New Toolkit for Outdoor Lighting Baseline Updates

Final Report

ET24SWE0055

Prepared by:

Sagar Deo, TRC
Michael Mutmansky, TRC
Alfredo Jahn, TRC
Jenna Lusczynski, TRC

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TAG members included:

Brett Close, TRC

Darcie Chinnis, HLB Lighting

Ron Gibbons, Virginia Tech

Kevin Houser, Oregon State University

Russ Large, TRC

Naomi Miller, N. M. Lighting Design

Morgan Pattinson, SSLS, Inc.

Todd Slind, TRC

Jae Yong Suk, University of California Davis

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Executive Summary

The primary goal of this study is to develop a new toolkit for conducting an outdoor lighting baseline study for California. This project and subsequent baseline study is crucial for updating the assumptions used in energy efficiency program design, codes and standards development, and for validating baseline energy load profiles in eTRM. Given the significant advancements in outdoor lighting technology since the last baseline study in 2003, an update to the information used to establish nonresidential outdoor lighting energy consumption is both necessary and warranted.

The project team developed a framework to categorize different types of data pertaining to outdoor lighting into static and dynamic attributes and different data collection methods into high fidelity and low fidelity methods. We recommend implementing a hybrid approach using both high and low fidelity methods to balance accuracy and resource constraints. This will involve developing a sample of sites, applying both high and low fidelity methods to a sub-sample, and using inference models to enhance the data for sites collected only using the low fidelity methods. Figure 1 provides an overview of the data collection framework, and the Data Collection Framework section of this report provides more details about the hybrid approach proposed by the project team.

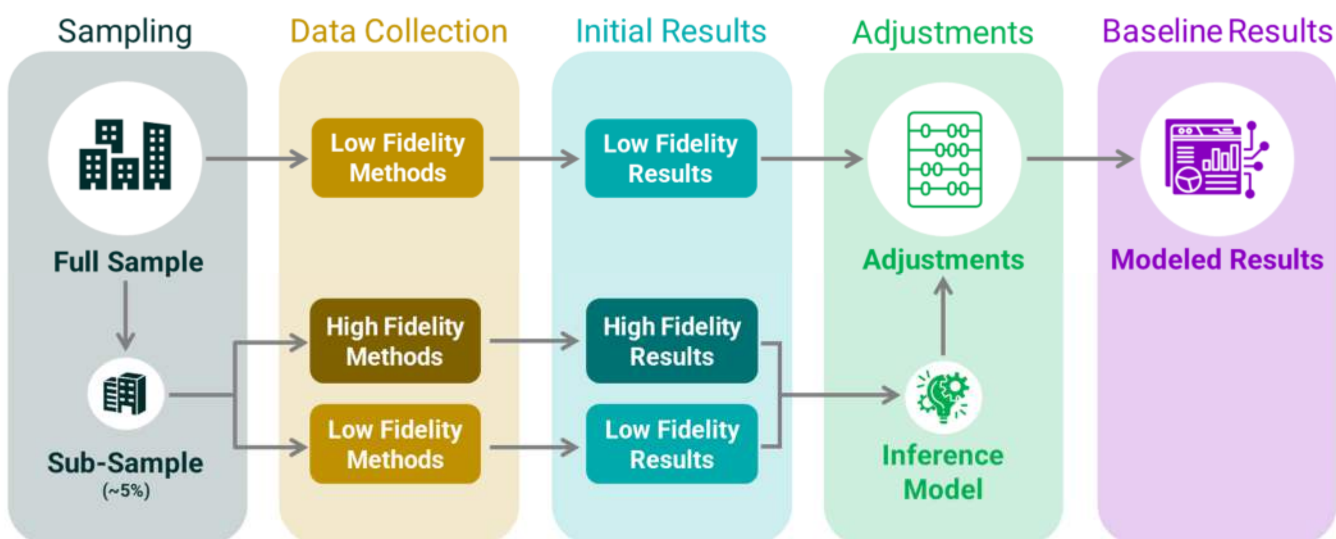

Figure 1: Overview of data collection framework.

The project team conducted a comprehensive review of promising high fidelity and low fidelity data collection methods. Following an in-depth technology review, along with gathering input from subject matter experts and industry stakeholders, the project team developed the following shortlist of data collection methods:

- **High fidelity methods**: Outdoor lighting audits, questionnaire-based surveys with facility managers or lighting technicians, and data loggers and current taps to monitor usage patterns and lighting energy consumption over time.
- **Low fidelity methods:** Use of satellite imagery or Google Street View, deployment of drones or balloons with instrumentation to capture overhead imagery and lighting characteristics, and use of vehicle-based drive-through surveys.

These methods form the foundation of a hybrid data collection strategy that balances the depth of high fidelity techniques with the reach and efficiency of low fidelity approaches. The integration of both methods supports the development of an inference model to interpolate across gaps in low fidelity data. Using the inference model will enable the project team to combine the precision of high fidelity data and the scalability of low fidelity data by helping train predictive relationships between data collected using low fidelity methods and true values confirmed via high fidelity methods. This will allow the project team to estimate key static and dynamic attributes for a much larger number of sites by applying calibration adjustments to data collected using low fidelity methods. The project team will develop these calibrated models using the following steps:

- **Step 1**: Identify and categorize different static and dynamic attributes.
- **Step 2**: Determine data collection feasibility.
- **Step 3**: Collect high fidelity and low fidelity data for a representative sample of sites.
- **Step 4**: Develop inference models.
- **Step 5**: Continuously refine the inference models as additional data is collected.

Table 6 in the Findings section provides an overview of how the project team will develop and apply the inference model to important attributes that are essential for a future baseline study.

Based on the analysis, stakeholder engagement, and evaluation of various data collection approaches, the project team offers the following actionable recommendations:

- Future data collection efforts should incorporate greater use of low fidelity data collection methods because they demonstrate potential for scalability and ease of implementation, and can enable rapid, cost-effective data acquisition, particularly for static attributes.
- Use the inference model proposed in this study as a core component of future baseline efforts. The model can be trained to calibrate or predict key lighting attributes across the full dataset by integrating data from high fidelity and low fidelity collection methods. This approach will help reduce overall costs and labor requirements while preserving accuracy.
- Conduct a focused follow-up project to pilot the shortlisted high fidelity and low fidelity data collection methods in real-world conditions to assess each method's viability, cost, and accuracy.

Abbreviations and Acronyms

Acronym	Meaning
AI	Artificial intelligence
CASE	Codes and Standards Enhancement
GIS	Geographic Information System
HF	High fidelity data collection method
HID	High-intensity discharge
HPS	High-pressure sodium
LED	Light-emitting diode
LF	Low fidelity data collection method
LiDAR	Light Detection and Ranging
MH	Metal halide
SME	Subject matter expert
TAG	Technical advisory group

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Introduction

This report presents findings from the research to develop a new toolkit for conducting an outdoor lighting baseline study for California. The project team used these findings to develop an array of field data collection methods and conducted interviews with industry stakeholders to get their feedback on the proposed methods.

The findings summarized in this report are a result of the following research activities the project team has undertaken to date:

- Assessing the data fields collected in the previous outdoor lighting baseline study.
- Developing a framework for collecting data about outdoor lighting.
- Convening a technical advisory group (TAG) of subject matter experts to provide the current best-practice field methods for outdoor lighting audits in general.
- Conducting interviews with different industry stakeholders.
- Conducting research into the different data collection methods identified through TAG and stakeholder engagement.

The following sections of this report provide additional details about the background and motivation for this research, its goals and objectives, the methodology used for conducting the analysis, and the findings and recommendations from the research activities undertaken as part of this project.

Background

When the first—and currently, only—California Outdoor Lighting Assessment study was completed in 2003, metal halide (MH) and high-pressure sodium (HPS) lamps, which are collectively included in the high-intensity discharge (HID) category, were the primary light sources chosen for high-output applications in the nonresidential and roadway spaces. Linear fluorescent, compact fluorescent, and even halogen and incandescent lighting sources were all used in outdoor lighting tasks in commercial properties, but less often.

Outdoor lighting systems have evolved considerably since then. Light-emitting diode (LED) light sources now dominate the market for new construction, and there has been a considerable push toward LED technology in existing stock through retrofit programs and equipment attrition.

LED light sources are not only considerably more efficient but are also an enabling technology for much more sophisticated outdoor lighting controls, including instantaneous on/off capabilities and dimming to 10 percent or lower of full output, neither of which had been cost-effectively possible with HID or fluorescent light sources. These new capabilities enable the application of more advanced outdoor lighting controls approaches and technologies, including motion-responsive switching and dimming, time-of-night scheduling, addressable control heads, and more. The increased potential for sophisticated controls—combined with the possibility of sites not meeting their lighting power allowances—could lead to savings calculations that overstate lighting savings when using the presumption of fully lighted site conditions for the prototype buildings in the Title 24 Statewide Codes and Standards Enhancement Team (CASE) Report energy calculations.[1]

The outdoor lighting codes that California adopted in 2008 were partially informed by the original 2003 baseline study. While these codes have been revised every three years as lighting sources and controls have improved, the baseline study has not been updated since 2003; the study is now over 20 years old, and nearly 25 years have passed since the site data collection occurred.

