Pacific Gas and Electric Company

Program	*Electric Program Investment Charge (EPIC)*
Project Name	**EPIC 1-23 – Demonstrate Additive Billing with Submetering for PVs to Increase Customer Billing Flexibility**
Project Reference Name	**Photovoltaic (PV) Submetering**
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Date	December 15, 2016
Version	Final

Table of Contents

List of Tables

List of Figures

List of Acronyms

AMI	Advanced Metering Infrastructure
AP	Access Point
API	Application Program Interface
BTM	Behind-the-Meter
CC	Correlation Coefficient
CDW	Customer Data Warehouse
CEC	California Energy Commission
CPUC	California Public Utilities Commission
CSI	California Solar Initiative
DER	Distributed Energy Resource
DG	Distributed Generation
ENOS	E-Net Online System
EV	Electric Vehicle
HAN	Home Area Network
MAPE	Mean Absolute Percent Error
MPB	Mean Percent Bias
NEM	Net Energy Metering
NREL	National Renewable Energy Laboratory
NSHP	New Solar Homes Partnership
PBI	Performance-Based Incentives
PG&E	Pacific Gas and Electric Company
PV	Photovoltaic
SEP	Smart Energy Profile
SIWG	Smart Inverter Working Group
SPID	Service Profile Identifier
TD&D	Technology Demonstration and Deployment

Executive Summary

This report summarizes the project objectives, technical results and lessons learned for EPIC Project 1.23, *Demonstrate Additive Billing with Submetering for PVs to Increase Customer Billing Flexibility*. In short, the project is referred to throughout the report and listed in the EPIC Annual Report[1] as "Photovoltaic (PV) Submetering."

As of December 2016, PG&E serves over 275,000 solar customers and the rate of solar adoption is increasing rapidly with PG&E interconnecting approximately 6,000 solar customers per month. To understand the needs and preferences of PG&E's solar customers, PG&E has internally conducted numerous surveys to collect feedback from these existing solar customers, including a qualitative survey on solar Net Energy Metering (NEM) satisfaction in 2012. One of the conclusions of this survey, along with other customer feedback, has indicated that residential customers desire full visibility into both their generation data and usage data. Due to the masking effects of solar generation and lack of access to generation data by the utility, solar customers cannot view their actual home energy usage data on PG&E's website, which is one of the contributors to the lower customer satisfaction of the solar customer segment. While PG&E currently provides solar customers with net usage data on the pge.com online customer portal YourAccount[2], the "full picture" of customers' generation, consumption, and import/export to the grid is not easily accessible or visible to PG&E, customers, or solar contractors.

Project Objectives

To help address these above stated concerns, EPIC Project 1.23, PV Submetering, was established with the following objectives:

- Develop, test, and validate various ways of collecting or estimating solar generation output data; and

- Enable a subset of customers to view their estimated solar generation data through integration with the PG&E YourAccount platform.

Key Accomplishments

The following is a summary of the key accomplishments of the project:

- Four methods for capturing photovoltaic (PV) generation data were evaluated. The two that were accepted and implemented for the project were:

  1. Installing additional SmartMeter[TM] devices acting as PV system submeters to measure PV generation; and

  2. Estimate the PV generation using a third party data-as-a-service platform. The data service included the provider incorporating PV specification data from PG&E, as well as environmental data, estimating the daily PV generation data and incorporating the data into the customers' YourAccount website.

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[1] 2015 EPIC Annual Report, PG&E. February 29, 2016.
http://www.pge.com/includes/docs/pdfs/about/environment/epic/EPICAnnualReportAttachmentA.pdf.
[2] YourAccount is the web portal where customers can view their account and usage information. Note that during the course of this project, the PG&E MyEnergy portal was fully integrated with the www.pge.com website and renamed YourAccount to provide customers with an optimal experience.

- The project developed Application Program Interfaces (APIs) and processes to receive solar generation estimates for approximately 10,000 solar customers from a third-party, data-as-a-service platform;

- The accuracy of the PV generation algorithm was determined to be at an acceptable level with all sites aggregated on a monthly basis showing <±5% error (mean percent bias)[3] when no significant shading takes place. This error is comparable with the error of non-revenue grade production submeters. On a daily basis, the algorithm showed significant increase in the estimation error primarily due to weather conditions caused by cloudy or foggy weather[4];

- The project demonstrated the use of existing SmartMeter™ infrastructure as a viable way to collect customer solar generation data and with further development could include additional metered data streams of other behind-the-meter distributed energy resources (DERs) such as behind the meter energy storage;

- The project developed an online tool, which was "live" for six months for 10,000 active solar customers, which enabled them to visualize both estimated solar generation and whole house consumption;

- Over the course of the six months that the solar generation view was live, there were 3,102 unique visitors out of the 10,000 customers that had access to view this information on the website;

- During the six months that the solar generation data view was live in PG&E's YourAccount website, PG&E received 24 calls to the call center related to this portal—a very low and reasonable number relative to the number of unique visitors to the website (over 3,100); and

- The project measured customer perception of the online tool and assessed the value proposition. The majority of survey respondents found the solar generation data and visualization to be useful or very useful (81%), easy or very easy to understand the information presented (86%), and were overall satisfied with the tool (74%).[5]

Key Takeaways

The following are key takeaways and lessons learned from this project:

- Each of the methods explored to capture solar generation data required ingesting additional metered data streams for a single service point (i.e. customer premise). The IT systems were designed to ingest a single metered data stream. In order to accomplish this project's goals, non-trivial IT modifications to system design and software development were required. The need for this type of IT modifications must be fully assessed when considering a full scale rollout of this or similar technology demonstration projects;

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[3] Mean Percent Bias (MPB) is reported, which is the net difference in estimates and actual generation, divided by the system daily max power output; it can be positive (over-estimate) or negative (under-estimate).

[4] On a daily basis the MPB reported is as follows: less ±5% error rate for 56% of the sites across all site; between ±5% and ±10% error rate for 40% of the sites; and in excess of ±10% for 4% of the sites).

[5] 74% of the customers rated the tool score of 4 and 5 on a scale 1-5, with 4 meaning "satisfied" and 5 meaning "extremely satisfied".

- Using the Advanced Metering Infrastructure (AMI) for enabling PV submetering requires significant investments for upgrading the AMI network firmware and back-end system software, including upgrades required related to data loading and data mapping;

- Retrofitting existing PV installations with SmartMeter™ devices acting as submeters is technically feasible, but expensive and invasive to the customer (costs for a third party to install a SmartMeterTM ranged between 25% and 280% more than PG&E's installation costs), which partially influenced PG&E's current decision to not pursue submetering solar customers at scale after the EPIC project to obtain and display generation data. This approach, however, was tested at a small scale to understand translatable learnings once cost comes down for displaying actual PV data from SmartMeter™ devices, which may also be applied for other DERs;

- There are limitations in data quantity and quality for all PG&E solar customers. Specifically, there are incomplete PV characteristics and environmental data for all PG&E customers, including projected shading from buildings and trees. To assess the accuracy of the solar generation estimation algorithm, the project leveraged customer interval data reported through the California Solar Initiative (CSI). However, over 60% of the customers from the initial sample data set were removed for two reasons, which impact the accuracy of the algorithm and future scalability of the project for all PG&E customers: (1) inconsistent data reporting since January 2015 and (2) poor quality data, likely due to extreme shading;

- Irregularly high PV estimation error is predominantly caused by a select few weather types, namely a shallow marine layer and fog at the coast. These irregularly high estimation-error cases were limited in scope and, in comparison to the impact of limited PV system characteristic data and unknown shading data, were not found to greatly reduce the PV estimation accuracy;

- Using the estimation algorithm demonstrated in this project, PG&E can provide accurate and reliable estimates of PV generation to fully, non-shaded systems with complete PV system characteristic information; however, in order to provide generation data to all solar customers, detailed information on shading at a system-level, in addition to complete PV system characteristics, are required; and

- Estimation accuracy aside, the ability to visualize solar generation, as well as energy consumption data, was found to be very valuable by the majority of solar customers who responded to the satisfaction survey.

Unique Challenges

There were some unique challenges addressed in the project:

- PG&E does not currently receive any data from solar companies, further limiting its ability to provide widespread display of solar generation data that has been documented as being important to customers. Getting access to third party solar inverter data presented data privacy challenges, as well as fairness of compensation challenges. Several solar companies expressed interest in providing generation data to PG&E; however, the questions around customer consent to share generation data and whether any compensation to solar companies for providing generation data is warranted are outstanding issues. It was confirmed that these issues are more appropriate to be addressed through existing, outside proceedings and working groups, rather than in a technology demonstration project such as this. Ultimately, the lack of third party solar generation data compounds the data gap listed above and impacts the future scalability of the project;

- Using data-as-a-service technology and passing account information to third parties with minimal Personal Identifiable Information (PII) to maintain information security required extra effort from the vendor to map estimated generation to the correct customer. In addition, this project faced the unique challenge of matching the solar customers account information with the California Solar Initiative (CSI) database information, which contained all of the solar system's technical characteristics; and

- Integrating submeter data from SmartMeter[TM] devices through utility IT systems requires a larger scale IT implementation project. As part of this project, it was decided to develop a manual process to extract the data from the submeters into the Customer Data Warehouse (CDW)[6] database, which is not scalable. Additionally, the process to add or remove customers from the pilot was mostly manual, which is effective for a small, technology demonstration project such as this one, but the process would need to be automated for a full scale roll-out.

Possible Next Steps

Although there were several technical challenges the project needed to overcome regarding data integration and IT support, the key driver to widespread application of this technology demonstration project is the ability to cost-effectively acquire all of the needed solar generation data elements. The project offers several recommendations for obtaining generation data for future applications:

- Continue to monitor the progress of key inverter manufacturers who have begun to support the ability to communicate with SmartMeter[TM] devices;

- Identify parallel efforts and synergies with Home Area Network (HAN) and third-party product capability for potentially providing this data in the future;

- Continue to align with the Smart Inverter Working Group (SIWG) that is currently in the process of defining technical communication protocols and provide policy and strategy input;

- Explore additional use cases for solar generation data within PG&E, such as improving operational visibility;

- Evaluate an extension to the entire solar population at PG&E after adequate improvements are made to the identified data quality issues (missing PV characteristic information) and monitor improvements made to predicted environmental impacts, like marine layer/fog, vegetation growth and shading to avoid gross inaccuracies in the estimated PV generation data displayed to the customer; and

- Continue to explore additional options for acquiring solar generation data, which may require policy changes to request that solar companies share, but not sell, generation data with utilities.

Conclusions

This project successfully achieved all of its key objectives, and in doing so, has captured key learnings that can be leveraged by other utilities and industry members to understand key inputs necessary to estimate PV generation data and understand how to engage with solar customers regarding information access and visualization. Through the work executed in this technology demonstration project and

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[6] The Customer Data Warehouse (CDW) is PG&E's data repository that is used for reporting and data mining and collected for PG&E's Electric and Gas customers. Such data includes but is not limited to the following: meter interval usage, reads, billed usage and reads, service points, etc.

documented in this report, PG&E has gained substantial experience in collecting and integrating solar generation data and enabling customers to view their generation data alongside their whole house usage data. While PG&E does not currently plan to scale the project to all solar customers due to the existing data limitations identified, the project achieved significant learnings that may lead to scaling if data limitations are resolved.

1. Introduction

This report documents EPIC Project 1.23, "Demonstrate Additive Billing with Submetering for PVs to Increase Customer Billing Flexibility," achievements, highlights key learnings from the project that have industry-wide value, and identifies future opportunities for PG&E to leverage this project. In short, the project is referred throughout the report as "PV Submetering."

