also recommended to build awareness and enthusiasm for solar bike paths. These efforts can address potential concerns about costs, aesthetics, or usability, ensuring that the projects resonate with the communities they aim to serve. By fostering strong collaboration and aligning project goals with community needs, stakeholders believe solar bike paths can deliver both environmental and social benefits effectively.

Technical and Design Considerations

Grid Integration and Energy Storage

Stakeholders emphasized that connecting solar bike paths to the electrical grid (a process known as grid integration) presents technical challenges. Due to the elongated nature of bike paths, voltage drops, where power weakens over long distances, were identified as a significant concern. To address this, participants recommended the use of microinverters or power optimizers to mitigate losses, though these solutions could raise initial costs.

Strategic site selection near existing grid infrastructure was suggested to minimize the need for extensive wiring and reduce interconnection costs.

Energy storage systems, such as batteries, were highlighted as essential for enhancing project functionality and resilience. Stakeholders noted that localized storage could address demand spikes from integrated charging stations and provide backup power during outages, particularly in regions with frequent grid instability. While storage increases project costs, participants emphasized its potential to improve energy reliability and maximize the utility of solar bike paths in urban and regional settings.

In locations where noise pollution is a concern, solar-integrated noise barriers represent an opportunity to combine environmental and community benefits. Drawing from examples like the Solar Highways project in the Netherlands, incorporating bifacial panels into sound barriers can optimize land use and improve public perception of infrastructure investments

Maintenance and Durability

Participants stressed the importance of designing solar bike paths with durability and low maintenance in mind. Concerns about dirt accumulation, vandalism, and general wear-and-tear from cyclists were frequently cited. Stakeholders recommended incorporating tamper-resistant designs and robust materials to enhance security and reduce maintenance needs. Modular system designs were also highlighted as an effective approach, allowing for quick replacements and repairs without significant disruptions to the infrastructure.

To address soiling, particularly in California's dry and dusty environment, participants suggested exploring self-cleaning technologies or coatings. Proper tilt angles of at least 15 degrees were also recommended to facilitate natural cleaning by rainwater, minimizing energy losses due to dirt buildup.

Adaptability for Green Transportation

The integration of e-bike and EV charging stations was identified as a major opportunity to expand the functionality of solar bike paths. Stakeholders noted that incorporating charging infrastructure would not only increase the utility of the paths but also encourage greater adoption of electric mobility solutions, addressing range anxiety for e-bike users in particular.

Participants emphasized the need for strategic placement of charging stations in high-traffic locations such as parks, campuses, and major intersections where cyclists frequently stop, such as those near transit hubs or popular biking route. Such placement ensures accessibility while maximizing the impact of the infrastructure. Additionally, integrating energy storage systems alongside charging stations was suggested to manage demand peaks and improve energy distribution. By supporting green transportation options, solar bike paths can align more closely with California's broader sustainability goals, making them a valuable addition to the state's clean energy and transportation portfolio.

Policy and Regulatory Considerations

Permitting and Compliance

Navigating California's regulatory landscape remains a key challenge for solar bike path projects. Stakeholders highlighted delays in utility-controlled interconnection processes as a frequent bottleneck, often caused by lengthy permitting timelines and complex procedural requirements. Participants emphasized the importance of early coordination with relevant regulatory bodies, such as local planning departments and utility companies, to streamline the permitting process. Additionally, zoning laws and environmental impact assessments were identified as potential hurdles, particularly in areas with sensitive habitats or urban constraints. Stakeholders recommended establishing clear regulatory frameworks for distributed energy projects to reduce uncertainty and accelerate project timelines. Simplifying permitting procedures for public infrastructure projects could also mitigate delays and associated costs.

Funding Mechanisms and Incentives

Funding challenges were consistently noted as a critical barrier to the implementation of solar bike paths. Stakeholders emphasized leveraging federal incentives, such as the ITC and direct pay options under the IRA, to alleviate upfront costs. State-level clean energy initiatives, particularly programs promoting distributed energy resources and transportation electrification, were also seen as valuable funding pathways.

PPPs were identified as essential for reducing the financial burden on public agencies while leveraging private sector expertise in project design, construction, and maintenance. Stakeholders suggested that PPAs could provide a viable alternative funding mechanism, particularly for projects with long-term energy generation goals. However, participants cautioned that the financial viability of PPAs would depend on favorable electricity rates and long-term commitments from stakeholders.

Learning from Other Projects

Lessons from similar solar infrastructure projects, such as carports and solar canopies, offer valuable insights for solar bike path initiatives. Stakeholders emphasized the importance of robust designs that account for long-term durability and ease of maintenance. Effective maintenance planning was highlighted as a critical factor in ensuring sustained energy production and operational efficiency. Clear energy use cases, such as powering adjacent facilities or integrating with microgrids, were deemed essential for justifying the investment and maximizing project benefits.

International examples, such as South Korea's solar highway [11], were cited as effective models of strategic placement and design. The highway's location between high-traffic lanes provided both visibility and protection from vandalism, offering lessons in site selection and infrastructure security. Adopting these best practices, while tailoring them to California's regulatory and environmental context, could enhance the feasibility and success of solar bike path projects.

Table 6. Summary of Stakeholder Insights on Solar Bike Paths.