An outdoor lighting baseline study is fundamental in establishing the opportunity presented by old and outdated lighting technology and controls approaches. Therefore, it is important to revisit the old study to ensure that the assumptions used for energy efficiency program design and codes and standards development are accurate.

The previous outdoor lighting baseline study relied on field observations and accounting of the installed lighting equipment and estimating the connected load of the lighting systems by calculating the total load to account for ballast losses based on the light source technology and the specific parameters of the lighting equipment wattage. The hours of operation and load profile were collected through interviews with the property owners and observation of the lighting controls on the system but mostly involved applying simplistic timeclock controls that were based on a photocell and occasional late-night shutoff. Due to the rapid shift toward the prevalence of LED fixtures, more sophisticated controls, and the addition of lighting controls under certain circumstances in the energy code, these methods are no longer suitable to provide an accurate assessment of parameters like site equipment type, connected load, and nightly load profiles. Therefore, it is necessary to develop new data collection methods for collecting outdoor lighting's performance information.

Objectives

The project team conducted this research with the following goals:

- Find solutions to the added difficulty that LEDs and complex controls have brought to producing accurate field audit data collection and energy modeling based on these audits.
- Engage lighting and data collection experts and other industry stakeholders to establish new methods of outdoor lighting data collection.
- Explore and characterize new data collection methods for collecting performance information on different outdoor lighting systems installed in California.

At the conclusion of this project, the project team will recommend an array of data collection methods for validation and testing in the field.

[1] Note that this potential overestimation of energy savings is possible in all CASE Report calculations when based on the industry "just" meeting the lighting power allowances on the property—therefore being code-compliant, but essentially not "better" than code in any manner. Part of a baseline study is to better understand how close to the site allowances the lighting system might be, and to account for that in energy savings calculations in CASE. In the previous baseline study, a considerable amount of the sites were not meeting the Illuminating Engineering Society (IES) design criteria recommendations and therefore were likely under the lighting power allowances for the site.

Methodology and Approach

To develop and assess the data collection methods, the project team structured this research into five key tasks, which are detailed in this section.

Task 1: Develop Data Requirements

The project team reviewed the data collected in the previous outdoor lighting baseline study to understand its structure, scope, and limitations. This review helped categorize the existing data and identify any gaps due to the increased adoption of LED lighting.

Based on this assessment, the team developed a data collection framework to organize and structure the data requirements. This framework served as a foundation for brainstorming and evaluating data collection methods in a systematic and effective manner.

Task 2: Technical Advisor Group (TAG) Data Collection

The project team assembled a TAG composed of subject matter experts (SMEs) from diverse fields, including lighting, field data collection, drone applications, Geographic Information Systems (GIS), sampling methodologies, and statistical analysis. TAG members were compensated for their time and contributions.

The project team first conducted an online workshop with the TAG to brainstorm potential data collection methods. The objective of this workshop was to leverage the expertise of TAG members to identify, share, and discuss data collection techniques they have used or encountered in their respective fields. Following the workshop, the project team assessed and refined the proposed methods, distilling them into a set of structured and viable data collection approaches.

Once the methods were formalized, the team reconvened with TAG members in a follow-up meeting to present the refined approaches and gather additional feedback. This iterative process helped ensure that the final data collection methods were practical, effective, and aligned with industry best practice.

Task 3: Industry Stakeholder Surveys and Interviews

Following the development of the draft data collection methods, the project team engaged a group of industry stakeholders to gather feedback and refine the proposed approaches. These stakeholders included system design professionals, utility representatives, and field technicians.

The primary objective of these interviews was to assess the feasibility and practicality of the proposed data collection methods, as well as to collect definitive information on what data utilities will need to enable better programs. The project team asked the stakeholders to provide insights on potential challenges, limitations, and opportunities for improvement. This feedback helped refine the methodologies to ensure they were both effective and implementable in real-world settings.

Task 4: Final Field Methods and Reporting

The project team then developed the final data collection methods and reported them out in accordance with the CalNEXT requirements.

Findings

This section presents the findings from the research conducted as part of this study. First, the project team first assessed the data fields collected in the previous outdoor lighting baseline study and used these insights to develop a structured data collection framework. Next, we convened a TAG of subject matter experts to gather insights on current best practices for field data collection. The team then identified key industry stakeholders for interviews, developed an interview guide to facilitate structed outreach, and performed the interviews. Finally, we performed additional research into the different data collection methods that came out of the TAG and industry stakeholder engagements to develop our final list. The project team used the findings from this comprehensive approach to develop new data collection methods detailed in this section.

Data Collection Framework

The project team created a data collection framework to ensure a structured and comprehensive approach to developing new data collection methods. This framework categorizes different types of data points that an outdoor lighting baseline study will collect, and the corresponding methods that will be used to collect them. This helps ensure that the project team considers all the different types of data points while developing data collection methods and establishes common terminology among all stakeholders, which reduces misunderstandings.

The project team began by reviewing the data points collected in the previous outdoor lighting baseline study and assessed their relevance to a future study. Given the rapid adoption of LED lighting sources, the project team also considered any new data points that may be required. Appendix A: Data Points for Outdoor Lighting Baseline Study includes a detailed list of data points from the previous outdoor lighting baseline study that the project team found relevant for a study.

The project team then categorized these data points into two broad categories:

- **Static attributes.** These data points remain constant or do not vary significantly over time. They include characteristics that technicians can directly observe or record in the field without needing extensive temporal measurements. Examples include fixture and lamp type, make and model number, land use type, building area, type of controls, fixture count, rated fixture wattage, etc.
- **Dynamic attributes.** These data points vary over time and require more complex data collection strategies. Examples include fixture output and wattage, operating hours, dimming schedule, etc.

The project team also categorized potential data collection methods into two categories:

- **High fidelity (HF) methods.** These methods are the gold standard and provide the most precise estimates. They are more resource-intensive and less scalable, and often involve sensor-based data logging, direct field observations and measurements, detailed audits, etc.
- **Low fidelity (LF) methods.** These methods are often indirect measurements with less precision—less resource-intensive and more scalable. They often involve timelapse or nighttime drone imaging, satellite imaging, vehicle-based mobile surveys, etc.

To strike a balance between accuracy and data collection costs, the project team developed a hybrid data collection schema that uses a combination of both HF and LF methods. This approach requires doing the data collection in the following phases:

- **Sampling:** Develop a full sample of sites that represent the broader population of outdoor lighting installations across California and select a sub-sample of sites from the full sample before moving to the next step.
- **Data Collection:** Apply both HF and LF methods to collect data for the sites included in the sub-sample and apply LF methods to the remainder of sampled sites that were not a part of the sub-sample.
- **Initial Results:** Analyze initial results and compile all the collected data in a dataset that can be used for further analysis.
- **Adjustments:** Train an inference model using the data collected by applying both HF and LF data collection methods on the sub-sampled sites. Use the inference model to develop adjustments that can be applied to the data collected using LF methods.
- **Baseline results:** Apply adjustments from the inference model to the data collected using LF methods for all the sites in the sample that were not included in the sub-sample.

Figure 2 below provides an overview of the data collection framework, illustrating how the project team characterized different data points and the different fidelity approaches that can be used for collecting data. This structured approach will serve as the foundation for development and evaluation of different data collection methodologies.

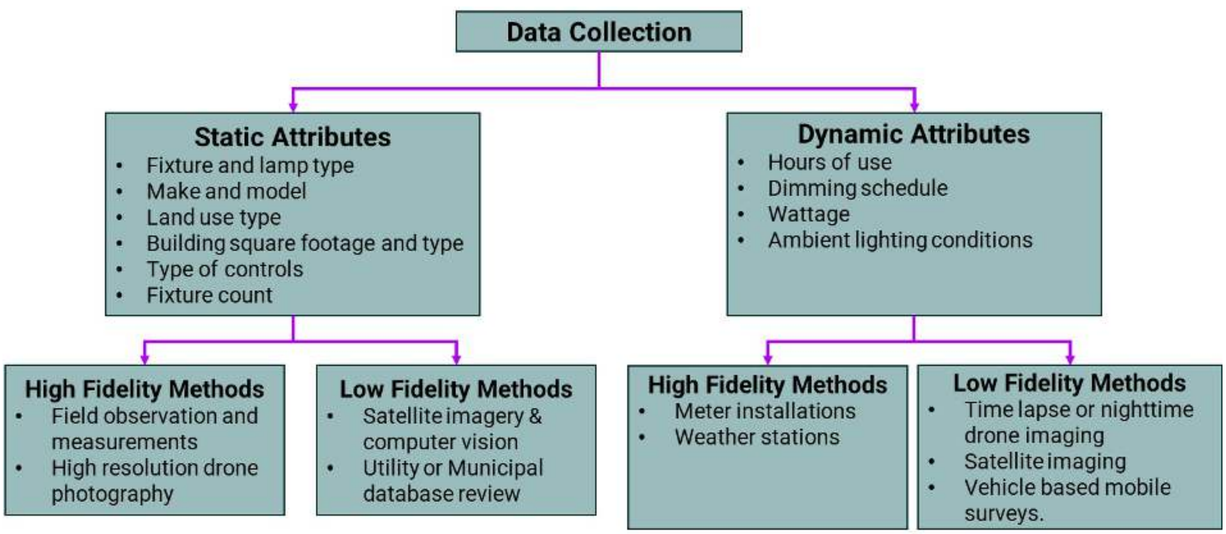

Figure 2: Overview of data collection framework.