The California Public Utilities Commission (CPUC) passed two decisions that established the basis for this technology demonstration program. The CPUC initially issued D. 11-12-035, *Decision Establishing Interim Research, Development and Demonstrations and Renewables Program Funding Level*[7], which established the Electric Program Investment Charge (EPIC) on December 15, 2011. Subsequently, on May 24, 2012, the CPUC issued D. 12-05-037, *Phase 2 Decision Establishing Purposes and Governance for Electric Program Investment Charge and Establishing Funding Collections for 2013-2020*[8], which authorized funding in the areas of applied research and development, technology demonstration and deployment (TD&D), and market facilitation. In this later decision, CPUC defined TD&D as "the installation and operation of pre-commercial technologies or strategies at a scale sufficiently large and in conditions sufficiently reflective of anticipated actual operating environments to enable appraisal of the operational and performance characteristics and the financial risks associated with a given technology."[9]

The decision also required the EPIC Program Administrators[10] to submit Triennial Investment Plans to cover three-year funding cycles for 2012-2014, 2015-2017, and 2018-2020. On November 1, 2012, in A.12-11-003, PG&E filed its first triennial Electric Program Investment Charge (EPIC) Application at the CPUC, requesting $49,328,000 including funding for 26 Technology Demonstration and Deployment Projects. On November 14, 2013, in D.13-11-025, the CPUC approved PG&E's EPIC plan, including $49,328,000 for this program category. Pursuant to PG&E's approved EPIC triennial plan, PG&E initiated, planned and implemented the following project: 1.23 PV Submetering. Through the annual reporting process, PG&E kept CPUC staff and stakeholder informed on the progress of the project. The following is PG&E's final report on this project.

2. Project Summary

This section summarizes the industry gap that the project addresses, as well as the project's objectives, the scope of work, and major tasks, milestones, and their corresponding deliverables. Initially, the EPIC 1.23 PV Submetering project sought to demonstrate how submetering data could provide additional billing clarity to solar customers; however, the costs associated to changing production-level billing systems were considered too significant to risk potentially impacting the billing process for the EPIC technology demonstration. The first step in that objective was to develop a submetering solution capable of demonstrating access to generation data and home energy usage, which is ultimately achieved through this project. As discussed in this report, the algorithm shows promise but requires additional data not readily available to be able to scale at this time.

2.1 Issue Addressed

To understand the feedback from the growing number of solar customers, PG&E has conducted numerous surveys. In 2012, PG&E conducted qualitative and quantitative research that included NEM

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[7] http://docs.cpuc.ca.gov/PublishedDocs/WORD_PDF/FINAL_DECISION/156050.PDF.
[8] http://docs.cpuc.ca.gov/PublishedDocs/WORD_PDF/FINAL_DECISION/167664.PDF.
[9] Decision 12-05-037 pg. 37.
[10] Pacific Gas & Electric (PG&E), San Diego Gas & Electric (SDG&E), Southern California Edison (SCE), and the California Energy Commission (CEC).

billing experience. The research indicated that while customers were satisfied with their decision to go solar, none were satisfied with their current NEM billing process. However, customers who spent time speaking with PG&E solar specialists generally felt satisfied with the information they received. As a result of the survey, PG&E worked to make the complex NEM bill more customer-friendly, which was started in 2014 and continues today. Overall, this survey, along with other customer feedback, has indicated that residential customers desire full visibility into their generation and usage data. The lack of generation data and home energy usage is one of PG&E solar customers' top reasons for dissatisfaction. While PG&E currently provides solar customers with net usage data on YourAccount, the "full picture" of customers' generation, consumption, and import/export to the grid is not accessible or visible to PG&E, customers, or solar contractors. Without this information, it is also challenging to help customers understand net energy metering.

Based on the customer feedback, PG&E identified the need to access solar customers' generation data. At the time this report was written, there is no market solution through either a vendor or PG&E to provide both home energy usage and generation information in one place to customers. Solar customer growth necessitates enhancing the existing customer-facing tools to meet customer needs, and to reduce the costs associated with serving these solar customers.

2.2   Project Objective

Accounting for solar customer feedback and anticipating large growth in PV customers that aligns with California's ambitious solar installation goals, the need for visibility into BTM solar generation and the lack of an existing market solution created the foundation for this project. This EPIC project's primary focus was to capture PV generation output data from current residential customers and integrate it with PG&E's billing system and online tools. EPIC Project 1.23 had two primary objectives:

1. Develop, test, and validate various ways of collecting solar generation output data; and
2. Enable a subset of customers to view their estimated solar generation data through integration with PG&E's customer facing online energy usage tool, called YourAccount.

Upon completion of these objectives, the outcomes delivered by the project include:

- An assessment of various methods to obtain PV generation data;
- A foundation for enhanced tools and monitoring capabilities for PV generation data;
- A blueprint to enable PG&E and the other IOUs to ingest multiple metered data streams associated with one premise (e.g. EV, storage, PV in addition to net metered data); and
- An assessment of the degree to which customers place value on more complete and easy to use online energy management tools.

2.3   Scope of Work

The project's primary focus was to capture PV generation output data from a subset of current residential solar customers and integrate the information with the existing online tool, YourAccount. The project was conducted in four phases, each with its own different work stream:

1. Phase 1: Identify and test low-cost and scalable ways to bring solar generation data to PG&E;

2. Phase 2: Determine how to incorporate and visualize solar generation data on PG&E's YourAccount site;

3. Phase 3: Evaluate the accuracy of PV output estimate for Algorithm A, which was leveraged for this project due to the ability of their existing API to interact with PG&E's online tools (one of the methods assessed in Phase 1); and

4. Phase 4: Assess customer satisfaction with the information displayed on the YourAccount "Solar Energy Produced" web tab.

In Phase 1, PG&E evaluated the following four methods to collect solar generation data:

A. Installing standard PG&E SmartMeter^{TM} devices to PV systems and use the existing infrastructure to send the PV generation data to the utility;

B. Reading meters directly from existing inverters that have ZigBee® radios using SmartMeter^{TM} devices;

C. Leveraging an algorithm to estimate PV generation based on PV system characteristics and solar irradiance data; and

D. Obtaining customer PV generation data from solar companies.

After exploring all four options, PG&E decided to pursue only two methods— (1) installing SmartMeter^{TM} devices onto PV systems and (2) estimating PV generation based on system characteristics and solar irradiance data. The reasons for this decision will be discussed in more detail in Section 3.1.

In Phase 2, PG&E determined how to incorporate the estimated PV generation data into the YourAccount platform. The visualization of generation and consumption data on YourAccount went live on December 11, 2015 and remained available to 10,000 pilot participants for six months. The majority of these customers were participants in the California Solar Initiative (CSI) program. All 10,000 customers selected to participate in the pilot were active users of YourAccount and had more than one year of whole house consumption data. Additionally, 10 PG&E employees with solar volunteered to be part of a small group that to have PG&E SmartMeter^{TM} devices connected to their PV systems as submeters.[11] This enabled PG&E to conduct a preliminary assessment of the IT requirements to configure meters and to pass the submetering data through back-end metering systems without impacting customers' bills, as well as the costs associated with using this method to capture solar generation data.

Concurrent with Phase 2, PG&E evaluated the accuracy of the PV generation estimates in Phase 3. This analysis was done by comparing the estimated PV generation data to the actual CSI metered data. Finally, in Phase 4, PG&E's Customer Insights group conducted a survey to assess overall customer satisfaction with the data availability and visualization.

2.3.1 Major Tasks

The four major tasks associated with the project correspond with the four project phases:

1. **Identify and test potential methods to capture solar generation data:** This task tested the viability of four different methods for capturing PV generation data.

   i. The first method was installing regular PG&E SmartMeter^{TM} devices to the PV system to be used as an Advanced Metering Infrastructure (AMI) submeter. The initial plan included 100 installed PV submeters; however, after assessing the cost, the modified plan included the installation and assessment of 10 submeters. This task required many levels of coordination to access the customer's property, to install the meter socket, and program the meter.

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[11] The initial goal was to install 100 PV submeters to get a sample large enough to yield statistically significant results to assess how well the third party estimation algorithm could estimate solar generation. To ensure effective use of ratepayers' monies, the target was reduced to 10 PV submeters and the project used the existing residential CSI metered data to ensure a statistically significant analysis. In the end, due to technical issues, customer moves, and customer attrition, only seven meters were actually installed and functioning as part of the demonstration project.

ii.   The second method tested the ability to read meters directly from existing inverters that have ZigBee® radios. The ZigBee®-compatible submeters and inverters were tested in the lab for their capabilities to join the meter's ZigBee® network in the same way as any other home area network (HAN) device.

Figure 2-1 represents how the submeter data would flow in the ZigBee® submeter configuration. As displayed, the PG&E SmartMeter™ includes two radios: (1) ZigBee® and (2) AMI Radio. ZigBee® is used to connect to other ZigBee® devices within the customers' home, such as a HAN device, solar inverter, etc., whereas the AMI radio connect to other Access Points (APs) to send the AMI SmartMeter™ data back to PG&E for billing and/or reporting.

Figure 2-1: ZigBee® Radio Submeter Configuration
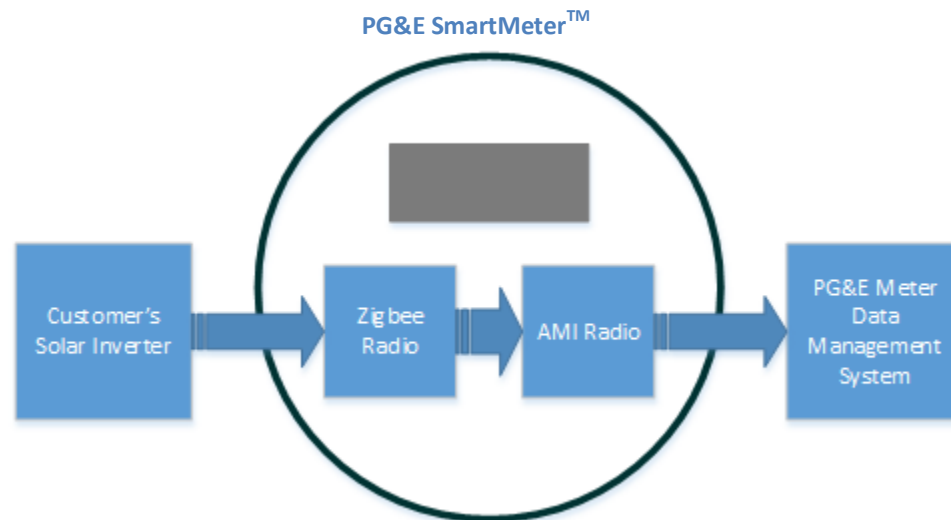
iii. The third method tested the capabilities of one of two algorithms (Algorithm A) to predict PV generation given system and weather data. The PV system was supplied by PG&E's interconnection database for the 10 customers selected to have submeters installed onto their systems. The remaining 10,000 customers in the technology demonstration project were selected randomly among the customers that PG&E had full PV system characteristics on record, were active users of the PG&E YourAccount tool and did not have systems that were significantly shaded, which would produce less accurate solar generation predictions. This system information came from their CSI applications. Weather data came from a commercially available tool that supplies historical and forecasted solar irradiance data.

iv.   The fourth method assessed the potential avenues and challenges of obtaining solar generation data from solar companies.

2.   **Integrate and visualize PV generation data on YourAccount:** This task aimed to develop web views to display PV generation data to solar customers within YourAccount. The goal was to enable customers to see their PV generation and household consumption data at varying degrees of granularity: by day and by month.