Category	Key Insights from Stakeholders
Opportunities	• Solar bike paths support clean energy and sustainable transportation goals. • Potential integration with e-bike and EV charging stations enhances green mobility options. • Aligns with California's climate policies and clean infrastructure investments.
Challenges	• High installation costs require alternative funding mechanisms (e.g., grants, public-private partnerships). • Grid integration issues, such as voltage drops over long distances, pose technical challenges. • Maintenance concerns include soiling, vandalism, and weather-related wear. • Regulatory and permitting barriers slow down project implementation.
Social and Environmental Benefits	• Provides shade and cooling effects, mitigating urban heat island impacts. • Promotes environmental justice by prioritizing underserved communities. • Encourages cycling and green transportation, contributing to GHG emission reductions.
Regulatory and Permitting Barriers	• Lengthy permitting timelines and complex interconnection standards delay project deployment. • Need for pre-approved solar bike path designs to streamline regulatory processes. • Local zoning restrictions may limit deployment in certain areas.
Recommended Strategies	• Early engagement with transportation agencies, utilities, and local governments to resolve regulatory issues. • Developing standardized permitting pathways to expedite approvals. • Pilot projects in high-visibility urban areas to demonstrate feasibility and benefits. • Exploring financial models like PPAs to enhance project viability.

Conclusion

The perspectives shared by stakeholders underscore the significant potential of solar bike paths as a dual-purpose infrastructure, integrating renewable energy generation with sustainable transportation solutions. While challenges such as high initial costs, regulatory complexities, and maintenance concerns pose barriers, the insights also highlight practical strategies to overcome these issues.

Key enablers for success include early engagement with regulatory bodies to streamline permitting processes, leveraging federal and state incentives to address financial constraints, and adopting lessons from established solar infrastructure projects. Public-private partnerships were particularly emphasized as vital for reducing financial burdens while incorporating private sector expertise in design and execution.

Technological innovations, such as modular system designs, tamper-resistant structures, and energy storage integration, can enhance the durability and resilience of solar bike paths. Additionally, strategic site selection and thoughtful grid integration can mitigate technical challenges like voltage drops and high interconnection costs.

The social and environmental benefits of solar bike paths further solidify their value, from reducing urban heat island effects and GHG emissions to improving access to green infrastructure in underserved communities. Stakeholders stressed the importance of inclusive community engagement to ensure these projects address local needs and foster widespread support.

By addressing the technical, financial, and regulatory challenges through collaborative and innovative approaches, solar bike paths can play a pivotal role in advancing California's clean energy and sustainable transportation goals. The insights and strategies outlined provide a roadmap for transforming this concept into a viable and impactful reality.

Challenges and Lessons Learned

Challenges in Implementation

Implementing solar bike paths involves navigating a range of technical, financial, and regulatory challenges. A critical technical difficulty is the integration of solar panels with bike path infrastructure while ensuring reliable energy production and maintaining usability and safety for cyclists. The elongated nature of bike paths often results in voltage drops, which can diminish energy efficiency unless mitigated through advanced technologies such as microinverters or hybrid systems. While these solutions improve performance, they increase the initial project costs.

Site-specific challenges further complicate implementation. Dirt accumulation is a persistent issue on bikeways, often requiring local maintenance efforts to keep paths clear of debris, which can impact safety and infrastructure longevity. Shading from surrounding structures or vegetation can significantly reduce energy yield, as demonstrated in projects like the Solar Highways in the Netherlands.

Vandalism and theft, particularly in isolated areas, pose significant risks to system reliability. Wire theft has been a recurring issue in other infrastructure projects, often leading to frequent outages and increased maintenance costs. Implementing protective measures, such as reinforced cable enclosures, security cameras, and community engagement strategies, may help deter such activity.

The financial feasibility of solar bike paths remains a substantial barrier. High upfront costs, driven by the need for specialized materials and systems, make these projects difficult to justify without innovative funding mechanisms or substantial subsidies. While canopy-mounted systems provide shade and renewable energy benefits, they may also create unintended issues, such as encampments forming beneath the structures. This challenge has been observed in solar projects like those in Freiburg, Germany, and South Korea. Addressing these concerns may require integrating design elements that discourage unintended use while maintaining accessibility.

Additionally, ensuring that the solar infrastructure does not interfere with maintenance vehicle access or cyclist safety is critical. Evaluating cyclist collision rates with similar structures and designing with sufficient clearance can help minimize risks.

Regulatory and permitting processes add complexity. Solar bike paths typically occupy public rights-of-way, necessitating coordination across multiple jurisdictions. Compliance with federal, state, and local regulations, including environmental reviews and interconnection agreements, can delay implementation and inflate costs. Interconnection logistics, particularly in projects located far from grid infrastructure, often require expensive trenching, conduits, and wiring, compounding the financial burden.

Engaging stakeholders presents additional challenges. Aligning the priorities of local governments, utility companies, community organizations, and transportation agencies requires extensive collaboration. Ensuring that project benefits extend to underserved communities adds another layer of complexity, emphasizing the importance of equitable planning and communication.

Lessons Learned

Insights from international and domestic projects highlight critical strategies for overcoming these challenges. Durable and modular system designs have proven effective in minimizing maintenance needs and enhancing project longevity. Features such as cantilevered canopy structures and optimally tilted panels not only improve energy generation but also enhance safety and comfort for cyclists, as demonstrated in Freiburg's solar cycle path roofing.