Figure 3 below provides an overview of the hybrid approach that can help optimize accuracy and costs by leveraging both high and low fidelity data collection methods.

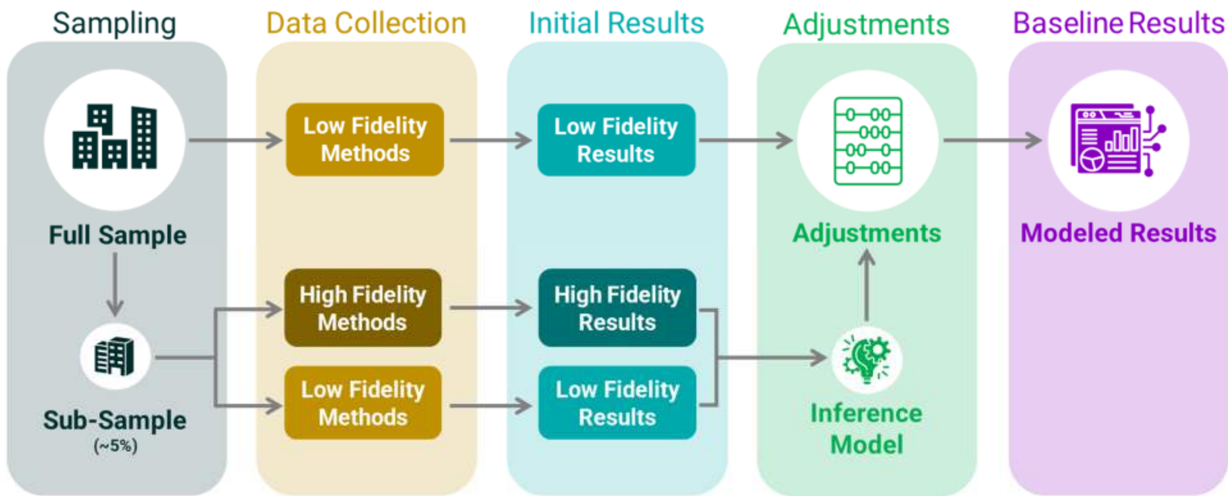

Figure 3: Overview of the hybrid approach used to develop the inference model.

TAG Engagement

To ensure a well-rounded discussion and help leverage expertise from different domains, the project team assembled a TAG comprising SMEs from various key disciplines relevant to outdoor lighting data collection.

The TAG included representation from:

- **Lighting SMEs:** Experts in lighting technologies, industry trends, and field applications.
- **Field data collection SMEs:** Specialists with hands-on experience in collecting and verifying outdoor lighting data.
- **Statistical modeling SMEs:** Experts in data modelling, calibration techniques, and ensuring data representativeness.
- **GIS SMEs:** Professionals with expertise in geospatial analysis and mapping techniques for large-scale assessments.

The diverse expertise enabled a comprehensive discussion on innovative data collection methodologies while considering feasibility from different perspectives.

The project team planned and structured the TAG workshop to brainstorm, evaluate, and refine different HF and LF methods for collecting static and dynamic attributes of outdoor lighting systems. Through the discussion, the TAG identified a range of approaches for both categories, considering various factors such as accuracy, cost, ease of implementation, and scalability.

Table 1 below outlines the different LF methods that the project team and TAG members discussed during the workshop for collecting information about different static attributes.

Table 1: Summary of different low fidelity (LF) methods for static attributes.

Method	Notes/Considerations
General satellite imagery analysis	It can help extract information about presence and distribution of outdoor lights, fixture types, mounting styles, and site footprint.
Flicker analysis	Depending on the accuracy of sensors used and other factors, it can be used to identify type and count of fixtures.
Analysis of Google Street View data	It can help identify fixture presence and type, mounting type and height, assess fixture density and spacing, and site use classification.
District zoning maps	It can help with land use classification, regulatory requirements, expected traffic, and pedestrian activities.
Review of available GIS databases	It can look for either publicly available datasets or those available for purchase. It can help with street light inventory, land use classification, transportation and roadway data, and parcel and building footprint.
Review of sales data from lighting distributors	It can give a sense of market share of lighting technologies, common fixture types, and installation trends over time.
Building data available at Overture Maps	Overture Maps are like Google Maps and can supply information about site usage classification and building footprint.
New construction permit statistics	It can help with identifying trends in building types and uses, geographic distribution of new construction, and inferring adoption of lighting technology based on code requirements.
Computer Vision models to extract details from publicly available terrestrially captured imagery	It can help gather information about fixture counts, fixture type, and mounting height.
Car-mounted cameras to collect pictures for Computer Vision and artificial-intelligence-based data extraction models	It can help gather information about fixture counts, fixture type, mounting height, and building footprint.

Method	Notes/Considerations
Vehicle-mounted Light Detection and Ranging (LiDAR) scanning	It can be calibrated to collect information about light fixture locations, count, height, type, and density. It can also be calibrated to tell whether the fixtures are on or off.

Source: Findings from the TAG workshop.

Table 2 below outlines the different HF methods that the project team and TAG members discussed during the workshop for collecting information about different static attributes.

Table 2: Summary of different high fidelity (HF) methods for static attributes.

Method	Notes/Considerations
Onsite audits and data collection	It can help collect very accurate information on all aspects of onsite lighting.
Publicly available lighting equipment inventory	Some cities have data about streetlights that are publicly available and can provide details about inventory and usage.

Source: Findings from the TAG workshop.

Table 3 below outlines the different LF methods the project team and TAG members discussed during the workshop for collecting information about different dynamic attributes.

Table 3: Summary of different low fidelity (LF) methods for dynamic attributes.

Method	Notes/Considerations
Drone-based data collection	Drones can fly above the fixtures and avoid triggering any motion sensors to make observations without interference. They can be equipped with infrared cameras and light sensors to collect information about operating hours and control operations. Drones require special waivers to fly at night, and the operators need pilot licenses.
Balloon-based data collection	It can be used in a similar way to drones with an added advantage of having fewer regulatory requirements compared to drones.

Method	Notes/Considerations
Remote sensing and satellite data analysis	It can be used to estimate operating hours.
Limited field verification walkthroughs	Walk by to see whether controls are working and what state the outdoor lighting system is at that time.

Source: Findings from the TAG workshop.

Table 4 below outlines the different HF methods the project team and TAG members discussed during the workshop for collecting information about different dynamic attributes.

Table 4: Summary of different high fidelity (HF) methods for dynamic attributes.

Method	Notes/Considerations
Sensor data logging	Installing current transformers, lux meters, luminance cameras, and high dynamic range (HDR) photography cameras can provide good quality data about operating hours and wattages.
Advanced Metering Infrastructure data analysis	Advanced Metering Infrastructure (AMI) data can be disaggregated to estimate operating hours for outdoor lights.

Source: Findings from the TAG workshop.

Proposed Data Collection Methods

The project team conducted a detailed assessment of the data collection methods proposed in the TAG workshop and conducted a follow-up discussion with the TAG to present the refined data collection approaches and gather additional feedback before finalizing the methodology.

This section provides details about the assessment the project team conducted of the different data collection methods proposed in the TAG workshops.

High Fidelity Methods

The following three high fidelity methods the project team investigated are incumbent technologies, which have been used to measure exterior lighting loads and are reliable and well-practiced.

QUESTIONNAIRE-BASED SURVEYS

While these surveys are an excellent way to obtain information, when they are distributed via a mass group email, it is typical that only some of the recipients will respond. If there is no incentive attached, they might not fill it out at all. This strategy ranks between medium and difficult in terms of the ease of implementation (Q, How to Conduct an Effective Commercial Lighting Audit - Step-By-step Guide 2024).

- **Suitability:** Static and dynamic data collection at site and local scale-up applications.
- **Ease of implementation:** Relatively easy to implement using online platforms or phone interviews. Digital tools allow for rapid dissemination and automated collection of responses. Can be deployed prior to on-site audits to collect preliminary data and guide field activities.
- **Cost:** From a deployment standpoint, surveys are low-cost relative to other high fidelity methods. Most costs are associated with initial survey development, translation or customization for different user groups, and follow-up outreach to ensure sufficient response rates.
- **Accuracy:** Depends heavily on the knowledge of the respondent and the clarity of the questions. Self-reported data can lack the precision of field-verified information, and it can be challenging to reach the right respondents. Accuracy can be improved through careful question design, visual aids, and validation checks within the survey tool.
- **Scalability:** Excellent scalability, especially in comparison with other resource-intensive high fidelity methods. Once a survey is developed and tested, it can be deployed to a large group with minimal incremental effort.

LIGHTING AUDIT

A comprehensive assessment involving examining both wattages and hours of use of existing fixtures to evaluate the lighting's overall energy efficiency (Q, How to Conduct an Effective Commercial Lighting Audit - A Step-By-Step Guide 2024).