3.   **Evaluate the accuracy of the PV generation estimates:** This task used actual solar output data collected as part of the CSI for residential customers included in the demonstration project and compared it to their estimated output from two PV generation algorithms (Algorithm A and Algorithm B). This allowed PG&E to assess the costs and benefits of using each algorithm. This

evaluation also included in depth analysis of the performance of the estimated generation data in the unique climate zones within the territory. In order to conduct this evaluation, PG&E had to clean the solar generation data collected as part of the CSI and remove any customers who had poor data as a result of shading on their PV systems or missing PV system characteristic information.

4. **Assess customer satisfaction:** This task evaluated customer satisfaction with the solar generation data and how the data were presented on YourAccount. PG&E used three tools to assess customer satisfaction: (1) an online survey; (2) web analytics; and (3) call center metrics. The online survey sought to answer questions related to customers' comprehension of the information presented, whether customers found the information useful, and whether customers used the knowledge of solar generation and premise usage to make informed decisions about rate and energy efficiency.

2.3.2 Milestones Achieved and Deliverables Produced

Each of the above four tasks had associated deliverables:

1. **Identifying ideal methods for capturing PV generation data:** PG&E assessed four different methodologies for capturing PV generation data:

   1) Installing SmartMeter^{TM} devices on PV systems to be used as submeters;

   2) Reading meters directly from existing inverters;

   3) Predicting PV generation using Algorithm A; and

   4) Obtaining solar generation data from solar companies.

   After assessing each method on technical feasibility, cost, and potential ease of implementation, PG&E decided to move forward with two of the four methods as the project's primary means for capturing solar generation data: installing a sample of submeters (method 1) and leveraging the PV generation algorithm (method 3).

2. **Producing views by day and by month of customer generation and consumption data in YourAccount:** PG&E successfully integrated the estimated solar generation data into YourAccount for all 10,000 customers in the technology demonstration project. The deliverable associated with this milestone is the Solar Production View on YourAccount that allowed these customers to visualize their solar production and home consumption data by each day and by each month in the EPIC project. The solar view platform went live on December 11, 2015 and was available to customers for just over six months until June 30, 2016. See Appendix A, which provides sample screenshots of the customers' view of their usage and generation data by day and by month.

3. **Evaluation of the accuracy of estimated PV generation:** PG&E evaluated the accuracy of the estimated PV generation algorithm from a vendor that had strong data interoperability competencies, enabling them to interface with the Application Program Interface (APIs) of the PG&E vendor that displays customer energy data in YourAccount. The algorithm captured data from customers' PV system specifications, which came from PG&E Interconnection Database. Additionally, the algorithm captured satellite and weather data, such as solar irradiance data. The vendor then developed their proprietary model to create an output of estimate PV generation data (Algorithm A).

The outputs from Algorithm A were compared to that of Algorithm B based on actual solar output collected for 77 customers.[12] The solar data was collected as part of the CSI for performance-based incentive (PBI) purposes. PG&E assessed three aspects of PV output estimation accuracy: (1) the overall estimation error of the vendor's algorithm; (2) the cause of the algorithm's highest estimation errors at its lowest estimation error locations and whether these errors were due to specific weather conditions; and (3) the algorithm's estimation error during common cloud patterns that affect PG&E's service territory. Section 3.2 provides further results and key takeaways from the accuracy assessment of the estimated PV generations data.

4. **Evaluation of customer satisfaction:** After the YourAccount Solar Production View tool went live for 10,000 solar customers PG&E used several approaches to collect user feedback. The deliverables associated with this milestone are the results from the online survey, web analytics captured from participants' usage of the solar production tool, and call center data for participants over the same period. Section 3.4 provides a summary of the results of the customer satisfaction of the YourAccount Solar Production Tool. Appendix C includes the list of online survey questions asked of the customers.

3. Project Results and Key Findings

This section summarizes the project's technical results, key findings, and recommendations.

3.1 Evaluation of Methods for Capturing Solar Generation Data

PG&E evaluated four methods to collect solar generation data based on technical feasibility, cost, and ease of implementation. Ultimately, PG&E decided to move forward with only two methods for the duration of the demonstration project: (1) installing SmartMeter^TM devices to existing PV systems to be used as PV submeters; and (2) estimating PV generation using Algorithm A. Overall, each of the methods explored required non-trivial IT modifications and/or software development. The need for this type of IT support must be fully assessed when considering larger scale applications of similar technology demonstration projects. The following sections 3.1.1 through 3.1.3 summarize the findings of each of the four evaluated methods for capturing solar generation data.

3.1.1 Installing PG&E SmartMeter^TM devices to Act as PV Submeters

After the decision to move forward with the two methods of capturing solar generation data described above, the project initially identified sample for installing PV submeters included 100 meters. The cost for a third party to install a regular PG&E SmartMeter^TM to be used as an AMI submeter on an existing PV system exceeded original estimates. Depending upon installation conditions, costs for a third party to install a SmartMeter^TM ranged between 25% and 280% more than PG&E's installation costs. In addition, all jurisdictions required building permits to install a new meter base and submeter, which extended the time for each installation, further contributing to costs and customer inconvenience. After assessing the overall costs and balancing the costs with potential benefits from successful submeter installations, the scope was adjusted to include only 10 submeters with PG&E employees, in order to still gain qualitative lessons learned for configuring the meters to display actual submeter data to inform future program considerations. Prior to installations, one customer moved and two others dropped out of the program. Therefore, PG&E moved forward and installed a total seven meters.

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[12] There were initially 211 PG&E residential customers with actual interval data reported through the CSI website; however, only 112 had consistently reported data since January 2015. Of those 112, an additional 35 customers were removed due to the poor quality of the data received.

After installing the submeters, the data needed to pass through back-end metering systems without impacting customers' bills. This required unique modifications to the accounts to ensure meter data are filtered and directed appropriately, and also required creating a database to store the PV generation data.

3.1.2   Reading Submeters Directly from Existing Inverters

While there are various low-cost, plug-and-play submeters under development, none are ready for field application at the time of this technology demonstration project. Reading submeters directly from existing inverters would require significant investment to AMI firmware and software. Instead, PG&E lab tested the potential to capture solar data using submeter devices that could communicate with their corresponding SmartMeter^{TM} using the ZigBee® protocol. The submeters can join the ZigBee® network in the same way as any other HAN device, such as an in-unit home display. These meters could then be read remotely by the PG&E back-end system along with the net metering data that is currently being directly read from the AMI meter.

To ingest multiple data streams from the SmartMeter^{TM}, there were non-trivial IT modifications that were necessary to be made. While utilities normally receive a single metered data per Service Account Identifier (SAID), this EPIC project demonstrated the ability to ingest multiple data streams from multiple meters. PG&E developed IT solutions to allow multiple meters to be attached to a premise or account. With further development beyond the scope of this project, it is possible that customers may be able to see energy usage broken down by submeter, such as PV generation, Electric Vehicle (EV) charging, battery storage charge and discharge, on a single display. This aggregated information would be useful to both the customer and to operational personnel.

While ZigBee® compatible submeters and inverters are a viable solution for reading PV generation data, there are several economical and technical issues identified by PG&E that would need to be addressed before these submeters could be used for widespread application.

- Currently, there is no method available to read the submeter values through the AMI network without substantial modifications to back-end AMI systems. These are needed to ensure there is enough bandwidth to move the PV generation data on the wireless AMI network, to test network messaging and firmware on SmartMeter™ devices, and to upgrade the software of the back end system components to ingest a new data stream. The cost of such an upgrade is substantial, and beyond the budget for this project for a demonstration.
- The accuracy of the devices varied from revenue grade (±0.5%) to ± 5% in the lab tests. In order for widespread application, accuracy requirements for this type of application need to be defined, as well as accuracy standards for the device itself.
- There were operational issues with submeter power register resets on power-up. Since the power register in the submeter resets on power-up, some means will be required on the back-end to account for this and maintain an accumulated power value.

In addition to resolving the technical issues described above, the widespread application of this method for capturing solar generation data would require the development of standardized installation methods, agreed upon data formats, data storage requirements for PV generation data, and IT infrastructure to support the backhaul of the data.

Overall, the investment needed to successfully field test this method of capturing solar generation exceeded the project's budget and timeline, therefore a lab test was conducted with the above noted results and more detail can be found in Appendix B - ZigBee® PV Submetering Case Study.

3.1.3   Leveraging an Algorithm to Predict PV Generation

Leveraging an approach that estimates PV generation based on a variety of PV system characteristics and environmental factors was an ideal consideration for obtaining PV generation data due to this option's affordability opportunity. Using estimated generation is more cost-effective than installing submeters to monitor and collect PV applications. However, it was crucial that the level of accuracy of the algorithm be verified in advance of displaying this information to customers, which was undertaken through this project. Additionally, for the purposes of displaying the estimated PV generation results to the customer, the selected algorithm also required the ability of the algorithm's vendor to interface with the Application Program Interface (API) of the PG&E vendor that displays customer energy data in YourAccount. The results of the accuracy assessment are further discussed in Section 3.2.

The key assumption for the success of this method is that high quality data on PV system characteristics, system shading, and other environmental factors are available. For this technology demonstration project, much of the system characteristics data was provided by PG&E's interconnection database, while other inputs, such as percent shading were provided by the CSI database. The availability of comprehensive, quality solar characteristic data is slowly declining as more solar customers come online, since this robust data set from the project came from the CSI program, which has achieved its objective and is generally closed to new applicants. Data such as shading characteristics are now optional for reporting and necessary for the PV generation data to be accurate. This ultimately impacts the future scalability of this demonstration project as PG&E will need to fill the data gap by collecting or modeling system shading and further expanding the algorithm to better integrate shading parameters and more accurately estimate solar generation. A summary of the inputs used in this project is shown in Appendix E –Algorithm Inputs, Source and Description.

3.1.4   Obtaining Data from Solar Companies

The option to obtain generation data from solar companies would allow PG&E to gain access to PV generation data and would offer solar companies a way to obtain SmartMeter™ energy data. While several solar companies expressed interest in selling PV generation data to PG&E, there were several technical and legal challenges that needed to be overcome. Specifically, there were questions regarding data transfer protocols and methods, customer consent, "fair" pricing of generation data, and data ownership questions. PG&E determined that the barriers to scalability, compounded by the need to integrate data from multiple vendors could not be overcome within the timeframe of this technology demonstration project and therefore this option was not leveraged in this project.

3.2   Solar Generation Algorithm Accuracy Assessment

PG&E subscribed to a vendor that created Algorithm A due to their ability to interface with the API of the PG&E vendor that displays customer energy data in YourAccount. This algorithm which used PV system characteristics data from PG&E's Interconnection database and historical irradiance data[13] to generate daily solar generation profiles for the 10,000 customers participating in the demonstration project.

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[13] Irradiance data is radiant flux (power) received by a surface per unit area.

In order to assess the accuracy of the estimated PV generation data, disparate data sets were compiled from external sources and the outputs from Algorithm A were compared to that of Algorithm B based on actual solar output collected for 77 customers across PG&E's territory.[14]

The metered solar generation interval data was collected as part of the CSI program for performance-based incentive (PBI) purposes. The CSI program offered cash incentives for new distributed solar installations in order to help promote adoption. As part of the CSI program, new installations had to record and report all necessary PV installation design specifications, including percent shading of the PV system. Furthermore, a subset of these CSI program participants provided interval generation data on an on-going basis. This data was leveraged for the design of Algorithm A.