Projects with clearly defined energy applications, such as supporting e-bike charging stations or contributing to grid stability, are more likely to secure financial and regulatory support. India's Healthway Solar Roof Cycle Track exemplifies how multifunctional infrastructure—combining a 23-kilometer protected bike path with a 16 MW solar array—can generate clean energy for the grid while promoting sustainable mobility, thereby reinforcing the case for projects that align renewable energy generation with tangible transportation and public health benefits.

Engaging stakeholders early in the process is essential. Collaborating with utility companies, local governments, and community organizations ensures that concerns are addressed proactively, and project goals align with community needs. Transparent communication builds trust and fosters public support, as evidenced by the Solar Highways project in South Korea, which involved extensive planning to align with local interests.

Tailoring projects to address equity concerns is vital for maximizing social and environmental benefits. Prioritizing underserved communities and integrating solar bike paths with community solar programs can enhance accessibility to renewable energy and align with broader environmental justice goals. These strategies not only ensure fairness but also contribute to public acceptance and the long-term success of projects.

Global examples such as the Solar Highways in the Netherlands and the SolaRoad in the Netherlands underscore the importance of site selection, robust designs, and multifunctional infrastructure. Strategic placement of installations in high-visibility areas reduces the risks of vandalism and theft while maximizing energy generation and public engagement. These projects demonstrate how careful planning and innovative design can overcome logistical and financial challenges, ensuring long-term sustainability.

Conclusions and Recommendations

Conclusions

Solar bike paths offer a transformative opportunity to combine renewable energy generation with sustainable transportation infrastructure. This study demonstrates that, despite significant challenges, these projects can yield considerable benefits, including reduced GHG emissions, enhanced urban mobility, and contributions to state and local renewable energy goals. Addressing technical, financial, and regulatory barriers is crucial to realizing their potential.

Technical hurdles, such as voltage drops, maintenance demands, and risks of vandalism, necessitate resilient system designs. High initial costs and funding complexities highlight the importance of leveraging public-private partnerships and government incentives. Moreover, navigating regulatory and permitting frameworks requires early coordination with relevant agencies to mitigate delays and associated costs.

Parking lots remain the most cost-effective and scalable surfaces for solar deployment, due to their proximity to energy loads like EV chargers and simpler grid interconnection. However, they do not address active transportation needs or deliver additional co-benefits such as shade, noise mitigation, or improved mobility in underserved areas. This study does not propose that solar bike paths replace parking-lot solar, but rather serve as a complementary strategy—particularly where land-use constraints, equity goals, or multi-functional infrastructure are priorities.

Integrating features such as e-bike charging stations, public lighting, or microgrid applications can improve cost-effectiveness and enhance the value proposition of solar bike paths. Demonstration projects will be essential to validate economic models, build public support, and establish the long-term viability of these systems. To ensure viability, solar bike paths must be designed with integrated use cases that enable electricity to be consumed at or near retail value, rather than relying on export to the grid at wholesale rates.

Recommendations

To maximize the feasibility and impact of solar bike paths, strategic actions are essential:

- **Innovative Design and Technology**: Implement modular and durable systems that balance energy efficiency with usability. Canopy-style structures can provide shade and optimize solar generation, while bifacial panels offer additional energy yield. In locations where noise mitigation is a priority, integrating solar panels into sound barriers can serve dual purposes: reducing traffic noise and generating clean energy. Energy storage systems can further enhance reliability, enable local electricity use, and support grid stability .

- **Financial Strategies**: Leverage federal and state incentives, such as the ITC, IRA, and California's clean energy programs, to address upfront costs. Public-private partnerships can share financial risks and bring private sector expertise to the table. Pilot projects in high-visibility areas can serve as proof of concept and attract broader investment.
- **Value Stacking**: Prioritize on-site energy use to reduce reliance on low wholesale export rates. Co-locating energy demand—such as pathway lighting, e-bike charging stations, or nearby public facilities—can improve financial performance. Site selection should consider where these synergies are most achievable.
- **Innovative Models**: Explore community solar programs to enhance project value, especially in underserved areas. These models allow solar electricity to be shared with local subscribers, increasing the financial return on generation while advancing environmental justice and energy equity goals.
- **Regulatory and Permitting Improvements**: Streamline permitting processes by pre-approving standardized project designs and issuing clear guidelines for integrating solar bike paths into public infrastructure. Early collaboration with utility companies can resolve interconnection challenges more efficiently. California agencies could develop standardized design templates to expedite CEQA review and permitting. Establishing an interagency task force—including Caltrans, the California Public Utilities Commission (CPUC), and the California Energy Commission (CEC)—could further support the creation of an expedited pathway for low-impact solar mobility projects.
- **Stakeholder Engagement**: Proactive and inclusive consultations with communities, local governments, and advocacy groups ensure alignment with real-world needs. Equity-focused strategies can ensure that project benefits to underserved populations.
- **Scalability and Demonstration**: Launch demonstration projects in prominent urban or recreational areas to validate the feasibility and benefits of solar bike paths. These pilot projects can build public trust and support for broader adoption.

By addressing these challenges through innovation, collaboration, and equity-focused planning, solar bike paths can contribute significantly to California's sustainability goals. They represent an opportunity to transform urban infrastructure, integrating renewable energy with modern transportation solutions for a more sustainable and equitable future.

Next Steps for Implementation

To transition solar bike paths from concept to reality, coordinated efforts among policymakers, agencies, and industry stakeholders are essential. The implementation roadmap should focus on pilot projects, regulatory streamlining, funding mechanisms, and long-term scalability.