- **Suitability:** Static and dynamic data collection at site and local scale-up applications.
- **Ease of implementation:** Difficult due to the time and travel needed to perform an onsite audit and manually count luminaires.
- **Cost:** Can be costly depending on factors such as travel time and the auditor salary.
- **Accuracy:** Excellent accuracy due to having site data in real time, as well as a watt meter if the auditor is unable to determine wattage through observation. It can also provide very accurate information on all aspects of onsite lighting.
- **Scalability:** Since this is manual, it would be difficult to scale up due to travel and labor hours constraints. Useful for site studies or audits only.

DATA LOGGERS

These devices measure and monitor parameters like current, wattage, light intensity, and more. They can record data over time and in some cases, can also transmit data wirelessly. Data loggers provide precise measurements independently without the need to manually record observations (The Science Behind Outdoor Light Sensors Explained 2025).

- **Suitability:** Dynamic data collection at site and local scale-up applications.
- **Ease of implementation:** Easy to implement and considered the gold standard for collecting on-site dynamic attributes. However, field technicians need to be trained to make sure they install and calibrate the loggers correctly.
- **Cost:** Cost of the equipment is relatively low, as they do not need to be replaced often and can be re-used. However, the resources required to manually install them can be relatively high.

The cost of equipment can vary from $50 for simple sensors to thousands of dollars for detailed power metering options.

- **Accuracy:** Types of outdoor sensors include photocells, which are primarily cost-effective; passive infrared sensors; and motion-activated smart sensors. Data loggers can achieve a high level of accuracy when calibrated and installed correctly.
- **Scalability:** Since this technology involves site visits to install manually, it would be difficult to scale up due to travel and labor hour constraints. They are useful for local studies or audits, but the sensors need to be installed by a field technician and then retrieved after the duration of the study, e.g., in six months or one year. This doubles the labor costs.

Low Fidelity Methods

The primary focus of this study is to determine the next generation of outdoor lighting measurement strategies meant to be used in conjunction with the incumbent HF methods. The project team selected the most promising technologies, which are described below.

GOOGLE EARTH AND GOOGLE STREET VIEW

Google Earth is a mapping system developed by Google that utilizes satellite data, allowing users to view images of most places on Earth. Google Street View is a tool available within Google Maps that allows a user to visualize a location in 360 degrees by using panoramic photographs at the street level (Wikipedia n.d.). Both methods are suitable for collecting static data attributes for lighting audit applications (Willing 2024).

Google Earth and Street View can be used to identify fixture presence, mounting type and height, fixture density and spacing, and site-use classification. Additionally, Google offers various tools that leverage data from these platforms, such as the Outdoor Lighting Calculator. This specialized tool measures key lighting parameters, including lumens, foot-candles, wattage, color temperature, and light distribution, making it particularly useful for outdoor lighting assessments (Outdoor Lighting Calculator n.d.).

The data collection process using these tools is relatively straightforward and requires minimal time to learn, making them accessible for users with varying levels of expertise. Both these tools are relatively inexpensive to use and provide a scalable and accurate way to collect data.

Despite their scalability, both Google Earth and Street View have inherent limitations due to the manual nature of the data collection process. Counting luminaires and assessing fixture density can be time-consuming, which may impact efficiency for larger-scale projects. Nevertheless, these tools remain cost-effective and practical options for outdoor lighting analysis.

DRONES AND BALLOONS EQUIPPED WITH INSTRUMENTATION

Drones and balloons equipped with cameras offer innovative solutions for static and dynamic data collection during site audits and local-scale applications. Drones can fly above properties and avoid triggering motion sensors, enabling unobstructed observation. They can also be programmed to follow the same route multiple times during the night, ensuring consistent data collection (Li 2020). Balloons, while similar in functionality to drones, have the added advantage of fewer regulatory requirements. Typically, balloons are regulated and controlled by each nation’s aviation authority, making them a more accessible option in certain contexts (Gyuk 2021).

Both drones and balloons are effective tools for capturing lighting dynamics in spatial and temporal dimensions, providing valuable insights for urban lighting assessments. However, drones require special waivers to operate at night, and their operators must hold pilot licenses. Obtaining certification to pilot a drone at night can be costly and time-consuming. An alternative approach is to hire companies that already possess the necessary documentation and expertise to operate drones legally. Public courses, such as the remote pilot certification program in Sacramento, California, are available to assist individuals in obtaining drone licenses (Remote Pilot Certification – Sacramento, CA n.d.)

Despite their advantages, drones face limitations due to Federal Aviation Administration regulations, which impose restrictions on their operation. Additionally, drones require specialized tools for effective data collection, including an altitude control system, on-board computer, and payload infrastructure. These requirements can reduce scalability and increase operational complexity. Nevertheless, drones remain a powerful tool for capturing city light dynamics, offering detailed insights into fixture performance and lighting patterns (Li 2020).

INSTRUMENTED VEHICLE DRIVING THROUGH PROPERTIES

The project team identified two potential strategies for collecting lighting data using vehicles:

- **Distribution by equipped vehicle.** This method involves measuring the light on the surface of the road to assess lighting sufficiency and quality. It evaluates the amount of light and its uniformity across the property, making it particularly useful for street lighting assessments. The calculation points for this method are positioned along the longitudinal and transverse directions relative to the lane width and the spacing of luminaires. Additionally, this strategy can assist in counting poles and heads, as well as performing equipment audits to gather detailed lighting equipment information.
- **Automatic illuminance measurement system for vehicles.** This system uses illuminance meters facing all directions, known as an image luminance measurement device, mounted on top of the vehicle. The image luminance measurement device enables comprehensive data collection by capturing illuminance levels from multiple angles, providing a detailed understanding of lighting performance.

Instrumented vehicles equipped with these systems are suitable for both static and dynamic data collection during site audits and local-scale applications. This approach is particularly useful for scaling up data collection to nearby properties using a near-neighbor methodology (Cheng-Hsien 2023). While the cost of implementing this technology is currently unknown due to the lack of case studies, it has the potential to be scalable depending on the availability of the required technology.

Unlike methods that rely on computer vision, this approach primarily involves video recording and manual data collection, which can still be significantly faster than traditional manual methods. Instrumented vehicles offer a practical and efficient solution for lighting assessments, enabling detailed audits and measurements with reduced time and effort.

SATELLITE IMAGERY AND OVERTURE MAPS

Satellites are equipped with specialized cameras and sensors that capture high-resolution images of the Earth's surface, which are then transmitted back for analysis. Satellites can be used to scale up a single site to nearby sites by factoring measured differences in surface luminance compared to the known property that has been audited directly. Additionally, satellites can be used for temporal adjustments, or load profiles, if there is sufficient imagery to observe a region at multiple points in the night (What is Satellite Imagery? 2022). Overture Maps—which are getting more accurate as new data is added—are part of an open data mapping project, providing reliable, high-quality, and validated map data that is interoperable and easy to use (Vichot 2024).

Satellites and Overture Maps are suitable for static and dynamic data collection at local and state scale-up applications. There are many sources for satellite data including: the National Oceanic and Atmospheric Administration (NOAA), the National Aeronautics and Space Administration (NASA), Google Earth, and others, but it would take time to manually go through images (What is Satellite Imagery? 2022). While Overture Maps offer high quality, reliable, interoperable, easy to use, and validated map data, it would also require some time to learn how to use these maps (Vichot 2024). Some of these resources—such as from NOAA—may be free, but there is still a cost to manually search and measure the lighting data.

These options are accurate at a local level and possibly better due to the sharpness of satellite imagery, which can accurately measure visible nighttime surface luminance. The US-operated Suomi National Polar-orbiting Partnership (NPP) satellite is known for mapping light at night (Suomi NPP (National Polar-orbiting Partnership) 2012). While these technologies are scalable, there would need to be an algorithm to automate measurements.

The project team identified and researched other strategies to measure outdoor lighting, including LiDAR, illuminance meters, GIS databases of city design companies, electrical distributor sales, and flicker of LEDs to count fixture types. These options were not included in the final analysis of this study due to being high cost, not easy to implement, and/or difficult to scale.

Industry Stakeholder Interviews

As part of our effort to ensure the feasibility and effectiveness of the proposed data collection methods, the project team engaged industry stakeholders to gather feedback on the finalized HF and LF methods. This outreach helped the project team assess the practicality, scalability, and industry acceptance of the selected approaches.

The project team engaged the following stakeholders for this study:

- **System design professionals,** to ensure that the proposed data collection methods are aligned with real-world design practices.
- **Utility representatives,** to assess how these methods can support policy and program objectives.
- **TRC field technicians and engineers,** to gather insights on implementation challenges and real-world applicability of the proposed data collection methods.

To facilitate these discussions, the project team developed different interview guides, which outline key topics and questions covered during the interviews, and can be found in Appendix B: Industry Stakeholder Interview Guide of this report.

Feedback on Data Collection Methods

This section details feedback the project team received from interviews with different industry stakeholders.

PUBLICLY AVAILABLE IMAGING DATA

The project team asked interview respondents about using publicly available imaging data, including Google Earth and Google Street View to help identify fixture and lighting type. Respondents reported that engineers already sometimes use this approach to collect data as part of site pre-assessments and felt it could be a good candidate for large-scale data collection. Satellite imagery can be used to identify large free-standing lights such as pole lights, whose shadows are often visible in satellite images. Street View could also be used to identify pole height.