PG&E assessed three aspects of PV output estimation accuracy:

(1) The overall estimation error of the vendor's algorithm;
(2) The cause of the algorithm's highest estimation errors at its lowest estimation error locations and whether these errors were due to specific climate zones; and
(3) The algorithm's estimation error during common cloud patters that affect PG&E's service territory.

PV estimation accuracy was evaluated using the following four metrics:

- **Daily Mean Percent Bias** (MPB) – Difference in daily total estimated generation and daily total actual generation, divided by the system daily max power output (AC system size multiplied by 24). This metric determines net difference in estimated generation and actual generation, normalized across varying PV system sizes, and values closer to zero indicate higher accuracy.

- **Daily Mean Absolute Percent Error** (MAPE) – Absolute value of difference between hourly estimated and actual generation, averaged by day, and divided by the AC system size. This metric determines the overall magnitude of estimation error, and values closer to zero indicate higher accuracy.

- **Afternoon Mean Absolute Percent Error** (MAPE) – same method as Daily MAPE, but calculated only from the 3pm to 8pm window, which coincides with the typical period of highest energy prices. This metric determines the magnitude of estimation error during the window of highest financial impact for time-of-use rate-plan customers, and values closer to zero indicate higher accuracy.

- **Daily Average Correlation Coefficient** (CC) – daily Pearson correlation coefficient of estimated versus actual generation. This metric reflects whether the progression of estimated generation increases/decreases in accordance with actual generation, and values closer to one indicate higher accuracy.

Table 3-1 clarifies the metric value ranges that were considered ideal, good, acceptable, or not acceptable for each metric.

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[14] There were initially 211 PG&E residential customers with actual interval data reported through the CSI website; however, only 112 had consistently reported data since January 2015. Of those 112, an additional 35 customers were removed due to the poor quality of the data received.

Table 3-1 Metrics Thresholds for PV Estimation Comparison

Metric	Ideal	Good	Acceptable	Not Acceptable
MPB	-0.05 to 0.05	-0.10 to -0.05 0.05 to 0.10	-0.15 to 0.10 0.10 to 0.15	< -0.15 > 0.15
MAPE	< 0.10	< 0.15	< 0.20	> 0.25
Afternoon MAPE	< 0.10	< 0.15	< 0.20	> 0.25
CC	> 0.95	> 0.80	> 0.70	< 0.70

3.2.1 Overall Algorithm Accuracy Analysis Results

Overall, the Algorithm A had under a 5% error of daily PV generation estimates when averaging the results across all sites, which is an acceptable level of accuracy. Depending on season, the daily MPB for Algorithm A is typically 3-5% less than actuals. However, this result of average daily PV generation across all sites is not indicative for a customer who is interested in their own PV generation data. Single-site and single-day extremes were found to have a ±30% error rate. This error rate for individual sites would not be appropriate to display to customers at full-scale.

The data also indicates that there is little variation by season, though estimation error is slightly lower during Q2 and Q3 (spring and summer) than Q1 and Q4 (fall and winter). Furthermore, there are not large differences in error by PG&E Division (i.e. climate), with errors more correlated to individual site characteristics such as un-recorded installation specifications and or localized shading effects.

Comparing the absolute value of Algorithm A's daily MPB to MAPE, MAPE is slightly higher (8-10%). This indicates that errors between each hour are offset over the course of the day and daily generation estimation is more accurate than hourly power output estimation. Furthermore, afternoon MAPE is higher still than daily MAPE (8-14%), indicating that afternoon estimation-errors are greater (i.e. less accurate than) the daily average. Lastly, daily Correlation Coefficient (CC) is at 0.83, which is sufficient[15]. Overall, the estimations from Algorithm A are good, and provide accurate estimations of daily generation. However, PG&E would like to see all the estimation errors metrics less than 10%, ideally less than 5%.

For a point of comparison, the Algorithm B estimations (which use the same weather inputs as the proprietary model from Algorithm A) out-performed Algorithm A in every category, in every season, and at nearly every location. This is primarily due to the fact that Algorithm B estimates more generation over the course of the day at most sites, thus splitting the difference between lower estimations and actuals in Algorithm A. It appears that the main driver of the PV generation estimation difference is how the two algorithms resolve irradiance in the plane of the array with Algorithm A systematically under-estimating plane of array irradiance, thus dictating the lower PV generation estimates. The results for the first analysis can be found in Appendix D – Estimation Error Results for PV Algorithm Accuracy Analysis.

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[15] A Correlation Coefficient (CC) value at or above 0.75 is typically considered good.

3.2.2   Cause of Algorithm's Highest Estimation Errors

The second analysis looked at understanding the highest estimation-error days at the five CSI locations with the lowest overall CPR estimation-error[16] in order to determine if abnormally high estimation-error was due to certain cloud patterns conditions, or merely an abnormality.

These five lowest estimation-error locations range geographically from two coastal locations (Santa Cruz and Santa Maria) to two bay locations (east and south bay), and one interior location (Stockton). Average daily MPB at each location ranges between -2% and 2%, and days where MPB were outside the location's average MPB plus/minus 2 standard deviations where selected for detailed analysis.

Overall, the most frequent cause of abnormally high PV estimation error was a shallow marine layer, followed next by magnitude/timing issues associated with either monsoonal moisture transport, or frontal passage. In the greater scheme though, these irregularly high error incidents were few and far between, in the regular or semi-regular occurrence of these types of events. More attention can be paid to this topic in the next analysis.

3.2.3   Determining Estimation error during common cloud patterns that affect PG&E's service territory

For the third analysis, weather records were reviewed from January 2015 through March 2016, in order to identify various dates in which common cloud patterns (or weather features) affected the PG&E service territory. Dates in which monsoonal moisture transport, frontal passage (both warm and cold), coastal marine fog, interior valley "Tule" fog, or high above-normal temperatures (with clear-skies) were all identified and grouped by type. PV estimation errors in the affected areas[17] were then evaluated to determine if the given conditions drove higher than typical estimation errors, and if certain areas (i.e. PG&E Divisions) exhibited higher error than others.

Overall, PV estimation error was not notably higher (than normal errors) for these events, indicating that the PV estimations remain at a similar level of accuracy between these various conditions and clear sky conditions. While there were division-by-division differences in PV estimation accuracy during the various cloud patterns, the errors are more driven by incomplete installation design specification data, and/or localized shading effects.

3.2.4   Summary of Results

Overall, based on the data set examined, the monthly aggregated results from Algorithm A were accurate enough to be considered for displaying to customers while the daily results may not be sufficiently accurate for displaying to customers. Figure 3-1 below demonstrates that as more data is provided at a more granular time interval, the higher the mean absolute error.

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[16] The benefit of focusing on the lowest estimation-error locations is that localized shading effects do not improperly skew the data, and therefore causes of estimation-error can be more clearly identified.

[17] Coastal fog is not something that affects an interior division, so interior divisions were left out of the analysis. Similar logic was applied to other weather event types and divisions.

Figure 3-1: Mean Absolute Error of Algorithm Accuracy based on Time Interval of data provided to Customers in YourAccount
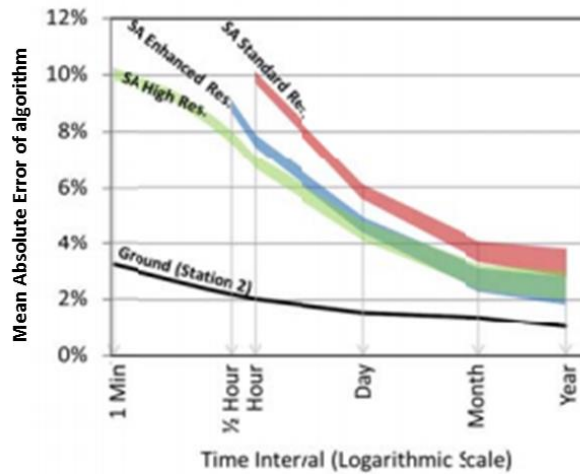
This analysis also revealed there was very little variation by season and little differences in error by PG&E Division (i.e., climate zone). The errors more correlated to individual site characteristics, such as incomplete installation specification data and/or localized shading effects. Additionally, this study discovered that irregularly high PV estimation error is predominantly caused by a select few weather types, namely a shallow marine layer at the coast or by magnitude/timing issues associated with either monsoonal moisture transport, or frontal passage. Furthermore, these irregularly high estimation-error cases were not necessarily guaranteed with these common weather types, and after a deeper review of these common weather patterns, none of them were found to greatly reduce the PV estimation accuracy.

In the end, this analysis showed that the PV generation estimates were comparable between Algorithm A and Algorithm B. For some measures of accuracy, Algorithm B performed better than Algorithm A. This revelation demonstrates an important cost-benefit consideration for potential further application of this demonstration project or others like it given there is a high difference in cost between these two algorithms.

Finally, it is important to note that the assumptions required for widespread implement this method are:

- PV system characteristics are available and complete (including tilt, azimuth, etc.); and
- No major shading is present or the shading pattern is known.[18]

In other words, with complete data on PV system characteristics, PG&E can generate accurate and reliable generation estimates for fully, non-shaded systems; however, capturing shading data is also required to generate the same level of generation estimates for the remaining PG&E solar population.[19]

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[18] According to the vendor, a future version of the algorithm may be able to infer shading.

[19] The importance of complete data on system characteristics and for understanding shading patterns at a system level were demonstrated through this study in the process for selecting the 77 solar customers used for comparison against the algorithms' estimations. Initially, 112 had consistent and complete generation data; however, 35 were removed due to poor data quality primarily arising from extreme shading conditions.

3.3   Integration of Estimated Solar Generation Data into YourAccount

In order to allow customers to view both solar generation and whole house consumption, PG&E needed to map each customer's meter badge number with the corresponding number in the vendor's database of estimated generation. There is no automatic process in place to sync these badge numbers; therefore, this became a largely manual process. Additionally, the processes to integrate customer estimated generation data and add customers to the Solar View tab were also largely done manually.

Once the data were integrated into YourAccount for each customer, PG&E provided daily and monthly views of solar generation combined with whole house consumption. The Solar Production View tab was "soft launched"[20] to 10,000 randomly selected solar customers on December 11, 2015 and was available through June 30, 2016. Appendix A shows two screenshots of the daily and monthly displays of solar production and whole home usage for the customers on YourAccount.

3.4   Tool Usage and Customer Satisfaction Survey Results

At the end of the demonstration project, PG&E used three approaches to understand how much the tool is used, obtain customer feedback and assess customer satisfaction: (1) an online survey; (2) web analytics; and (3) call center metrics.

3.4.1   Customer Satisfaction and Results of Online Survey

Customers that logged in to view their PV generation and usage data were prompted to take a brief customer satisfaction survey to assess overall satisfaction and use of the tool. Of the approximately 10,000 customers with access to the Solar Production View tool, 102 customers participated in the online survey.[21] Table 3-2 summarizes the survey results. Overall, the majority of respondents found the solar generation data and visualization to be useful or very useful (81%), easy or very easy to understand the information presented (86%), and were overall satisfied with the tool (74%). While the distribution of log-on frequency was fairly spread out, the majority of respondents said they were likely to return to the page, and were likely to log-on more frequently if the information were to continue to be available.

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[20] PG&E did not communicate to customers that the product was available.

[21] A customer is defined as participating in the survey if he/she answered at least one non-demographics question.