Short-Term (0-3 Years)

Initial efforts should focus on demonstration projects in urban and high-visibility areas, securing state and federal funding, and simplifying permitting processes. Collaboration with local governments, transportation agencies, and utilities will be critical in establishing standardized designs and streamlined regulatory approvals. Community outreach and stakeholder engagement will help build public support and refine project feasibility.

Long-Term (3+ Years)

With pilot projects validated, the focus should shift to scaling up deployment across California, prioritizing underserved communities and integrating solar bike paths into regional transportation networks. Advances in solar technology, energy storage, and vandalism-resistant designs should be incorporated to improve long-term durability and efficiency. Developing stable funding mechanisms and clear policy frameworks will ensure sustainable expansion and widespread adoption.

By following this phased approach, California can lead the way in solar-integrated transportation infrastructure, creating a cleaner, more resilient mobility system while meeting climate and energy goals.

References

[1] "SB-32 California Global Warming Solutions Act of 2006: emissions limit", https://leginfo.legislature.ca.gov/faces/billNavClient.xhtml?bill_id=201520160SB32

[2] "Low Carbon Fuel Standard", https://ww2.arb.ca.gov/our-work/programs/low-carbon-fuel-standard/about.

[3] "AB32 Climate Change Scoping Plan", https://ww2.arb.ca.gov/our-work/programs/ab-32-climate-change-scoping-plan/2022-scoping-plan-documents

[4] "SB 100 Joint Agency Report", https://www.energy.ca.gov/sb100.

[5] "Project Nexus", https://www.tid.org/current-projects/project-nexus/

[6] UCLA. "A Feasibility Analysis of Installing Solar Photovoltaic Panels Over California Water Canals", https://www.ioes.ucla.edu/wp-content/uploads/2016/10/adeptfinalreport1.pdf, 2022

[7] McKuin, B., et al., "Energy and water co-benefits from covering canals with solar panels". Nature, Sustainability, https://www.nature.com/articles/s41893-021-00693-8, 2021.

[8] "World's first solar cycle lane opening in the Netherlands." The Guardian, Nov. 5, 2014. https://www.theguardian.com/environment/2014/nov/05/worlds-first-solar-cycle-lane-opening-in-the-netherlands. Accessed Dec. 30, 2024.

[9] SolarClue. "India's First Solar Roof Cycling Track in Hyderabad: A Green Future for Urban Mobility." https://blog.solarclue.com/blog/indias-first-solar-roof-cycling-track-in-hyderabad-a-green-future-for-urban-mobility/?utm_source=chatgpt.com. Accessed Feb. 26, 2025.

[10] SOLARWATT. "Germany's First Solar Cycle Path Roofing." https://www.solarwatt.com/company/press/news/germanys-first-solar-cycle-path-roofing#:~:text=Germany's%20first%20solar%20cycle%20path%20completed. Accessed Dec. 30, 2024.

[11] ABC News. "Solar Panel Bike Lane Generates Eco-Friendly Energy in South Korea." https://abcnews.go.com/International/solar-panel-bike-lane-generates-eco-friendly-energy/story?id=90197800. Accessed Dec. 30, 2024.

[12] PEDAL AND TRING TRING, "INDIA'S 1ST SOLAR ROOF CYCLE TRACK IN HYDERABAD." https://pedalandtringtring.com/2023/09/30/indias-1st-solar-roof-cycle-track-in-hyderabad/?utm_source=chatgpt.com. Accessed Sep. 30, 2023

[13] ArcGIS, Esri's enterprise geospatial platform. https://www.esri.com/en-us/arcgis/geospatiallatform/overview. Accessed Dec. 30, 2024.

[14] PVWatts, NREL. https://pvwatts.nrel.gov/. Accessed Dec. 30, 2024.

[15] The System Advisor Model™ (SAM™), NREL. https://sam.nrel.gov/. Accessed Dec. 30, 2024.

[16] JEDI, NREL. https://www.nrel.gov/analysis/jedi/. Accessed Dec. 30, 2024.

[17] "City of Riverside Bike Lane Map", https://www.arcgis.com/apps/Profile/index.html?appid=c691fc450bc241668cf17692ee92d3d0

[18] "City of Riverside Bicycle Master Plan. May 22, 2007". https://riversideca.gov/pworks/pdf/masterplan-bicycle/Bicycle_Master_Plan.pdf

[19] Solar Installed System Cost Analysis. NREL. https://www.nrel.gov/solar/market-research-analysis/solar-installed-system-cost.html. Accessed Dec. 30, 2024.

Data Summary

Products of Research

- **BikePaths_Riverside.lpkx**: A geospatial layer detailing bike paths in Riverside, used for spatial measurements and site selection
- **SAM_Input_Variable_Values.xlsx**: Input parameters for the SAM, including system specifications and financial assumptions
- **SAM_Results_Summary.xlsx**: Simulation outputs from SAM, detailing energy production, financial metrics, and economic performance
- **JEDI_Results_Summary.xlsx**: Results from the JEDI model, summarizing job creation and economic impacts
- **PVWatts_Results.pdf**: Energy production estimates and greenhouse gas emission reductions from the PVWatts tool

Data Format and Content

- **BikePaths_Riverside.lpkx**: A geospatial layer package compatible with ArcGIS software, used for spatial analysis of bike paths.
- **SAM_Input_Variable_Values.xlsx**: A spreadsheet in .xlsx format documenting input variables used in SAM simulations.
- **SAM_Results_Summary.xlsx**: A spreadsheet in .xlsx format summarizing SAM simulation results, including energy output and financial metrics.
- **JEDI_Results_Summary.xlsx**: A spreadsheet in .xlsx format containing JEDI model results, including job creation metrics.
- **PVWatts_Results.pdf**: A report in .pdf format containing energy production estimates and greenhouse gas emission reductions.