Respondents also noted potential challenges with this approach, stating that these images can be outdated, it can be difficult to identify small lights or wall packs that may be hidden from view or not visible at available resolution, and the scope will be limited to what is visible from the street or area imaged by the Google Street View car. This approach may miss lighting and buildings that are set back from the street, or lights that are obstructed by buildings. An additional challenge would be to ensure fixtures could be identified efficiently.

One respondent pointed out that artificial intelligence (AI) image identification—even through standard AI products like ChatGPT—is reasonably capable of handling a task like this without significant additional training. However, Google may limit use of its imaging data in AI applications, and further research into these limitations may be warranted.

DRONE IMAGING

Respondents generally had positive views of the use of drones for data collection as part of a lighting baseline study and saw video drone technology as sufficiently mature to be ready for this data-gathering application. One respondent noted that some utilities in California already used drone-based imaging technology for transmission line inspection. Respondents discussed several possible applications that could benefit a lighting baseline study:

- Drones could fly from fixture to fixture in a smaller area to gather detailed information, especially if the drone was equipped with an upward-facing camera.
- Drones could be used at night to collect data on light color, patterns, and intensity to identify lighting type and wattage. They could identify lighting cover and range, measure uplight, and identify underlit areas. They could be used at several sites or flown over a large area to assess lighting levels over entire neighborhoods.
- Drones could fly over the same area several times using a preprogramed flight path to gather temporal data. This could provide information on when lights turn on and off and dimming, and could also detect scheduling errors and poor commissioning.

However, respondents also raised concerns about security and privacy with drone imaging. Additionally, one respondent noted that drones may present scaling challenges for data collection because researchers conducting lighting baseline studies would be required to collect the data themselves, rather than relying on data that had already been gathered by a third party, such as satellite data. When asked about the feasibility of balloon-based imaging, respondents said that they felt drones were a superior technology given their controllability and common use. They did not see advantages of balloons over drones for any data-gathering applications useful in a lighting baseline study.

SITE DRIVE-THROUGH IMAGING

The project team asked respondents about their views on gathering site image data by site drive-throughs using a vehicle-mounted camera. Respondents noted a primary application for this data collection method could be to test and gather data on occupancy sensors that would trigger as a vehicle drives near them. This approach could gather information on luminance as well as fixture placement. Drive-throughs may be well-suited to gathering lighting data in areas not accessed by products like Google Street View and may have fewer privacy-related challenges than drone-based imaging.

Respondents also noted several challenges to this approach. On-site drive-throughs may be costly and time-consuming given the need to train drivers to ensure they are capturing important data, as well as costs associated with time and staffing spent at each site. Additionally, drive-through imaging may not capture pathway- and wall-mounted lights that are too far out of view of a driving area. For these reasons, respondents expressed concern over the potentially limited scalability of this approach.

SCIENTIFIC SATELLITE IMAGING

Respondents generally felt positively about using scientific satellite imagery with nighttime image data as part of a lighting baseline study. Data on light spectrum and patterns could be used to identify lighting technology. The project team also discussed the use of nighttime imagery as a major strength of this approach, as gathering data at night from in-person walk-throughs can be challenging. Nighttime data can reveal the location of light sources that might be hidden, and that data at scale could be significantly informative as part of a lighting baseline study. This approach could be used to identify the persistence of lighting zones to assess how well observed lighting matches lighting zone prescriptions.

Potential challenges of using satellite imaging include not having the required resolution to positively identify lighting source type, and potential difficulty in differentiating street lighting and building-related outdoor lighting. Another challenge might be identifying and accessing scientific satellite data that would meet research needs.

Table 5 below provides a summary of the stakeholder feedback the project team received on different data collection methods.

Table 5: Summary of interview respondent feedback on different data collection methods.

Method	Benefits	Drawbacks
General satellite imagery analysis	Currently used by engineers to perform site pre-assessments. Useful for en masse data collection. AI and computer vision tools could be used for performing image analysis with additional training. It is useful for pole lighting because it tends not to change frequently. Pole lighting shadows are typically visible.	Images can be outdated. May be difficult to assess wattage and fixture type. Google may limit AI image processing of its copyrighted content. It is difficult to measure pole height. Difficult to identify small lighting and wall packs.
Analysis of Google Street View data	Useful for en masse data collection. AI and computer vision tools could be used for performing image analysis with additional training. Can be used to determine pole heights.	Images can be outdated. May be difficult to assess wattage and fixture type. Google may limit AI image processing of its copyrighted content. Not well suited to buildings that are set back from the street, away from the view of the car.
Drone-based data collection	Technology is sufficiently mature for data collection. It can gather granular information. Can observe light colors and patterns to identify lighting types. Can observe lighting schedules, dimming, scheduling errors, and poor commissioning. Can assess light levels over large areas.	Security and privacy concerns. Data is collected by the research team, which could be costly and time-consuming.

Method	Benefits	Drawbacks
Balloon-based data collection	Fewer licensing requirements compared to drones.	Inferior to drone technology for accomplishing similar task.
Car-mounted cameras to collect pictures for computer-vision- and AI-based data extraction models	Ability to test occupancy sensors. Can measure luminance. Minimal privacy concerns.	May miss pathway and mounted lighting. Potential high cost and time requirements may present challenges to scalability.
Remote sensing and satellite data analysis	Potentially cost-effective. Image and light spectrum data can be used to identify lighting technology. Can reveal obscured light sources. Can identify the persistence of lighting zones.	Existing datasets may not have the necessary resolution to positively identify lighting types. Potential challenge in differentiating street lighting and outdoor lighting associated with buildings.

Use of Inference Models

To maximize the value of both high fidelity (HF) and low fidelity (LF) data collection methods, the project team proposes the use of an inference model. This model will help leverage the scalability and cost-effectiveness of LF methods while maintaining the accuracy and granularity of HF methods.

Using the inference model will help bridge the gap between the precision of HF data and the scalability of LF data, train predictive relationships between observable LF indicators and true values confirmed via HF methods, and estimate key static and dynamic attributes for a much larger number of sites by applying calibrated models to LF data.

This section covers the different steps involved in developing and using the inference model. Figure 4 below provides an overview of the hybrid approach that will be used to develop the inference model.

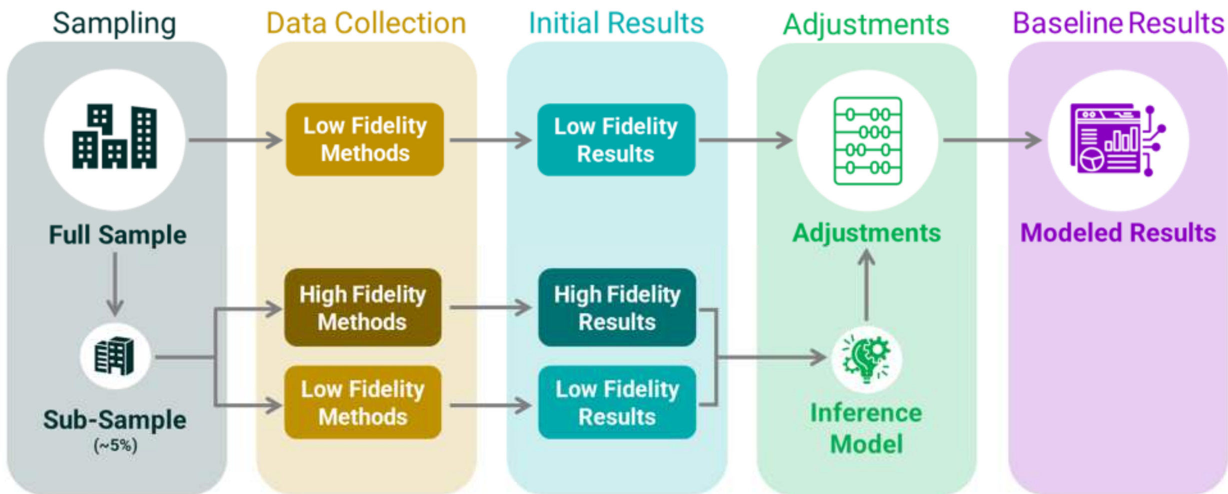

Figure 4: Overview of the hybrid approach used to develop the inference model.

Step 1: Identify and Categorize Different Static and Dynamic Attributes

To ensure that the outdoor lighting baseline study captures all relevant aspects of lighting systems and their operations, the project team has developed an exhaustive list of data attributes relevant for the study. These attributes, which are discussed in Appendix A: Data Points for Outdoor Lighting Baseline Study, include both physical characteristics of the lighting systems—e.g., type of fixture, lamps wattage—and operational parameters—e.g., hours of use, variation in wattage over time. This list of attributes can be further expanded based on the needs identified during scoping of the future baseline study.

The project team will categorize each attribute as either a static or dynamic attribute. Static attributes are those that do not typically change throughout the year and can be reliably captured at a single point of time, such as lamp type, make and model, and facility type. Dynamic attributes, on the other hand, represent conditions that vary over time, such as hours of operation, light intensity levels, and hourly power consumption. This classification will play a critical role in guiding the selection of appropriate data collection methods and informing the structure of the inference model by allowing the project team to perform a more accurate assessment of which attributes the project team can feasibly measure using LF methods and which will require HF methods.