Table 3-2: Summary of Solar View Customer Satisfaction Survey Results

Customer Demographics and Characteristics	**Gender**	**Female**			**Male**			**Prefer not to respond**	**N**
		15.0%			79.0%			6.0%	100
	Age Range	**18 - 24**	**25 - 24**	**35 - 44**	**45 - 54**	**55 - 64**	**65 - 74**	**75 or older** · **Prefer not to respond**	**N**
		0.0%	1.0%	7.1%	29.6%	36.7%	17.4%	2.0% · 6.1%	100
	Region	**Bay Area**		**Central Coast**		**Central Valley**		**Northern Region** · **Not sure**	**N**
		36.0%		30.0%		17.0%		15.0% · 2.0%	100
	Solar Customer Length	**< 1 Year**	**1 to < 2 Years**	**2 to < 3 Years**	**3 to < 5 Years**		**5 + Years**	**Not sure**	**N**
		1.0%	2.0%	24.0%	41.0%		32.0%	0.0%	100
	Receive 3rd Party Solar Generation Data	**Yes**			**No**			**Not sure**	**N**
		58.0%			36.0%			6.0%	100
Customer Satisfaction and Comprehension	**Usefulness of Information**	**1 = Not at all Valuable**		**2 = Not Valuable**		**3 = Neither Valuable nor Not Valuable**	**4 = Valuable**	**5 = Highly Valuable**	**N**
		6.9%		5.0%		7.9%	20.8%	59.4%	101
	Ease of Understanding	**1 = Very Difficult**		**2 = Difficult**		**3 = Neither Difficult nor Easy**	**4 = Easy**	**5 = Very Easy**	**N**
		4.0%		2.0%		7.9%	30.7%	55.4%	101
	Overall Satisfaction	**1 = Very Dissatisfied**		**2 = Dissatisfied**		**3 = Neither Satisfied nor Dissatisfied**	**4 = Satisfied**	**5 = Very Satisfied**	**N**
		5.9%		5.9%		13.7%	27.4%	47.1%	102
Frequency of Use	**Frequency of Log On**	**Daily**	**About Once a Week**	**About Once a Month**	**Every Few Months**	**A Few Times / Year**	**Less Often**	**First Time**	**N**
		5.1%	13.4%	19.6%	25.8%	4.1%	2.1%	29.9%	97
	Likelihood of Returning to Solar Product Tab	**1 = Very Unlikely**		**2 = Unlikely**		**3 = Neither Likely nor Not Likely**	**4 = Likely**	**5 = Very Likely**	**N**
		6.0%		2.0%		6.0%	13.0%	73.0%	100
	Likelihood of Logging on more Frequently if Information Persists after Pilot	**Yes**			**No**				**N**
		85.0%			15.0%				100
Other	**Likelihood of Recommending Solar Production Tab**	**1 = Very Unlikely**		**2 = Unlikely**		**3 = Neither Likely nor Not Likely**	**4 = Likely**	**5 = Very Likely**	**N**
		6.1%		5.1%		13.3%	14.3%	61.2%	98
	PG&E Supports Customer Choice to go Solar (Agree or Disagree)	**1 = Strongly Disagree**		**2 = Disagree**		**3 = Neither Agree nor Disagree**	**4 = Agree**	**5 = Strongly Agree**	**N**
		12.0%		12.0%		33.0%	14.0%	29.0%	100

The survey also included a free response question, asking respondents to suggest improvements to the tool. 40 of the 102 respondents provided suggestions, which can all be grouped under one of three themes:

1. User Interface and Additional Capabilities
   - Make website more visually appealing
   - Include an explanation for how solar generation was produced
   - Include data export functionality
   - Allow customers to select a specific date range to view
   - Display dollar amount owed to/from PG&E (e.g., cumulative YTD, average net)
   - Change display to correspond to actual billing cycle rather than calendar month
2. Technical Capabilities and Data Accuracy
   - Improve data accuracy (e.g., data shown on Solar View was not consistent with customer bill)
   - Provide more historical data to allow customers to track PV panel performance
   - Offer to integrate with third-party solar provider data
3. Rate and Bill Support
   - Combine display with Time of Use (TOU) information
   - Show comparison of TOU vs. tiered rates and the amount offset by solar generation
   - Provide additional rate and bill support (e.g., suggest optimal bill, estimated bill)

3.4.2   Solar Usage Webpage Views

Over the course of the six months that the solar production view was live, there were 3,102 unique visitors out of the 10,000 customers that had access to view this information on the website. These 10,000 customers were selected based on the availability of one year's worth of historical production data, as well as having a previous history of logging into their YourAccount tool on pge.com.

3.4.3   Call Center Metrics

Over the course of the six months that the solar generation data view was live in PG&E's YourAccount website, PG&E received 24 calls to the call center related to this portal. Overall, the number of calls is very low and reasonable relative to the number of unique visitors to the website (over 3,100). Additionally, the volume of calls is not concerning from a cost-effectiveness perspective to manage this number of inquiries.

The content of these calls were primarily related to understanding the difference between their generation data provided by PG&E and that provided by their solar provider. Their data did not 100% align for two factors: (1) PG&E's monthly billing days to not align with the solar provider, and (2) The PV generation data is an estimate based on an algorithm, which does not exactly match the generation data.

4. Unique Technology Implementation Issues

The PV Submetering project aimed to develop a cost-effective method to capture solar generation data and integrate it with PG&E's YourAccount portal so that customers could view both generation and consumption of their home. Given the cost of implementing an existing market solution, the project experienced several issues around data transfer coordination and IT implementation. The following section summarizes the technological issues, key lessons learned, and recommendations for addressing future challenges.

4.1   Accuracy of Algorithms Require Additional and Complete Data

The assumptions required for maintaining accurate algorithms to estimate PV generation data, include:

- PV system characteristics are available and complete (including tilt, azimuth, etc.); and
- No major shading is present or the shading pattern is known.[22]

For a period of time, tilt and azimuth data fields were optional in the Interconnection Application. While these fields are now mandatory, this data gap impacted the completeness of the data to accurately estimate PV generation data across the entire data set, which further impacts the ability to scale the estimated generation data to all solar customers. Additionally, this project leveraged data available from participants in the CSI program, which included comprehensive data, such as shading patterns. Appendix E –Algorithm Inputs, Source and Description clarifies the data sources leveraged in this project as inputs to the algorithm.

Furthermore, with complete data on PV system characteristics, PG&E can generate accurate and reliable generation estimates for fully, non-shaded systems; however, capturing shading data is also required to generate the same level of generation estimates for the remaining PG&E solar population.[23]

4.2   Challenges with matching estimated solar generation to customer consumption data

Currently, there is no automatic process to align customer generation estimates with actual house consumption data collected by PG&E SmartMeter[TM] devices. Each meter badge number needed to be manually matched with the badge number supplied by the vendor in order to match a customer's consumption data with the estimated solar generation data. Additionally, the processes for adding customer generation data and adding customers to the Solar Production View tab were largely manual and ad-hoc. This created several error prone work streams and required several iterations of coordination between PG&E and the vendor.

4.3   Ensuring all the data is referenced in the same time zone

In this particular implementation, there was a system design issue identified where the databases did not initially match the time zones between the interval information from the estimated data platform and the customers' net metering information. This can cause errors in the accuracy of the estimated generation data and was resolved.

4.4   Integrating submeter data from SmartMeter[TM] devices requires a larger scale implementation

As part of this project it was decided to manually obtain the data from the sub meters into the CDW database, as an automated approach it was too costly for a demonstration-scale effort. This should be re-evaluated for full scale deployment.

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[22] According to the vendor, a future version of the algorithm may be able to infer shading.

[23] The importance of complete data on system characteristics and for understanding shading patterns at a system level were demonstrated through this study in the process for selecting the 77 solar customers used for comparison against the algorithms' estimations. Initially, 112 had consistent and complete generation data; however, 35 were removed due to poor data quality primarily arising from extreme shading conditions.

5. Key Accomplishments and Future Opportunities

5.1 Key Accomplishments

The following is a summary of the key accomplishments of the project:

- Evaluated four methods for capturing photovoltaic (PV) generation data. Two were accepted and implemented for the project: (1) Installing SmartMeter^{TM} devices on PV systems to be used as sub-meters and (2) predicting PV generation using a third party software;

- Determined the accuracy of Algorithm A to predict PV generation was an acceptable level for customer use when daily predictions were aggregated at the monthly level;

- Comparison of algorithms determined that averaged across all sites, both algorithms had under a 5% error, while single-site and single-day extremes can range between ±30% error rate.

- Enhanced PG&E production systems (Customer Data Warehouse [CDW]) to ingest and store multiple submetered data streams;

- Developed process to receive solar generation estimates for approximately 10,000 PV systems from a third-party tool;

- Developed a tool to allow customers to visualize solar generation and whole house consumption that was "live" in the field for approximately six months;

- Surveyed customers to measure the value proposition of the displayed PV generation data; and

- As a result of this project, the PG&E interval data warehouses may be extended to include additional metered data streams of other behind-the-meter distributed energy resources (DERs).

5.2 Future Opportunities

Although there were several technical challenges the project needed to overcome regarding data integration and IT needs, the key driver to widespread application of this technology demonstration projects is the ability to cost-effectively acquire solar generation data. PG&E identified several options for future options for acquiring PV generation data, including improving the accuracy of the algorithm or acquire the actual solar data cost-effectively.

5.2.1 Improving the Accuracy of the Algorithm

While PG&E was able to successfully determine the necessary inputs to develop an accurate algorithm at a monthly level by customer based on system characteristics and weather, the data set was massaged for quality and completeness in order accurately estimate PV generation data. To improve the accuracy of the estimated generation data, there are multiple needs that may be further assessed:

- Understanding the angles of the PV equipment, which has been rectified by requiring this information in the interconnection application; and
- Having an accurate understanding of the degree of shading on solar installations (impacted by tree growth and buildings), which is difficult to predict. Further expansion of these constraints can be found Section 3.2 - Solar Generation Algorithm Accuracy Assessment.

Data that is captured by Light Detection and Ranging (LIDAR)[24] may be one potential future opportunity to improve the understanding of the angles and the degree of shading of solar installations, which may help improve the accuracy or the algorithms and completeness of the data.

5.2.2 Options for Acquiring Solar Generation Data

Various considerations noted below may potentially involve policy changes to require solar companies share, and not sell, generation data with utilities. Other potential avenues for acquiring solar generation in the medium and long-term are:

- Considering the requirement for utility-owned PV submeters to be installed with each new PV installation in selected areas with higher PV penetration;

- Continuing to monitor the progress of key inverter manufacturers who have begun to support ZigBee® communications in various use cases;

- Identifying parallel efforts and synergies with HAN and third-party product capability; and

- Continuing to align with the Smart Inverter Working Group (SIWG) that is currently in the process of defining technical communication protocols and provide policy and strategy input.

5.2.3 Explore Additional Use Cases for Solar Generation Data

PG&E identified several additional opportunities for estimated solar generation data to be explored for leveraging within PG&E:

- PV generation data may allow for better visibility into distributed generation (DG) production patterns, which are useful for transmission and distribution (T&D) planning;

- The ability to view PV generation may help operators understand how much load DG is masking, which is especially relevant to load switching operations; and

- Access to PV generation data may allow PG&E to improve forecasting of retail load requirements and lower procurement costs with their participation in the California Independent System Operator (CAISO).[25] Improved forecasting may decrease the costs to serve PG&E load obligation by allowing greater accuracy of energy purchased in the Day Ahead Market relative to unplanned energy imbalances addressed through volatile CAISO Real-Time Markets.

5.2.4 Expand Synergies with HAN (Home Area Network) and Third-Party Products

While PG&E demonstrated through this project that ZigBee® compatible submeters and inverters are a viable solution for reading PV generation data, PG&E identified several economical and technical issues that would need to be addressed before these submeters could be used for widespread application:

- Developing accuracy requirements of submeters and inverters;
- Developing standardized protocols for data transfer; and
- Developing standardized installation methods.