Data Access and Sharing

The data generated during the project will be made available through the Dryad repository, with most datasets accessible under a Creative Commons Attribution (CC BY) license. However, the BikePaths_Riverside.lpkx ArcGIS layer file, sourced from ArcGIS Online, cannot be shared directly due to external licensing restrictions. Instead, users will be provided with information on how to access the file through its original source.

Reuse and Redistribution

Project datasets shared via Dryad can be reused and redistributed under a CC BY license, ensuring openness while requiring proper attribution. However, the ArcGIS layer file is governed by external licensing terms, and redistribution is prohibited. Users must follow the licensing terms provided by the original publisher for this file. The dataset should be cited as follows:

[citation from Dryad]

Appendix A

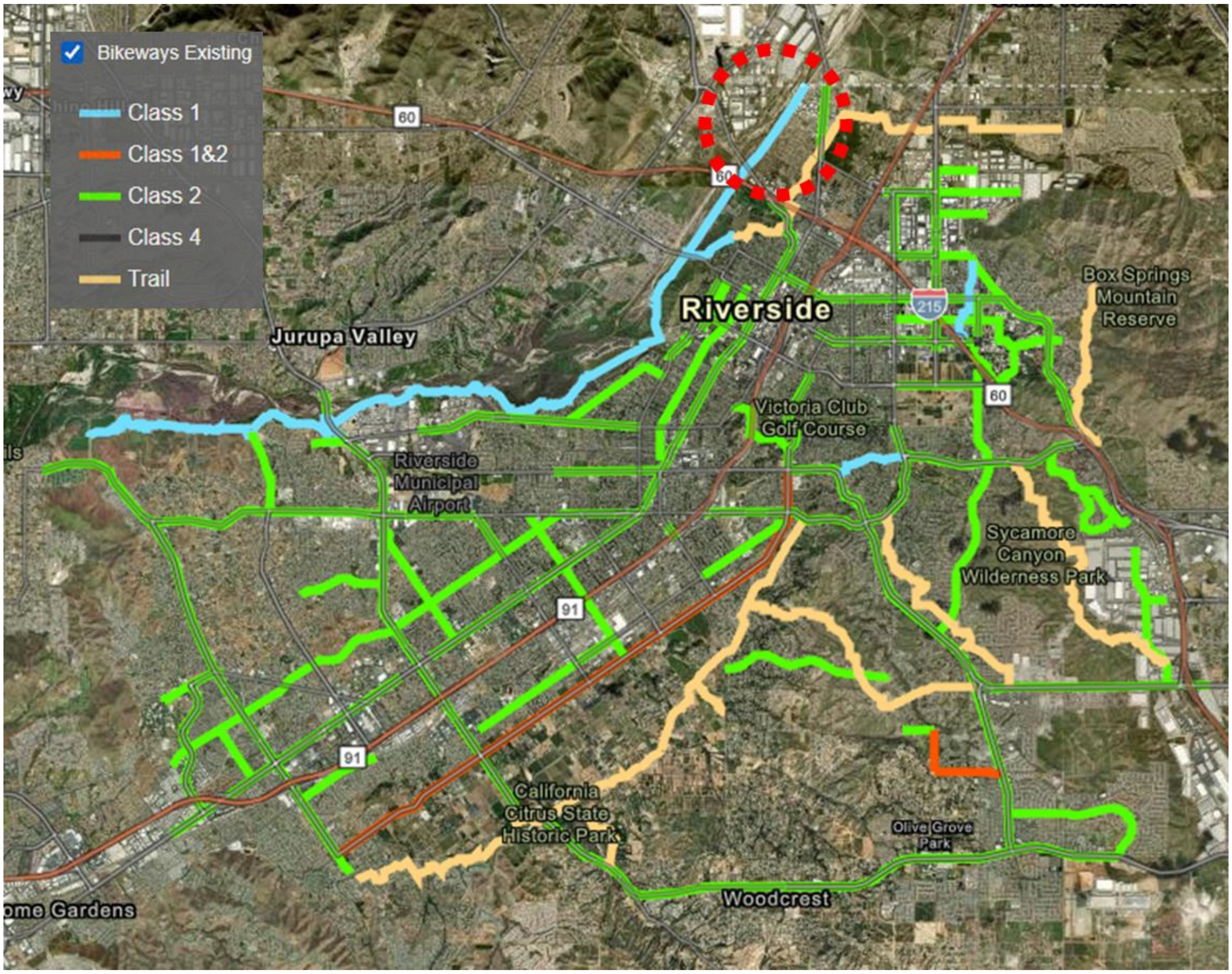

Figure A1. Existing bikeways in the city of Riverside from the ArcGIS external Existing bikeways in the City of Riverside from ArcGIS online data, developed as part of the Riverside Bicycle Master Plan (2007).