Step 2: Determine Data Collection Feasibility

Next, the project team will identify the most appropriate HF and LF data collection methods for each attribute. HF methods, such as lighting audits, data loggers, and questionnaire or surveys, typically provide high-resolution data with great accuracy. However, they are often resource-intensive and may not be feasible to deploy at scale. LF methods, such as satellite imagery, street view analysis, analysis for publicly available datasets, and drone- or car-mounted instruments, will offer the benefit of lower costs and broader coverage, though often at reduced granularity.

To determine the suitability of each method, the team will consider the expected accuracy of the method for the specific attributes and their corresponding feasibility of use. For instance, some attributes—such as lamp type or control strategy—may only be observable through field-based HF methods, while others—such as facility area or lamp count—may be more amenable to LF approaches, particularly when enhanced by geospatial analysis or computer vision techniques.

This step was informed by the findings from the TAG workshops, stakeholder interviews, and the research the project team conducted on the different HF and LF data collection methods as part of this study. The team will use this information to develop a structured mapping between each attribute and the proposed HF and LF method best suited for collecting it.

Step 3: Collect HF and LF Data for a Representative Sample of Sites

To build a robust inference model, the project team will first develop a representative sample of outdoor lighting sites across California. This sample should capture the full diversity of outdoor lighting types, building types, geographical distribution, lighting controls, and utility service territories that exist across the state. Ensuring that the sample is representative is critical for maximizing the applicability of the inference model and for supporting broader extrapolation to the statewide outdoor lighting stock.

To establish a representative sample, the team will use a stratified sampling strategy. Stratification variables will include climate zones, urban versus rural location, facility type, lighting density, and more. The project team will design the sampling strategy to include all major categories and subcategories of outdoor lighting in proportions that reflect their actual prevalence in the population. This will also involve coordination with utilities, municipalities, and regional planning entities to identify relevant candidate sites.

Once the project team selects the sample, the team will apply both HF and LF data collection methods to each of the sampled sites. The simultaneous use of HF and LF methods at the same location will provide paired observations for each attribute of interest, which will be essential for developing and validating the inference model. The HF methods will serve as ground-truth or reference data, while the LF methods will offer more scalable but potentially less precise and less complete observations. For example, lamp count, which is a static attribute, will be determined using HF methods, such as structured outdoor lighting audit or on-site visual inspections. The project team will also establish the same attribute using LF methods, such as satellite imagery or street view data, possibly augmented by image recognition tools. The availability of both HF and LF observations at the same locations will allow the team to train statistical models to predict or calibrate usage patterns based on scalable, remotely accessible LF data. The next step provides more details about statistical modeling.

During field deployment, the project team will also collect supplemental LF data for neighboring sites adjacent to those selected in the representative sample. These neighboring sites will not undergo HF data collection, but their inclusion will support model testing and expansion and allow for preliminary extrapolation of attributes using LF-based predictions. This strategy will also provide early insights into the feasibility of extending the inference model to broader populations without the need for additional field-based efforts.

Through this approach, the team will ensure that the inference model is grounded in a rich set of matched HF and LF observations, drawn from sampled that is designed to reflect the complexity and variability of the broader outdoor lighting landscape in California.

Step 4: Develop Inference Models

Once the project team establishes a representative sample and collects paired observations using both HF and LF methods, the next step in the modeling process will involve developing appropriate statistical and machine learning models to either calibrate or predict specific lighting attributes across the larger dataset. A key consideration at this state will be determining which attributes the project team can calibrate using LF data and which will need to be predicted instead, based on the inherent limitations of the LF methods.

The project team will use calibrations for adjusting LF measurements that partially reflect an attribute but may suffer from systematic bias or measurement error. The team will use HF data to develop a statistical relationship that corrects or scales the LF estimates. For example, lamp count may be visible in satellite or street view images—LF methods—but the counts may be inaccurate due to resolution issues or not all fixtures being visible. If HF audits provide the actual lamp count at a subset of sites, the project team will train a calibration model to correct LF estimates accordingly.

On the other hand, the project team will use predictions when an attribute cannot directly or reliably be measured through LF methods. In such cases, the project team will infer the values based on other observed characteristics of the site. For instance, the team cannot discern attributes, such as lighting control strategy, through imagery or street views. Instead, the team will need to predict these attributes based on related information such as facility type; facility area; location based on zip code, city, county, etc.; facility age; and lamp type.

Accurate modeling for calibration or prediction depends on the availability of well-selected independent variables that capture relevant differences in lighting systems across sites. Variables such as facility type, facility area, facility age, and location will play an important role in explaining variation in both static and dynamic lighting characteristics. For example, big-box retail stores may have different hours of outdoor lighting use compared to schools or industrial sites. By including facility type and other contextual variables in the model, the analysis can capture these patterns and improve the accuracy of both calibration and prediction.

A range of statistical and machine learning models are available for use in this analysis. For continuous dependent variables, such as lamp count and wattage, the team will test linear and non-linear regression models, generalized additive models, or random forest regressors. For categorical dependent variables, such as control strategy or lamp type, the team will explore classification models such as logistic regression, decision trees, or gradient boosting classifiers. The choice of model will depend on the type of attribute, the distribution of underlying data, and the complexity of relationships between LF inputs and the target variable. The project team will ensure that model selection is driven by diagnostic testing, performance evaluation, and a clear understanding or interpretability and scalability for future use.

Finally, it is important to note that the modeling process will need to account for differences in how categorical and numerical dependent variables are treated. While calibration of numeric variables involves adjusting a continuous value, calibration of categorical variable involves identifying the correct classification, which introduces added complexity in model structure and evaluation. The project team will use probabilistic classification models to address uncertainty and increase model robustness for categorical variables.

Table 6 below provides an overview of different data attributes, their type, the most appropriate HF and LF methods for estimating them, and notes about how the project team will approach calibrating and predicting them. The project team will perform temporal measurements for the lighting intensity level attribute. This will involve performing multiple measurements over a period to develop a time series dataset that the team can use to predict hourly wattage. The project team has also identified facility type, facility area, and facility age as attributes that can be used to estimate at a reasonable level of accuracy using LF methods and will not need calibration. The project team will use these attributes as independent variables to predict or calibrate other attributes.

Lastly, the project team has identified the attributes shown in Table 6 as essential for future baseline study and will target them for use with the inference model proposed here. The project team can expand to include any additional attributes deemed appropriate during scoping of the future outdoor lighting baseline study.

Table 6: Data attributes and proposed calibration and prioritization approach.

Attribute	Type	Most Appropriate HF Method	Most Appropriate LF Method	Calibration/Prediction
Lamp Count	Static	Outdoor lighting audit	Google Earth/Satellite imagery/Street View, car drive through, or drone/balloon	**Calibration** (numerical) using facility type, facility area, location (zip/city/county, etc.)
Lamp Wattage	Static	Outdoor lighting audit	N/A	**Prediction** (site level) using facility type, facility area, lamp count, type of lamp, location (zip/city/county, etc.), facility age
Facility Area	Static	Questionnaire or outdoor lighting audit	Google Earth/Satellite imagery/Street View	Use as independent variable to predict/calibrate other variables
Facility Type	Static	Questionnaire or outdoor lighting audit	Google Earth/Satellite imagery/Street View or Car drive through	Use as independent variable to predict/calibrate other variables
Facility Age	Static	Questionnaire or outdoor lighting audit	Assessor records, building permits, etc.	Use as independent variable to predict/calibrate other variables
Make and Model	Static	Outdoor lighting	N/A	N/A

Attribute	Type	Most Appropriate HF Method	Most Appropriate LF Method	Calibration/Prediction
Type of Lamp (LED, HPS, Metal Hallide)	Static	Outdoor lighting audit	Car drive through or drone/balloon	**Calibration/Prediction** (categorical) using facility type, location (zip/city/county, etc.), facility age
Control Strategy	Static	Questionnaire or Outdoor lighting audit	N/A	**Prediction** (site level) using facility type, facility area, location (zip/city/county, etc.), facility age, lamp type
Hours of Use	Dynamic	Data loggers	N/A	**Prediction** (site level) using facility type, facility area, location (zip/city/county, etc.), control strategy
Hourly Wattage	Dynamic	Data loggers	N/A	**Prediction** (site level) using lamp wattage, hours of use, light intensity level (temporal), date, time
Light Intensity Level	Dynamic	N/A	Drone/balloon (temporal) or car drive through (temporal)	Use as independent variable to predict/calibrate other variables

Conclusions and Recommendations

The findings from this study offer a strong foundation for designing and implementing an improved outdoor lighting baseline study. Based on the analysis, stakeholder engagement, and evaluation of various data collection approaches, the project team offers the following actionable recommendations.

Incorporate the Use of LF Methods in Future Outdoor Lighting Baseline Study

Given the cost and logistical limitations of HF methods, future data collection efforts should incorporate greater use of LF methods, as they demonstrate greater potential for scalability and ease of implementation—and can also be integrated with existing HF methods. These LF methods can enable rapid, cost-effective data acquisition, particularly for static attributes.