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[24] Light Detection and Ranging (LIDAR) is a remote sensing method that uses light in the form of a pulsed laser to measure ranges (variable distances) to the Earth.

[25] All PG&E retail load, on an hourly basis, is bid/scheduled into the CAISO Day Ahead Markets daily.

Further application of HAN and third-party products as a method for collecting solar generation data would require PG&E, with input from other industry members, to develop a method to read submeter values through the AMI network, which includes but is not limited to the following actions:

- Ensuring there is sufficient bandwidth to move PV generation data through the wireless AMI network;
- Testing network messaging and new firmware on SmartMeter™ devices;
- Upgrading the software of backend system components to accommodate the new data stream; and
- Understanding storage requirements for storing PV production data.

6. Value proposition

6.1 EPIC Primary and Secondary Guiding Principles

While the project determined the need to improve the data quality and quantity to develop a scalable algorithm that accurately estimates PV generation data, it is possible for the following EPIC primary and secondary principles could be fulfilled once these discrepancies are resolved. The estimated PV generation information helps customers better understand the relationship of their solar generation and their daily load usage. This information also helps PG&E understand the utility's changing base load characteristics as new solar generation is added every day. Table 6-1 summarizes the specific primary and secondary EPIC Guiding Principles advanced by this technology demonstration project.

Table 6-1: EPIC Primary and Secondary Guiding Principles

Primary EPIC Guiding Principles			Secondary EPIC Guiding Principles					
Safety	Reliability	Affordability	Societal Benefits	GHG Emissions Mitigation / Adaptation	Loading Order	Low-Emission Vehicles / Transportation	Economic Development	Efficient Use of Ratepayer Monies
	✔	✔	✔					✔

The PV Submetering technology demonstration project advances the following primary EPIC principles:

- *Reliability:* While the project determined the limitations in the existing data quality, once resolved the estimated PV generation data identified in this technology demonstration project may help PG&E understand the changing base load characteristic resulting from increased PV generation. It may also provide planners with more detailed and accurate information to better understand the gross load to properly account for actual demand on specific assets. The data could also be useful for distribution operators to more accurately quantify load masking and generated more accurate predictions of expected PV generation for short term forecasting. This could potentially help improve the distribution planning process and energy procurement.

- *Affordability:* The use of estimated generation is more cost effective than installing submeters for PV applications or paying for the data from a third party solar provider. Customers can also have a better understanding of their individual PV systems with respect to their energy usage.

The PV Submetering technology demonstration project advances the following secondary EPIC principles:

- *Societal Benefits:* Providing PV generation to customers allows them to understand the impact of their generation on their individual energy usage especially when combined with time of use metering and disaggregated load information. This could ultimately help customers be more efficient energy users.

- *Efficient Use of Ratepayer Monies:* This project suggests an efficient use of ratepayer monies by providing for more cost effective ways to obtaining and providing estimated generation

6.2   Technology Transfer Plan

One benefit of the EPIC program is the technology and knowledge sharing that occurs both internally within PG&E, and across the other IOUs, the CEC, and the wider industry. In order to facilitate this knowledge sharing, PG&E is considering sharing the results of this project in relevant industry workshops, such as ESource, Behavior, Energy and Climate Change (BECC) conference, and other solar-relevant forums like Smart Electric Power Alliance or Intersolar North America. Additionally, this report will remain published on the PG&E website and included in the 2016 EPIC Annual report. PG&E will continue to explore potential opportunities to engage in platforms to share the project's results.

6.2.1   Adaptability to other Utilities / Industry

The following findings of this project are relevant and adaptable to other utilities and the wider industry:

- For PV generation estimates to be accurate at the individual solar PV system level, it is necessary to include accurate modeling of shading (if the system is subject to shading) and have a complete dataset of PV system information, including tilt and azimuth;

- The accuracy of monthly estimated PV generation is sufficient for customer application (if the data set is complete including system characteristics and shading estimates);

- While utilities normally receive a single metered data per service point, this technology demonstration project demonstrated the ability to ingest multiple data streams per service point; and

- There is at least a subset of solar customers who view the ability to visualize solar generation data in addition to consumption as a valuable tool.[26]

6.3   Data Access

Upon request, PG&E will provide access to data collected that is consistent with the CPUC's data access requirements for EPIC data and results.

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[26] Because the number of survey respondents is small relative to the population of participants in the demonstration project, the data are useful for making qualitative assessments, but now allow for a robust quantitative evaluation that can be applied to other solar customers in PG&E's or the other IOUs' service territories.

7. Metrics

The following metrics were identified for this project and included in PG&E's EPIC Annual Report[27] as potential metrics to consider project benefits at full scale. Given the proof of concept nature of this EPIC project, these metrics are forward looking.

D.13-11-025, Attachment 4. List of Proposed Metrics and Potential Areas of Measurement (as applicable to a specific project or investment area in applied research, technology demonstration, and market facilitation)	See Section
5. Safety, Power Quality, and Reliability (Equipment, Electricity System)	
c. Forecast accuracy improvement	See Section 6.1
7. Identification of barriers or issues resolved that prevented widespread deployment of technology or strategy	
b. Increased use of cost-effective digital information and control technology to improve reliability, security, and efficiency of the electric grid (PU Code § 8360)	See Section 6.1
j. Provide consumers with timely information and control options (PU Code § 8360)	See Section 6.1
8. Effectiveness of information dissemination	
a. Web-based surveys of people viewing materials or participating in program reviews	See Section 3.4
f. Technology transfer	See Section 6.2
9. Adoption of EPIC technology, strategy, and research data/results by others	
d. Successful project outcomes ready for use in California IOU grid (Path to market)	See Section 5.2

8. Conclusion

This project successfully achieved all of its key objectives, and in doing so, has captured key learnings that can be leveraged by other utilities and industry members to address how behind-the-meter PV installations affect the grid and how to engage with solar customers regarding information access and visualization. Through the work executed in this technology demonstration project and documented in this report, PG&E has gained substantial experience in collecting and integrating solar generation data and enabling customers to view their generation data alongside their whole house usage data. Specifically, the project achieved the following:

- Four methods for capturing photovoltaic (PV) generation data were evaluated. The two that were accepted and implemented for the project were:

  o Installing additional SmartMeter™ devices acting as PV system submeters to measure PV generation; and

  o Estimate the PV generation using a third party data as a service platform. The data service included the data service provider sending daily estimated solar generation data.

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[27] 2015 PG&E EPIC Annual Report. Feb 29, 2016.
http://www.pge.com/includes/docs/pdfs/about/environment/epic/EPICAnnualReportAttachmentA.pdf.

- The accuracy of the third party software to predict PV generation was determined to be at an acceptable level of accuracy for customer use when predictions were aggregated to the monthly level;

- The project demonstrated the use of existing SmartMeter™ infrastructure as a viable way to collect customer solar generation data and with further development could include additional metered data streams of other behind-the-meter distributed energy resources (DERs) such as behind the meter energy storage;

- The project developed Application Program Interfaces (APIs) and processes to receive solar generation estimates for approximately 10,000 PV systems from a third-party data as a service platform;

- The project developed an online tool to allow customers to visualize solar generation and whole house consumption. This tool was "live" in the field for six months and received positive feedback from customers who used it; and

- The project measured customer perception of the tool and assessed the value proposition.

Using the estimation algorithm demonstrated in this project, PG&E can provide accurate and reliable estimates of PV generation to fully, non-shaded; however in order to provide generation information to all solar customers, detailed information on shading at a system-level, in addition to complete PV system characteristics, are required. Although system shading characteristics are available for some systems in the CSI database, it is currently optional in the PG&E interconnection application. The overall value of the data from the CSI is decreasing as PG&E closed the program to new CSI applications in 2013, and the statewide program is closing at the end of 2016. This ultimately impacts the future scalability of this demonstration project, this data gap will need to be filled by collecting or modeling system shading and further expanding the algorithm to better integrate shading parameters and more accurately estimate solar generation. Additionally, PG&E does not currently receive any solar generation data from solar companies, which further limits its ability to visualize solar generation data for customers. Due to the data limitations and technical challenges described above and throughout this report, PG&E does not currently plan to scale the project to all solar customers. However, the successful execution of this project laid the foundation for potential future opportunities that may include, but are not limited to:

- Evaluate an extension to the entire solar population at PG&E upon improvements made to existing data quality issues and/or assumptions defined to avoid gross inaccuracies in the estimate of PV generation data displayed to the customer; and

- Continue to explore additional options for acquiring solar generation data, which may require policy changes to request that solar companies share, but not sell, generation data with utilities.

The experience has ultimately informed solar generation data collection strategies, and the project's learnings will enable future improvements to collecting and integrating solar generation data, as well as improve how PG&E, and potentially other utilities, engage with solar customers.

Appendix A – Sample Customer View of Generation and Usage Data in YourAccount

The following images are screen shots of two key pages in PG&E YourAccount site that provided solar usage and generation data on a daily basis and monthly basis.

Figure A-1: Sample Screenshot of Solar Usage and Generation Data by Month
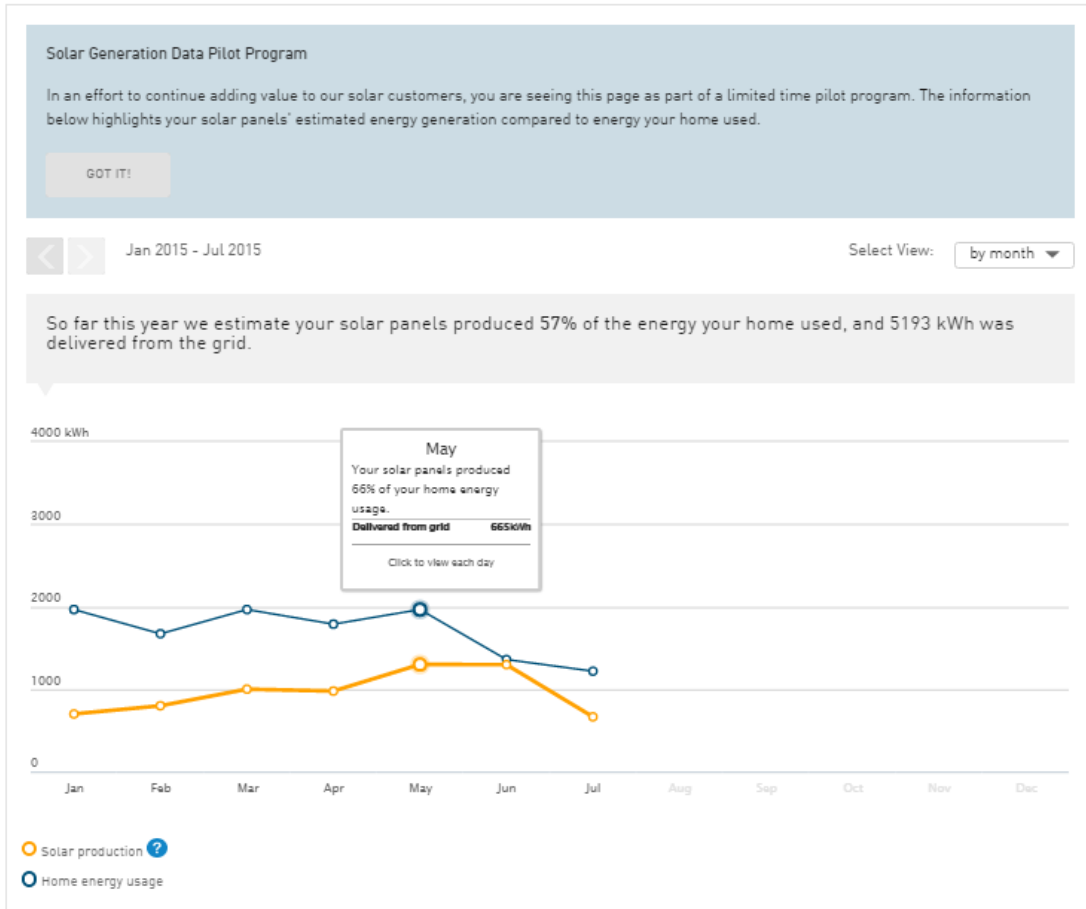
Figure A-2: Sample Screenshot of Solar Usage and Generation Data by Day

Solar Energy Produced

Solar Generation Data Pilot Program

In an effort to continue adding value to our solar customers, you are seeing this page as part of a limited time pilot program. The information below highlights your solar panels' estimated energy generation compared to energy your home used.