Metric	Value
Annual AC energy in Year 1	1,671,991 kWh
DC capacity factor in Year 1	18.9%
Energy yield in Year 1	1,659 kWh/kW
Performance ratio in Year 1	0.80

Project Metrics	
LCOE Levelized cost of energy nominal	15.83 ¢/kWh
LCOE Levelized cost of energy real	12.64 ¢/kWh
PPA price in Year 1	15.00 ¢/kWh
LPPA Levelized PPA price nominal	16.21 ¢/kWh
LPPA Levelized PPA price real	12.94 ¢/kWh
Net capital cost	$3,616,818
Equity	$1,814,668
Size of debt	$1,802,150
Debt percent	49.83%

Developer Metrics	
IRR Developer internal rate of return	7.72%
Year developer IRR is achieved	20
NPV Developer net present value	$60,570

Host Metrics	
Host net present value	$-1,867,734
Host indifference point in year 1	3.41¢/kWh
Host indifference point levelized nominal	4.33¢/kWh
Host indifference point levelized real	3.46¢/kWh

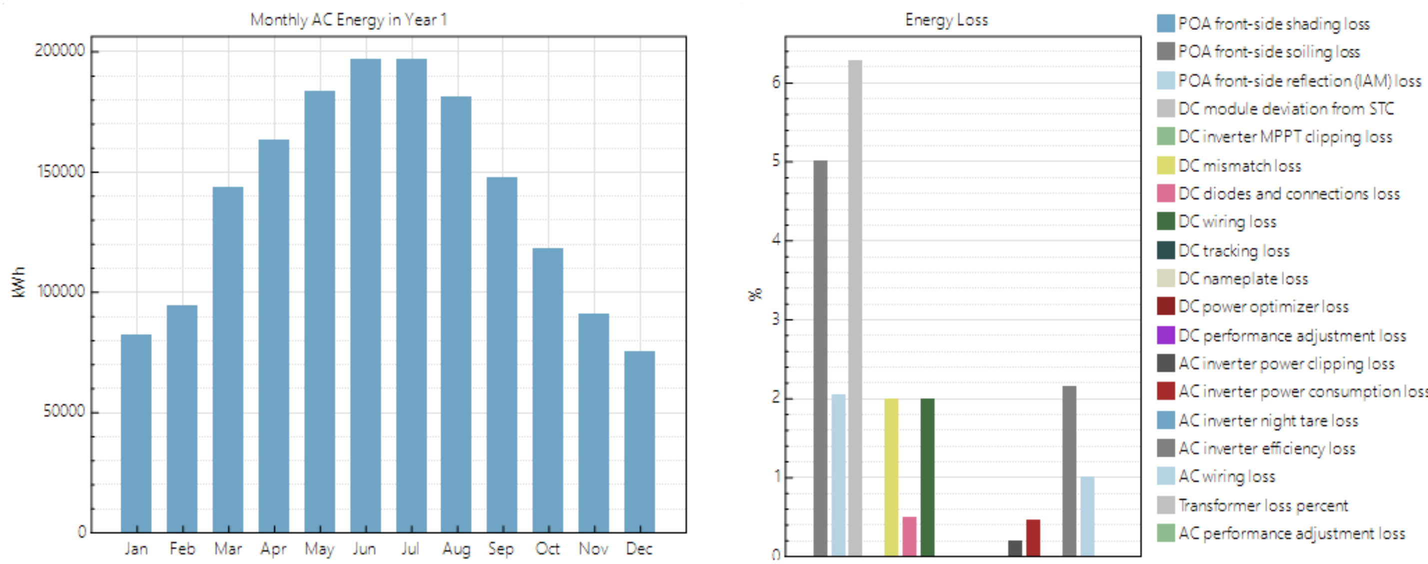

Figure A2. Results of the SAM financial and performance simulation. This figure illustrates the system's long-term financial viability under SAM analysis, with real LCOE at 12.64¢/kWh.