Use the Inference Model to Expand Coverage and Reduce Costs

The project team recommends applying the inference model proposed in this study as a core component of future baseline efforts. By collecting both HF and LF data at a carefully selected representative sample of sites, the project team can train a model to calibrate or predict key lighting attributes across the full dataset. This approach will help reduce overall costs and labor requirements while preserving accuracy.

Conduct a Follow-up Field Pilot to Test HF and LF Methods

The project team recommends conducting a dedicated follow-up project focused on piloting the shortlisted HF and LF data collection methods under real-world conditions. This pilot will allow for practical assessment for each method's viability, cost, and accuracy, and will support the application of the inference model proposed in this study.

The pilot will begin with the selection of a small sample of sites that represent major facility types and different types of lighting and control systems across California. At each pilot site, the project team will apply both HF and LF methods. This dual application will allow direct comparison of the data collected through each approach and will help test the inference model. Where possible, the project team will also apply the LF methods to neighboring properties not included in the sample. This will allow evaluation of each LF method's potential scalability and its ability to extrapolate lighting characteristics across a large population.

The LF methods recommended from further testing during the pilot include:

- Use of Google Earth/Satellite Imagery/Street View to extract static and limited dynamic lighting attributes.
- Deployment of drones/balloons with instrumentation to capture overhead imagery and lighting characteristics.
- Use of vehicle-based drive-through surveys with mounted sensors and HDR cameras for rapid, scalable field scanning.

The HF methods recommended for testing are:

- Outdoor lighting audits involving on-site inspections to capture detailed static and dynamic lighting information.
- Questionnaire-based surveys with facility managers or lighting technicians to gather contextual data on equipment and control strategies.
- Possible installation of data loggers and current taps to monitor usage patterns and lighting performance over time.

Although these HF methods have been used in other studies before, it is essential to test them in conjunction with the LF methods to help support the testing of the inference model. Testing the operational integration of these two methods and the inference model will enable extrapolation from a small number of HF samples to larger LF datasets.

References

n.d. https://lmplx.uk/blogs/outdoors/science-behind-outdoor-light-sensors.
n.d. https://droneaviate.com/product/commercial-uas-remote-pilot-certification-sacramento-ca/.
Cheng-Hsien, Chen. 2023. *Sustainability.* May 10. https://www.mdpi.com/2071-1050/15/13/10478.
n.d. *Drone Pilot Ground School.* https://www.dronepilotgroundschool.com/drone-license/.
Gyuk, Geza. 2021. *Light Pollution Mapping from a Stratopheric High-Altitude Balloon Platform.* March 3. https://lightingjournal.org/index.php/path/article/view/106.
Li, Xi. 2020. *Elsevier.* January 21. https://www.sciencedirect.com/science/article/pii/S0034425720303126.
n.d. *Outdoor Lighting Calculator.* https://calculator.dev/construction/outdoor-lighting/.
Q, Sam. 2024. *How to Conduct an Effective Commercial Lighting Audit - A Step-By-Step Guide.* September 3. https://jqzlighting.com/blogs/news/how-to-conduct-an-effective-commercial-lighting-audit-a-step-by-step-guide.
—. 2024. *How to Conduct an Effective Commercial Lighting Audit - Step-By-step Guide.* Septmeber 3. https://jqzlighting.com/blogs/news/how-to-conduct-an-effective-commercial-lighting-audit-a-step-by-step-guide.
n.d. *Remote Pilot Certification – Sacramento, CA.* https://droneaviate.com/product/commercial-uas-remote-pilot-certification-sacramento-ca/.
2012. *Suomi NPP (National Polar-orbiting Partnership).* https://www.eoportal.org/satellite-missions/suomi-npp.
2025. *The Science Behind Outdoor Light Sensors Explained.* April 16. https://lmplx.uk/blogs/outdoors/science-behind-outdoor-light-sensors.
Vichot, Swann. 2024. *What Does Overture Maps Mean for OpenStreetMap and the Future of Open Source Mapping?* September 24. https://blog.jawg.io/what-does-overture-maps-mean-for-openstreetmap-and-the-future-of-open-source-mapping/.
2022. *What is Satellite Imagery?* October 10. https://geoimage.com.au/blog/what-satellite-imagery.
n.d. *Wikipedia.* https://en.wikipedia.org/wiki/Google_Earth.
Willing, Nicole. 2024. *What is Google Street View?* Septmeber 8. https://www.techopedia.com/definition/google-street-view.

Appendix A: Data Points for Outdoor Lighting Baseline Study

Outdoor Lighting and Site-Specific Data Points

- What is the overall building floor area?
- What is the building footprint?
- What is the overall site area?
- How many floors?
- Circle the appropriate building type description
- Functional Use Area
- How many individual tenants (businesses) occupy this building?
- Do the majority of tenants have their own electric meter?
- Ask the respondent if they have building plans available; this will provide site acreage, building area and possibly an outdoor lighting power plan with schedule of fixtures.
- (Exterior lighting lamp types) Are you familiar with the lamp types and lamp wattage that are used at this facility?
- How are the exterior lights controlled (options: manual, timeclock, photocell, both, DK)?
- Draw lines to represent schedules for weekdays, weekends, and Holidays
- Are there any lights that are not turned on at night, except for special occasions (for example: loading dock lights)?
- Daytime weather conditions
- Luminaire Information
- Functional Use Area (FUA)
- Ballast Type
- LED driver information
- Notes
- Fixture type
- Fixture quantity
- Lamp type
- Lamp wattage
- Luminaire height
- Distance from luminaire
- Ft candle reading
- Suitability/lens cond.
- Signage information
- Quantity of Signs
- Fixture type
- Number of faces
- Fixture quantity per sign
- Lamp type
- Lamp wattage/linear feet
- Size
- Suitability

- Nighttime weather conditions
- Describe the environmental conditions of the neighborhood
- Site sketch

Lighting Fixture Catalogue: Typical Lamp Types and Wattages

- Metal Halide • May be coated or clear lamp, normally clear lamp • Will normally be found in higher budget installations or retail applications • ‘White’ or ‘Cool White’ light color • Typical Lamp Wattages: ƒ 50 ƒ 70 ƒ 100 ƒ 175 ƒ 250 ƒ 400 ƒ 1000
- High Pressure Sodium • Never coated lamp; always clear • Used on more utilitarian installations, not normally found on retail • ‘Yellow-orange’ light color • Typical Lamp Wattages: ƒ 50 ƒ 70 ƒ 100 ƒ 150 ƒ 250 ƒ 400 ƒ 1000
- Low Pressure Sodium • Never coated lamp; always clear • Used on more utilitarian installations, not normally found on retail • Monochromatic ‘Orange’ light color, no other colors present • Typically found only in southern CA • Typical Lamp Wattages: ƒ 90 (21” length) ƒ 135 (31” length) ƒ 180 (45” length)
- Fluorescent • Always coated lamp, never clear • Traditional ‘4-foot tube’ style lamp • Used in retail, gas stations, building façade lighting, signage • ‘White’ light color • Typical Normal Output Lamp Wattages: ƒ 25 (2’ length, T12 lamp, magnetic ballast) ƒ 30 (3’ length, T12 lamp, magnetic ballast) ƒ 34 (4’ length, T12 lamp, magnetic ballast) ƒ 40 (4’ length, T12 lamp, magnetic ballast) (Uncommon) ƒ 50 (5’ length, T12 lamp, magnetic ballast) ƒ 56 (6’ length, T12 lamp, magnetic ballast) ƒ 75 (8’ length, T12 lamp, magnetic ballast) ƒ 17 (2’ length, T8 lamp, elec. ballast) ƒ 25 (3’ length, T8 lamp, elec. ballast) ƒ 32 (4’ length, T8 lamp, elec. ballast) ƒ 40 (5’ length, T8 lamp, elec. ballast) ƒ 59 (8’ length, T8 lamp, elec. ballast) • Typical High Output (HO) Lamp Wattages: ƒ 35 (2’ length, T12 lamp, magnetic ballast) ƒ 50 (3’ length, T12 lamp, magnetic ballast) ƒ 60 (4’ length, T12 lamp, magnetic ballast) ƒ 75 (5’ length, T12 lamp, magnetic ballast) ƒ 85 (6’ length, T12 lamp, magnetic ballast) ƒ 95 (8’ length, T12 lamp, magnetic ballast) • Very High Output (VHO) lamps are not common but may be found
- Compact Fluorescent • Always coated lamp, never clear • Small ‘Bent-Tube’ style lamp • Used in downlights, small wall sconces, steplights, sometimes used in globes • ‘White’ light color • Typical Normal Output Lamp Wattages: ƒ 13 ƒ 15 ƒ 18 ƒ 22 ƒ 26 ƒ 32 ƒ 42
- Incandescent • Normally frosted lamp, sometimes clear • Traditional residential ‘light bulb’ shape most common • Used in downlights, small wall sconces, steplights, globes • ‘White’ light color • Typical ‘A-Lamp’ Lamp Wattages: ƒ 25 ƒ 40 ƒ 50 ƒ 60 ƒ 75 ƒ 100 ƒ 150
- Incandescent – PAR or R • Traditional residential ‘floodlight’ style PAR and R lamps • Used in downlights, PAR floodlight holders, bare lamp socket holders • ‘White’ light color • Typical PAR or R Lamp Wattages: ƒ 75 ƒ 100 ƒ 150 ƒ 250
- Incandescent – MR • ‘Projector’ style low voltage MR lamps • Used in downlights, landscape accent • ‘White’ light color • Typical MR Lamp Wattages: ƒ 20 ƒ 50 ƒ 75
- Incandescent – Halogen • ‘Double-ended’ style halogen lamp • Used in ‘halogen’ floodlights primarily • ‘White’ light color • Typical Halogen Lamp Wattages: ƒ 300 ƒ 500 ƒ 1000
- Will include LED light options

Nighttime Subjective Lighting Evaluation

- It would be safe to walk here, alone, during the day.