GOT IT!

< >   Jun 1, 2015 – Jun 30, 2015   Select View: by day ▼

So far this month we estimate your solar panels produced 95% of the energy your home used, and 62 kWh was delivered from the grid.

150 kWh

125

100

75

50

25

0

Jun 1   3   5   7   9   11   13   15   17   19   21   23   25   27   29

○ Solar production ❓
○ Home energy usage

Appendix B – ZigBee® PV Submetering Case Study

Background

EPIC Project 1.23, PV Submetering, explored various means for PG&E to obtain photovoltaic (PV) generation data from residential customer's PV systems. One method examined was using a submetering device that can communicate with the customers' SmartMeter™ devices using the ZigBee® radio, which can thereby be read remotely by the back-end system along with the net metering data that is currently being read directly from the AMI meter. This document describes PG&E's experience using a submetering device made by Schneider Electric, model number WISERCTPM200.

Description

The submetering device used, Schneider Electric model WISERCTPM200, has one voltage input that is used for both the power supply and for power measurement. The four current inputs to the ZigBee® device are provided through clamp-on current transformers (CT) can be placed on different circuits in the home. Figure B-1 is an image of the ZigBee® PV submeter, including the clamp-on CTs and four inputs to the device.

Figure B-1: Image of ZigBee® PV submeter, including Current Transformer (CT)

Testing Approach

For this test, only one channel was used. When the ZigBee® submeter is connected to a test load, it demonstrates the same performance as if it were connected to a PV system, and communicates with the SmartMeter® using the ZigBee® Smart Energy Profile (SEP) 1.1. For the test, the submeter is first configured with the device address and security key information, which enables it to join the SmartMeter™ ZigBee® network as if it were any other home area network (HAN) device, such as an in-home display unit.

At this time there was no way to actually read the submeter values completely through the SmartMeter™. Therefore, to test the submeters' communication capabilities, commands were sent to the SmartMeter™ through the AMI network to trigger the meter to read the data off of the submeter, and the ZigBee® network traffic is monitored using a sniffer device to see the values that are being sent to the meter. To verify that the submeter is accurately measuring load value, varying loads are placed on the circuit being monitored by the submeter and periodic reads of the submeter are conducted to validate the data measurement accuracy.

Conclusion

This experimental case study demonstrated the technical capability of a ZigBee®-enabled submeter to produce accurate measurements and connect to a SmartMeter™. Although the case study had a limited scope, it showed that this device is a technologically viable solution to capturing PV generation data; however, there were several downstream issues identified that would need to be addressed before widespread application:

- The accuracy requirements for this application need to be defined.
- The accuracy of the device must be determined.
- Since the power register in the sub-meter resets on power-up, some a means may be required on the back-end to account for this and maintain an accumulated power value there.
- A set of standardized installation methods and practices should be developed.
- At this time there is no method available to read the sub-meter values through the AMI network, so this must be addressed at different levels in the AMI and back-end systems including: ensuring there is enough bandwidth to move the PV generation data on the wireless AMI network; testing network messaging and new firmware on SmartMeter^{TM} devices; upgrading new software of backend system components for additional functionality for a new data stream; and understanding data storage requirements for storing PV production data.

Appendix C – Customer satisfaction survey questions

The following introduction and survey questions were asked via the web survey to the solar customers that were provided visibility to the Solar Energy Produced tab in their YourAccount web portal on www.pge.com.

Introduction: Thanks for visiting the new ''Solar Energy Produced'' tab we are piloting with a small group of solar customers. The 'Solar Energy Produced' tab displays both your solar generation and energy usage data, by month and by day. Please take our 2 – 3 minute survey to help us make improvements to this information for solar customers like you. Thank you for your feedback.

1. Overall, how satisfied would you say you were with the information provided specifically on the 'Solar Energy Produced' tab? (1=Very Dissatisfied, 5=Very Satisfied)

2. Please rate how easy or difficult it was to understand the information provided on the 'Solar Energy Produced' tab. (1=Very Difficult, 5=Very Easy)

3. Please rate how useful the information provided on the 'Solar Energy Produced' tab is to you as a solar customer. (1=Not at all Valuable, 5=Extremely Valuable)

4. How likely will you be to return to the 'Solar Energy Produced' tab in the future? (1=Very Unlikely, 5=Very Likely)

5. How likely would you be to recommend the information provided on the 'Solar Energy Produced' tab to someone else? (1=Very Unlikely, 5=Very Likely)

6. If you could suggest one improvement specifically to the 'Solar Energy Produced' tab, what would it be? Please be as specific as possible.

7. Please indicate how long you have been a solar customer.
   • Less than 1 year
   • 1 to less than 2 years
   • 2 to less than 3 years
   • 3 to less than 5 years
   • 5 years or more
   • Not sure

8. How frequently do you log in and review your solar data on the PG&E website?
   • First time
   • Daily
   • About once a week
   • About once a month
   • Every few months
   • A few times a year
   • Less often

9. Do you think you would log in to your PG&E online account more often if this generation data is available after the pilot ends?
   - Yes
   - No

10. Are you currently receiving solar generation data from your contractor or a 3rd party?
    - Yes
    - No
    - Not sure

11. Now, please tell us how much you agree or disagree that 'PG&E is a company that supports your choice to go solar.' (1=Strongly Disagree, 5=Strongly Agree)

12. Are you:
    - Male
    - Female
    - Prefer not to respond

13. Your age range is:
    - Under 18 years of age
    - 18-24
    - 25-34
    - 35-44
    - 45-54
    - 55-64
    - 65-74
    - 75 and older
    - Prefer not to respond

14. Which of the following best describes the area in which you live?
    - Bay Area Region (e.g., Oakland, Alameda, Contra Costa, San Francisco, Marin and Napa areas)
    - Central Coast Region (e.g., Fremont, Livermore, Santa Clara, San Mateo, Monterey, Santa Barbara and nearby areas)
    - Central Valley Region (e.g., Fresno, Kern, San Joaquin, Amador, Merced, Tuolumne and nearby areas)
    - Northern Region (e.g., Sacramento, Sonoma, Solano, Butte, El Dorado, Humboldt, Lake, Shasta, Sierra and nearby areas)
    - Not sure

Appendix D – Estimation Error Results for PV Algorithm Accuracy Analysis

The below table displayed the error bins for daily MPB[28] for Algorithm A and Algorithm B.

Table D-1: Algorithm A vs. Algorithm B for Daily MPB Estimation Error Bins

MPB	Algorithm A	Algorithm B
-0.15 to -0.10	3	0
-0.10 to -0.05	26	20
-0.05 to 0.0	26	32
0.0 to 0.05	12	16
0.05 to 0.10	3	4
0.10 to 0.15	0	0

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[28] Difference in daily total estimated generation and daily total actual generation, divided by the system daily max power output (AC system size multiplied by 24). This metric determines net difference in estimated generation and actual generation, normalized across varying PV system sizes, and values closer to zero indicate higher accuracy.

The below table includes the estimation error metrics for Algorithm B, split by PG&E Division and Quarter. The identifiers of ideal, good, acceptable and bad are based on the metrics thresholds as found in Table 3-1 Metrics Thresholds for PV Estimation Comparison. Dark red indicates the error rate is ideal, orange indicates the error rate is good, yellow indicates the error rate is acceptable and white indicates the error rate is bad. The below table demonstrates that the majority of these metrics are acceptable based on the dataset leveraged for the analysis, fairing slightly less accurate than Algorithm B overall (See Table D-3 & Table D-4).

Table D-2: Algorithm A Estimation Error Metric by Division and Quarter

Division	Daily MPB				Daily MAPE				Afternoon MAPE				Daily CC				Daily MPB	Daily MAPE	Afternoon MAPE	Daily CC
	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4				
Humboldt	-0.096	-0.085	-0.087	-0.125	0.109	0.156	0.141	0.135	0.171	0.314	0.291	0.199	0.761	0.797	0.794	0.697	-0.098	0.135	0.244	0.762
Sonoma	-0.060	-0.011	-0.027	-0.074	0.071	0.080	0.079	0.086	0.084	0.136	0.135	0.096	0.890	0.918	0.922	0.879	-0.043	0.079	0.113	0.902
Sacramento	-0.103	-0.155	-0.141	-0.129	0.106	0.168	0.151	0.130	0.110	0.183	0.163	0.095	0.470	0.490	0.492	0.480	-0.132	0.139	0.138	0.483
Sierra	0.000	0.031	-0.050	-0.053	0.106	0.167	0.127	0.100	0.083	0.187	0.152	0.082	0.694	0.770	0.816	0.792	-0.018	0.125	0.126	0.768
North Bay	-0.037	-0.008	-0.011	-0.045	0.063	0.074	0.072	0.071	0.056	0.093	0.087	0.047	0.876	0.932	0.920	0.878	-0.025	0.070	0.071	0.901
San Francisco	-0.043	-0.034	-0.041	-0.069	0.067	0.068	0.072	0.082	0.074	0.105	0.106	0.072	0.837	0.953	0.954	0.929	-0.047	0.072	0.089	0.918
East Bay	-0.048	-0.022	-0.031	-0.063	0.069	0.065	0.070	0.078	0.069	0.097	0.098	0.067	0.871	0.949	0.947	0.925	-0.041	0.071	0.082	0.923
Diablo	-0.035	-0.011	-0.037	-0.063	0.053	0.057	0.064	0.068	0.069	0.082	0.109	0.081	0.855	0.964	0.961	0.939	-0.036	0.061	0.085	0.930
Peninsula	-0.065	-0.045	-0.058	-0.070	0.076	0.076	0.088	0.080	0.080	0.117	0.132	0.077	0.767	0.817	0.811	0.771	-0.060	0.080	0.102	0.792
Mission	-0.032	-0.005	-0.009	-0.056	0.066	0.056	0.051	0.071	0.064	0.088	0.077	0.059	0.749	0.952	0.947	0.874	-0.026	0.061	0.072	0.880
De Anza	-0.030	-0.046	-0.021	-0.031	0.059	0.119	0.117	0.065	0.060	0.182	0.165	0.055	0.693	0.754	0.755	0.723	-0.032	0.090	0.115	0.731
San Jose	-0.068	-0.042	-0.042	-0.076	0.081	0.078	0.074	0.092	0.100	0.127	0.119	0.098	0.854	0.952	0.950	0.828	-0.057	0.081	0.111	0.896
Central Coast	-0.006	0.005	-0.013	-0.011	0.069	0.121	0.100	0.064	0.082	0.211	0.170	0.067	0.763	0.607	0.801	0.801	-0.006	0.088	0.132	0.743
Los Padres	-0.021	-0.022	-0.025	-0.040	0.063	0.070	0.070	0.069	0.079	0.126	0.127	0.086	0.892	0.940	0.935	0.881	-0.027	0.068	0.104	0.912
Stockton	0.072	0.024	0.036	0.047	0.068	0.098	0.096	0.088	0.073	0.115	0.100	0.081	0.669	0.864	0.855	0.806	0.045	0.087	0.092	0.799
Fresno	-0.064	-0.033	-0.056	-0.076	0.069	0.068	0.072	0.078	0.055	0.080	0.083	0.053	0.896	0.952	0.949	0.895	-0.057	0.072	0.068	0.923
All	-0.040	-0.029	-0.038	-0.058	0.075	0.095	0.090	0.085	0.082	0.140	0.132	0.082	0.784	0.851	0.863	0.819	-0.041	0.086	0.109	0.829

	Ideal
	Good
	Acceptable
	Bad

The below table includes the estimation error metrics for Algorithm B, split by PG&E Division and Quarter. The identifiers of ideal, good, acceptable and bad are based on the metrics thresholds as found in Table 3-1 Metrics Thresholds for PV Estimation Comparison. Dark red indicates the error rate is ideal, orange indicates the error rate is good, yellow indicates the error rate is acceptable and white indicates the error rate is bad. The below table demonstrates that the vast majority of these metrics are acceptable based on the dataset leveraged for the analysis, fairing slightly more accurate than Algorithm A overall (See Table D-2 & Table D-4).