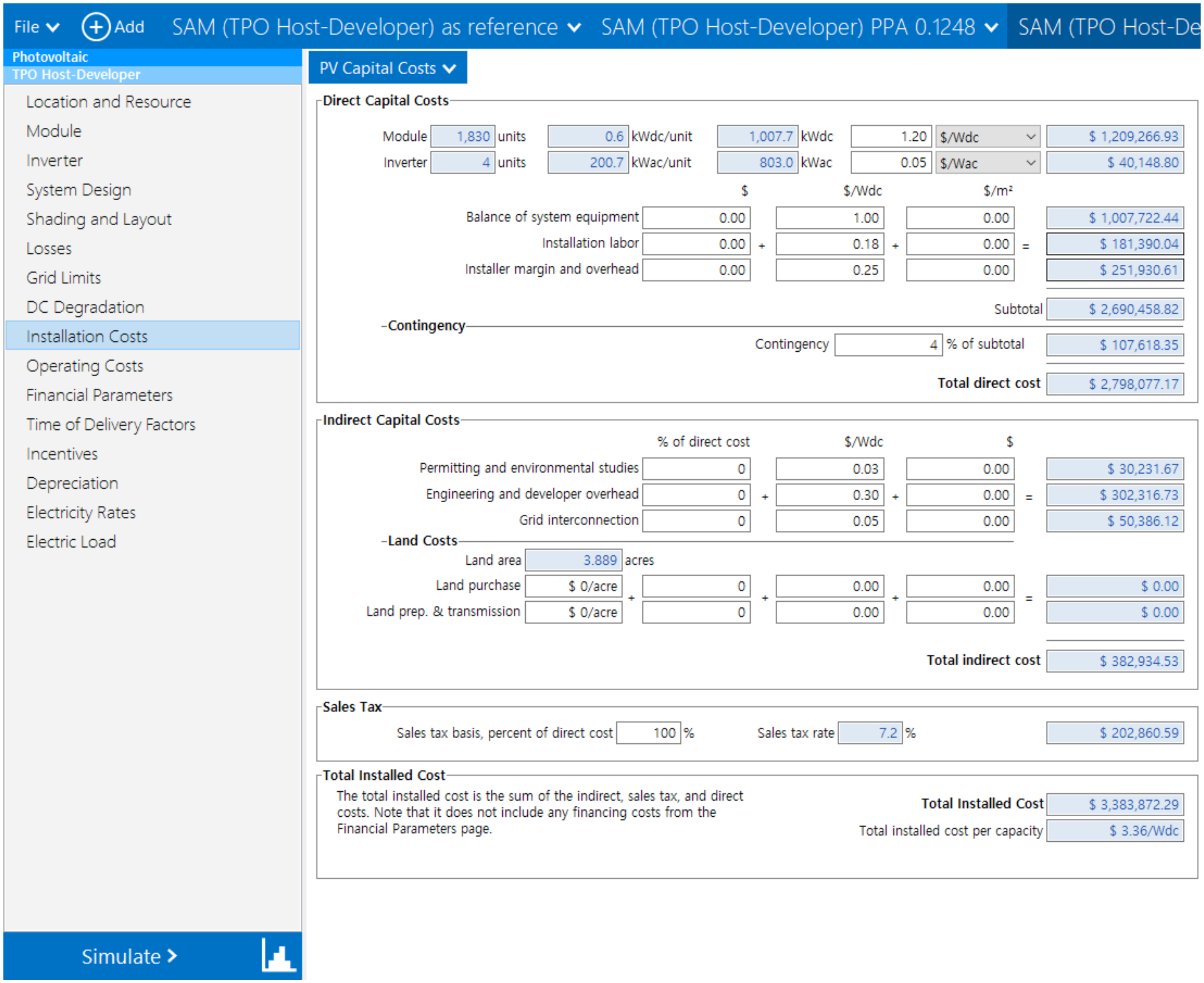

Figure A3. Estimated installation cost per capacity based on SAM analysis. Depicts cost breakdown per watt for system installation, highlighting capital intensity.

Appendix B

Table B1. Site specifications and solar system configuration for the solar bike path project in Riverside.

Parameter	Value
Distance	1 mile
Width	11 ft
Total Area	58,080 square feet
Module Size	89.72 x 44.64 x 1.38 inches (assumed)
Number of Solar Panels	2,087 panels
Panel Orientation	Portrait
Power Output	550 watts
Total System Size	1,147.85 kW

Table B2. Input parameters and configuration settings for PVWatts energy generation estimate.

System Size	**1,147.85 kW**					
Annual AC Energy	2,022,343 kWh/year					
Module Type	Premium (21% efficiency)					
Array Type	Fixed (open rack)					
System Losses	11.08%					
Array Tilt	20°					
Array Azimuth	180°					
DC to AC Size Ratio	1.2					
Inverter Efficiency	96%					
Ground Coverage Ratio	0.4					
Albedo	*From weather file*					
Bifacial	No (0)					
Monthly Irradiance Loss	Jan	Feb	Mar	Apr	May	June
	0%	0%	0%	0%	0%	0%
	July	Aug	Sept	Oct	Nov	Dec
	0%	0%	0%	0%	0%	0%
DC Capacity Factor	20.1 %					

Table B3. Input parameters for JEDI analysis.

Parameter	Value
Project Location	California
Year of Construction or Installation	2030
System Application	Commercial
System Tracking (Utility - Defaults always assume fixed mount for commercial and residential)	Fixed Mount
Average System Size - DC Nameplate Capacity (kW)	1,000
Number of Systems Installed	1
Total Project Size - DC Nameplate Capacity (kW)	1,000
Base Installed System Cost ($/kW$_{DC}$)	$3,360
Annual Direct Operations and Maintenance Cost ($/kW)	$15.00
Money Value (Dollar Year)	2030

Table B4. JEDI results during construction and installation period.

	Jobs	Earnings $000 (2026)	Output $000 (2026)	Value Added $000 (2026)
Project Development and Onsite Labor Impacts				
Construction and Installation Labor	3.6	$236.1		
Construction and Installation Related Services	4.3	$402.0		
Subtotal	7.9	$638.1	$1,207.9	$951.1
Module and Supply Chain Impacts				
Manufacturing Impacts	0.0	$0.0	$0.0	$0.0
Trade (Wholesale and Retail)	1.5	$141.5	$513.8	$316.7
Finance, Insurance and Real Estate	0.0	$0.0	$0.0	$0.0
Professional Services	1.0	$82.1	$254.4	$158.6
Other Services	1.8	$284.0	$775.8	$486.6
Other Sectors	4.0	$179.8	$422.2	$283.6
Subtotal	8.3	$687.4	$1,966.3	$1,245.6
Induced Impacts	4.2	$293.6	$1,061.3	$644.0
Total Impacts	20.4	$1,619.1	$4,235.5	$2,840.7

Table B5. JEDI results during operating years.

	Annual Jobs	Annual Earnings $000 (2026)	Annual Output $000 (2026)	Annual Output $000 (2026)
Onsite Labor Impacts				
PV Project Labor Only	0.1	$8.4	$8.4	$8.4
Local Revenue and Supply Chain Impacts	0.0	$2.3	$8.6	$5.2
Induced Impacts	0.0	$1.1	$4.0	$2.4
Total Impacts	0.2	$11.8	$20.9	$16.0

Notes: Earnings and Output values are thousands of dollars in the year 2026 dollars. Construction and operating period jobs are full-time equivalent for one year (1 FTE = 2,080 hours). Economic impacts "During operating years" represent impacts that occur from system/plant operations/expenditures. Totals may not add up due to independent rounding.