- It would be safe to walk here, alone, at night.
- The lighting is comfortable.
- The lighting is too bright.
- The lighting is too dark.
- The lighting is uneven (patchy).
- The lighting is glaring.
- The lighting is too limited in area.
- The lighting is poorly matched to the site.
- I cannot tell the colors of things.
- How does the lighting here compare with the lighting of similar areas at light?

General Questions About the Site

- Is your business a home-based business, or is it located in a commercial/industrial building?
- What are the primary business functions of this building?
- Approximately how many employees work in the building?
- Does your building have an outdoor parking lot?
- Approximately how many parking spaces does your outdoor parking lot contain?
- Is outdoor lighting an important part of the building's business?
- Is outdoor lighting used to attract customers or light showrooms?
- Does your building serve customers at night?
- During what times does your building serve customers at night?
- Does your building have a night shift?
- Approximately how many employees work on the night shift?
- What are the hours of the building's night shift?
- What are your building's operating hours?
- Does your building have signs that are lit up at night?
- How many signs that are lit up at night does your building have?
- What are the approximate size(s) of these signs?
- Are there lights meant to provide safety attached to the outside of the building or integrated into landscaping or walkways?
- Are there lights meant to light up the building that are attached to the outside of the building?

Appendix B: Industry Stakeholder Interview Guide

CalNEXT New Toolkit for Outdoor Lighting Baseline Updates: Stakeholder Interview Guide (Utility Stakeholder)

Introduction

1. First, can you please introduce yourself and describe your familiarity with outdoor lighting? [PROBE] Have you ever conducted a study of outdoor lighting? How long have you worked with outdoor lighting?

General Outdoor Lighting

1. In your view, what types of information collected during an outdoor lighting baseline study are most valuable for supporting Title 24 development?
2. From a code setting perspective, which lighting attributes are currently less understood and require further exploration?
3. Are there particular types of usage patterns that are currently less understood and require further exploration?

Data Collection Methods

One of the main goals of this research is to assess the potential of different technological and data gathering approaches for understanding the use of different fixtures for outdoor lighting in California. In this section, I will ask about a few of those approaches, and I would like to hear your thoughts on some of the benefits and drawbacks of those approaches, as well as the overall feasibility of using them as part of a broad lighting baseline study.

1. The first method is **using Google Search with Google Earth and Street View to count luminaires.** Based on your experience, how effective do you find this method for understanding the types of lighting systems that are currently in use?
   a) Do you have any concerns about the accuracy or representativeness of using this method to assess existing lighting systems?
2. The next approach is **flying drones and balloons over properties** to gather data. Based on your experience, how effective do you find this method for understanding the types of lighting systems that are currently in use? [temporal observations]
   a) Do you have any concerns about the accuracy or representativeness of using this method to assess existing lighting systems?
3. The next approach is using a **car or small vehicle able to drive through properties** to gather information. Based on your experience, how effective do you find this method for understanding the types of lighting systems that are currently in the market?
   a) Do you have any concerns about the accuracy or representativeness of using this method to assess existing lighting systems?

4. The next approach is using **scientific satellite imagery and Overture Maps.** Based on your experience, how effective do you find this method for understanding the types of lighting systems that are currently in use?
    a) Do you have any concerns about the accuracy or representativeness of using this method to assess existing lighting systems?

Close

1. Is there anything else you want to mention that you think we did not already address?
2. As a thank you for your input, we'd like to send you a $100 Tango gift card, which is an online card that can be applied to a wide variety of businesses or nonprofits of your choice. Alternately, we could also donate $100 to your local United Way in the name of your choice. Which would you prefer?

CalNEXT New Toolkit for Outdoor Lighting Baseline Updates: Stakeholder Interview Guide (Program Design Stakeholder)

Introduction

1. First, can you please introduce yourself and describe your familiarity with outdoor lighting? **[PROBE]** Have you ever conducted a study of outdoor lighting? How long have you worked with outdoor lighting?

General Outdoor Lighting

1. What types of outdoor lighting systems do you work with? Such as different fixture types or control strategies.
2. Which outdoor lighting and control technologies are most frequently incentivized by energy efficiency (EE) programs?
3. Are there specific fixture types or control strategies that tend to dominate participation in energy efficiency (EE) programs?
   [PROBE] Dominant applications (e.g., parking lots, pathways, streetlights)?

Data Collection Methods

One of the main goals of this research is to assess the potential of different technological and data gathering approaches for understanding the use of different fixtures for outdoor lighting in California. In this section, I will ask about a few of those approaches, and I would like to hear your thoughts on some of the benefits and drawbacks of those approaches, as well as the overall feasibility of using them as part of a broad lighting baseline study.

1. The first method is **using Google Search with Google Earth and Street View to count luminaires.** Based on your experience, how effective do you find this method for understanding the types of lighting systems that are currently in use?
   a) Do you have any concerns about the accuracy or representativeness of using this method to assess existing lighting systems?
2. The next approach is **flying drones and balloons over properties** to gather data. Based on your experience, how effective do you find this method for understanding the types of lighting systems that are currently in use? [temporal observations]
   a) Do you have any concerns about the accuracy or representativeness of using this method to assess existing lighting systems?
3. The next approach is using a **car or small vehicle able to drive through properties** to gather information. Based on your experience, how effective do you find this method for understanding the types of lighting systems that are currently in the market?
   a) Do you have any concerns about the accuracy or representativeness of using this method to assess existing lighting systems?

4. The next approach is using **scientific satellite imagery and Overture Maps.** Based on your experience, how effective do you find this method for understanding the types of lighting systems that are currently in use?
   a) Do you have any concerns about the accuracy or representativeness of using this method to assess existing lighting systems?
5. Based on your experience, are there any customer-related concerns or challenges associated with the four data collection methods we shared with you today?
6. From your perspective, where do you see the most significant data gaps in outdoor lighting baseline studies?
   [PROBE] Operating hours, fixture types, wattages?
7. Are there other data collection methods or approaches you believe we should consider to improve the accuracy or practicality of outdoor lighting baseline studies?

Close

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CalNEXT New Toolkit for Outdoor Lighting Baseline Updates: Stakeholder Interview Guide (Lighting Design Professional Stakeholder)

Introduction

1. First, can you please introduce yourself and describe your familiarity with outdoor lighting? [**PROBE**] Have you ever conducted a study of outdoor lighting? How long have you worked with outdoor lighting?

General Outdoor Lighting

1. In your view, what types of information collected during an outdoor lighting baseline study are most valuable for informing design and application decisions?
2. What types of outdoor lighting systems do you most frequently encounter in your work? [**PROBE**] fixture types, control strategies, etc.
    a) What types of systems do you typically specify in your outdoor lighting projects?
    b) What trends have you observed recently in the outdoor lighting design space? [**PROBE**] types of LED technologies, advanced control systems?

Data Collection Methods

One of the main goals of this research is to assess the potential of different technological and data gathering approaches for understanding the use of different fixtures for outdoor lighting in California. In this section, I will ask about a few of those approaches, and I would like to hear your thoughts on some of the benefits and drawbacks of those approaches, as well as the overall feasibility of using them as part of a broad lighting baseline study.

1. The first method is **using Google Search with Google Earth and Street View to count luminaires**. Based on your experience, how effective do you find this method for understanding the types of lighting systems that are currently in use?
    a) Do you have any concerns about the accuracy or representativeness of using this method to assess existing lighting systems?
2. The next approach is **flying drones and balloons over properties** to gather data. Based on your experience, how effective do you find this method for understanding the types of lighting systems that are currently in use? [temporal observations]
    a) Do you have any concerns about the accuracy or representativeness of using this method to assess existing lighting systems?
3. The next approach is using a **car or small vehicle able to drive through properties** to gather information. Based on your experience, how effective do you find this method for understanding the types of lighting systems that are currently in the market?
    a) Do you have any concerns about the accuracy or representativeness of using this method to assess existing lighting systems?

4. The next approach is using **scientific satellite imagery and Overture Maps.** Based on your experience, how effective do you find this method for understanding the types of lighting systems that are currently in use?
    a) Do you have any concerns about the accuracy or representativeness of using this method to assess existing lighting systems?
5. Do you know of any building permit data sources that could help us in collecting outdoor lighting baseline data?
6. How often are there discrepancies between lighting design plans and systems that are ultimately installed?
    [PROBE] what are the discrepancies? Do they follow a trend?

Close

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