Table D-3: Algorithm B Estimation Error Metric by Division and Quarter

Division	Daily MPB				Daily MAPE				Afternoon MAPE				Daily CC				Daily MPB	Daily MAPE	Afternoon MAPE	Daily CC
	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4				
Humboldt	-0.084	-0.061	-0.068	-0.114	0.103	0.149	0.135	0.129	0.161	0.289	0.271	0.187	0.777	0.803	0.801	0.729	-0.082	0.129	0.227	0.777
Sonoma	-0.049	0.008	-0.011	-0.065	0.066	0.078	0.076	0.081	0.077	0.131	0.129	0.089	0.891	0.919	0.925	0.884	-0.029	0.075	0.106	0.905
Sacramento	-0.062	-0.014	-0.017	-0.071	0.073	0.061	0.059	0.078	0.077	0.077	0.071	0.068	0.885	0.969	0.972	0.952	-0.041	0.067	0.073	0.944
Sierra	0.008	0.049	-0.035	-0.042	0.105	0.164	0.124	0.098	0.078	0.179	0.142	0.078	0.711	0.772	0.818	0.798	-0.005	0.123	0.119	0.775
North Bay	-0.028	0.011	0.005	-0.037	0.060	0.070	0.069	0.068	0.052	0.088	0.082	0.045	0.875	0.933	0.921	0.880	-0.012	0.067	0.067	0.902
San Francisco	0.042	0.017	0.026	0.058	0.067	0.061	0.068	0.077	0.070	0.105	0.105	0.068	0.903	0.952	0.952	0.926	0.036	0.069	0.087	0.933
East Bay	-0.043	-0.004	-0.015	-0.054	0.067	0.062	0.066	0.074	0.064	0.091	0.092	0.061	0.896	0.949	0.947	0.927	-0.029	0.067	0.077	0.930
Diablo	-0.041	0.009	-0.022	-0.054	0.052	0.053	0.058	0.063	0.062	0.070	0.097	0.073	0.944	0.971	0.960	0.939	-0.027	0.057	0.075	0.953
Peninsula	-0.044	-0.001	-0.019	-0.051	0.062	0.072	0.063	0.067	0.066	0.107	0.093	0.065	0.903	0.891	0.946	0.904	-0.029	0.066	0.083	0.911
Mission	-0.035	0.006	0.001	-0.050	0.068	0.058	0.053	0.069	0.062	0.086	0.077	0.056	0.793	0.953	0.947	0.876	-0.019	0.062	0.070	0.892
De Anza	-0.007	0.024	0.038	-0.007	0.060	0.076	0.084	0.057	0.054	0.110	0.102	0.042	0.789	0.912	0.908	0.859	0.012	0.069	0.077	0.867
San Jose	-0.067	-0.023	-0.027	-0.066	0.080	0.071	0.068	0.087	0.092	0.112	0.106	0.091	0.919	0.953	0.951	0.833	-0.046	0.076	0.100	0.914
Central Coast	0.006	0.025	0.003	0.000	0.069	0.120	0.098	0.064	0.075	0.193	0.154	0.059	0.770	0.611	0.812	0.807	0.008	0.088	0.120	0.750
Los Padres	-0.015	-0.011	-0.018	-0.034	0.063	0.068	0.068	0.069	0.074	0.116	0.119	0.081	0.894	0.943	0.939	0.885	-0.020	0.067	0.098	0.915
Stockton	0.069	0.044	0.053	0.058	0.091	0.103	0.102	0.093	0.077	0.103	0.094	0.082	0.855	0.869	0.860	0.811	0.056	0.097	0.089	0.849
Fresno	-0.057	-0.005	-0.030	-0.065	0.065	0.064	0.056	0.072	0.048	0.082	0.065	0.049	0.915	0.959	0.962	0.892	-0.039	0.064	0.061	0.932
All	-0.031	0.002	-0.012	-0.044	0.072	0.083	0.078	0.078	0.074	0.121	0.112	0.074	0.858	0.897	0.914	0.869	-0.021	0.078	0.096	0.884

	Ideal
	Good
	Acceptable
	Bad

The below table compares the estimation error between Algorithm A and Algorithm B, which are the results of cells in Table D-2 less results for same cells in Table D-3. Blue shading indicates lower error (closer to zero) for Algorithm B relative to Algorithm A. Red indicates the lower error rate for Algorithm A compared to Algorithm B. This table visually shows that Algorithm B was slightly more accurate than Algorithm A.

Table D-4: Estimation Error Metric Differences between Algorithm A and Algorithm B

Division	Daily MPB				Daily MAPE				Afternoon MAPE				Daily CC				Daily MPB	Daily MAPE	Afternoon MAPE	Daily CC
	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4				
Humboldt	-0.012	-0.024	-0.019	-0.011	-0.006	-0.007	-0.006	-0.006	-0.009	-0.025	-0.020	-0.012	-0.016	-0.006	-0.008	-0.032	-0.016	-0.006	-0.017	-0.015
Sonoma	-0.011	-0.002	-0.016	-0.010	-0.004	-0.002	-0.002	-0.004	-0.005	-0.004	-0.006	-0.008	-0.001	-0.002	-0.003	-0.005	-0.014	-0.003	-0.006	-0.003
North Valley																				
Sacramento	-0.041	-0.141	-0.124	-0.058	-0.034	-0.107	-0.092	-0.052	-0.033	-0.106	-0.092	-0.027	-0.415	-0.479	-0.481	-0.472	-0.091	-0.071	-0.064	-0.462
Sierra	0.007	0.018	-0.015	-0.010	-0.001	-0.003	-0.004	-0.003	-0.005	-0.009	-0.010	-0.005	-0.017	-0.003	-0.001	-0.006	-0.013	-0.003	-0.007	-0.007
North Bay	-0.009	0.004	-0.006	-0.008	-0.003	-0.004	-0.003	-0.003	-0.003	-0.006	-0.005	-0.003	0.001	-0.001	-0.001	-0.002	-0.013	-0.003	-0.004	-0.001
San Francisco	-0.001	-0.017	-0.015	-0.010	0.000	-0.004	-0.004	-0.005	-0.004	0.000	-0.001	-0.004	-0.066	0.002	0.002	0.003	-0.011	-0.003	-0.002	-0.015
East Bay	-0.005	-0.019	-0.016	-0.009	-0.002	-0.003	-0.003	-0.004	-0.005	-0.006	-0.006	-0.005	-0.026	0.000	0.000	-0.002	-0.012	-0.003	-0.006	-0.007
Diablo	0.006	-0.002	-0.016	-0.009	-0.002	-0.004	-0.006	-0.005	-0.007	-0.012	-0.013	-0.007	-0.089	-0.007	0.000	0.000	-0.009	-0.004	-0.010	-0.024
Peninsula	-0.021	-0.044	-0.040	-0.019	-0.015	-0.004	-0.025	-0.014	-0.014	-0.010	-0.039	-0.012	-0.136	-0.074	-0.136	-0.133	-0.031	-0.014	-0.019	-0.120
Mission	0.002	0.001	-0.007	-0.007	0.003	0.002	0.002	-0.002	-0.002	-0.002	0.000	-0.004	-0.044	0.000	0.000	-0.002	-0.006	0.001	-0.002	-0.012
De Anza	-0.023	-0.023	0.016	-0.024	0.001	-0.042	-0.033	-0.008	-0.006	-0.072	-0.063	-0.013	-0.096	-0.158	-0.153	-0.136	-0.020	-0.021	-0.038	-0.136
San Jose	-0.001	-0.018	-0.014	-0.009	-0.001	-0.007	-0.006	-0.005	-0.009	-0.016	-0.013	-0.007	-0.065	-0.001	-0.001	-0.004	-0.011	-0.005	-0.011	-0.018
Central Coast	0.000	0.020	-0.010	-0.011	0.000	-0.002	-0.002	0.000	-0.007	-0.017	-0.017	-0.008	-0.007	-0.004	-0.011	-0.006	0.002	-0.001	-0.012	-0.007
Los Padres	-0.006	-0.011	-0.007	-0.006	0.000	-0.003	-0.003	-0.001	-0.005	-0.009	-0.008	-0.005	-0.002	-0.003	-0.004	-0.004	-0.007	-0.002	-0.007	-0.003
Stockton	-0.003	0.020	0.018	0.011	0.023	0.005	0.006	0.005	0.004	-0.013	-0.006	0.001	-0.186	-0.005	-0.004	-0.005	0.011	0.010	-0.004	-0.050
Yosemite																				
Fresno	-0.007	-0.028	-0.026	-0.011	-0.005	-0.004	-0.016	-0.007	-0.007	0.001	-0.018	-0.005	-0.019	-0.006	-0.013	0.003	-0.018	-0.008	-0.007	-0.009
Kern																				
All	-0.009	-0.026	-0.026	-0.014	-0.003	-0.012	-0.012	-0.007	-0.007	-0.019	-0.020	-0.008	-0.074	-0.047	-0.051	-0.050	-0.020	-0.008	-0.014	-0.055

Appendix E – Algorithm Inputs, Source and Description

The below table clarifies the inputs to the algorithm, as well as the source of the data and the description of the predictor.

Table E-1: Algorithm Inputs, Data Sources and Descriptions

Input	Source	Description
Mounting Method	ENOS[29]	Specifies if the system is roof or ground mounted
Tracking Type	ENOS	Specify is the system is fixed, or has single or dual-axis tracker
Tilt	ENOS	The angle of the system from the horizontal
Azimuth	ENOS	The angle the panels make with the true North
Shading Pattern and Derating Factor	CSI	The %-age of the system shaded during the year due to objects in proximity of the system
Model of inverter	ENOS	n/a
Number of inverters	ENOS	n/a
Rating	ENOS	The rating of the inverter in watts
Efficiency	ENOS	The efficiency of the inverter expressed in %
Model of panels	ENOS	n/a
Number of panels	ENOS	n/a
Rating	ENOS	The rating of each panel in watts
Capacity	ENOS	The total system capacity in watts

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[29] E-Net Online System (ENOS) is PG&E's internal database for solar applications that is used to determine if a customer has submitted an interconnection application for solar service and if the application has been approved.