Table B6. Stakeholder types and areas of expertise for the interview.

No.	Stakeholder Type	Industry/Expertise
1	Public Agencies	Project development and sustainability
2	Public Agencies	Project management and renewable energy solutions
3	EPC Firms	Engineering, system design, and construction
4	EPC Firms	Electrical engineering and project execution
5	Renewable Energy Advisors	Renewable energy policy and project development
6	Renewable Energy Providers	Sales, renewable energy strategies, and solutions
7	Renewable Energy Consultants	Renewable energy solutions and grid integration
8	Solar Energy Providers	Solar energy solutions and installation
9	Solar Energy Providers	Solar installation and energy solutions
10	Energy Storage Firms	Energy storage solutions and project development
11	Solar Energy Providers	Solar energy operations and installation
12	Electrical Contractors	Commercial project engineering and energy solutions

Appendix C: Glossary of Technical Terms

Table C1. Glossary of Technical Terms.

Term	Definition
LCOE	Levelized Cost of Energy – the average cost per kilowatt-hour (kWh) of building and operating a generating plant over its lifetime.
DC-to-AC Ratio	The ratio of the system's direct current (DC) capacity to its alternating current (AC) inverter capacity, affecting energy conversion efficiency.
Microinverter	A device installed on individual solar panels to convert DC to AC and optimize output independently.
Albedo	A measure of how much sunlight a surface reflects; important in solar modeling for estimating reflected light contributions.
PVWatts	A modeling tool from NREL that estimates the energy production of grid-connected photovoltaic systems.
SAM (System Advisor Model)	A performance and financial modeling tool developed by NREL for evaluating renewable energy projects.
JEDI Model	Jobs and Economic Development Impact – a model from NREL used to estimate economic impacts of energy projects, including job creation.
Bifacial Panel	Solar panels that can absorb sunlight from both their front and back sides, improving efficiency under certain conditions.
Array Tilt	The angle at which solar panels are inclined from the horizontal to maximize exposure to sunlight.
Azimuth Angle	The compass direction that a solar panel faces, typically optimized for solar gain (e.g., 180° = south-facing in the Northern Hemisphere).
LCOE	Levelized Cost of Energy – the average cost per kilowatt-hour (kWh) of building and operating a generating plant over its lifetime.
DC-to-AC Ratio	The ratio of the system's direct current (DC) capacity to its alternating current (AC) inverter capacity, affecting energy conversion efficiency.

Appendix D: List of Interview Questions

General Insights on Solar Bike Paths

I. **Opportunities and Challenges:**

- What are the primary challenges associated with integrating solar power into bike paths, particularly in an urban and transportation context?
- How can solar bike paths be leveraged to support California's and Caltrans' energy and transportation goals effectively?
- Are there any similar projects, either domestically or internationally, that offer valuable lessons or best practices that California can adopt?

II. **Environmental and Social Impact:**

- In what ways can solar bike paths contribute to California's environmental goals, such as carbon emission reductions and renewable energy advancement?
- What strategies should be implemented to ensure these projects deliver benefits to disadvantaged communities or address environmental justice concerns?

III. **Stakeholder Involvement:**

- How should various stakeholders (e.g., local governments, transportation agencies, cyclists, residents) be engaged during the planning and development of solar bike paths to ensure their interests and needs are considered?
- What are the most effective strategies for gaining public support and enthusiasm for these solar bike path projects?

Technical and Design Considerations

I. **Grid Integration:**

- What are the critical considerations for designing solar bike paths that connect with and feed energy into the grid? What technical barriers, especially those related to California's energy grid infrastructure, might arise?
- How could solar bike paths be adapted to support other green transportation options, such as electric vehicles (EVs) or e-bikes, and what specific infrastructure would be required?

II. **Maintenance and Longevity:**

- What maintenance issues might occur with solar panels embedded in bike paths (e.g., dirt accumulation, vandalism, damage from bike traffic), and how can they be mitigated?
- What design features are essential for ensuring the durability and longevity of solar bike paths, particularly in natural habitats or urban areas?

III. **Resilience and Storage:**

- How can solar bike paths be engineered to withstand California's environmental conditions, including wildfires, extreme heat, and seismic activity?
- Is it feasible to store solar energy generated by bike paths locally for use during grid outages or emergencies? What role could energy storage systems play in this scenario?

Policy and Regulatory Environment

I. **Permitting and Code Compliance:**

- What potential regulatory or permitting challenges might arise when developing solar bike paths, and what strategies could effectively address these issues?
- Are there specific local, state, or federal policies that could either facilitate or hinder the development of solar-integrated bike paths?

II. **Financing and Partnerships:**

- What are the key funding mechanisms or financial incentives available to support the development of solar bike paths in California?
- How critical will public-private partnerships be in advancing this project, and what roles could industry players or utility companies take on?

III. **Learning from Other Solar Projects:**

- Based on your experience with other solar initiatives or projects, what best practices or lessons should be applied to the development of solar bike paths?
- What factors typically contribute to the success or failure of large-scale solar projects, and how can these lessons be incorporated into this initiative to enhance its chances of success?