Community Scale Solar Water Heating – Methodology Report

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Executive Summary

The *Methodology Report* explains how qualitative and quantitative analyses will be conducted as part of evaluating the potential of community scale solar water heating to reduce energy consumption and emissions from the residential housing sector in Los Angeles County. First, criteria and data sources used to identify potentially suitable sites for community scale water heating are listed. The *Case Study Selection Criteria* will give a full explanation of the selection process. Second, the *Methodology Report* explains how annual energy savings and other associated metrics will be calculated for each case study. This study uses standard assumptions the number of units per residential parcel to develop hot water demand schedules. The performance of community scale solar water heating systems are simulated using NREL's System Advisor Model Software. Finally, the analysis of how location and, parcel, and supra-parcel characteristics of residential parcels predict gas consumption is summarized.

Introduction

The *Methodology Report* explains how quantitative and qualitative analyses will be conducted for each of the community scale SWH case studies. The first section of this report discusses how the pool of sites suitable for community scale SWH (referred to as "energy communities") is generated and the data sources used. Both privately and publically owned properties will be considered in this study. It concludes with an explanation of the qualitative analysis to be included with each case study. The second section of the *Methodology Report* describes how the suitability criteria discussed in the first section are used to generate a pool of potential case study sites.

The third, fourth, and fifth sections of the *Methodology Report* explain how energy savings will be estimated in each case study. The calculation of energy savings requires both the energy demanded for residential water heating and the energy supplied by putative solar thermal water heating systems. Descriptions of the methods used to calculate energy consumed for residential water heating and the energy supplied by community scale SWH systems are included in the third and fourth sections of this report, respectively.

The sixth section of the report describes a supplementary analysis of parcel and community-level variables using an artificial neural network. The CCSC's Energy Atlas relates a rich set of geospatial, zoning, and demographic variables to monthly billing data.[1] Building a neutral network model to measure the predictive strength of the descriptive variables in the Energy Atlas will help state and local governments understand drivers of demand, and how to target energy efficiency measures.

1 Definition of Community for Solar Water Heating Systems

Community scale energy systems are defined by the National Renewable Energy Laboratory (NREL) and California Energy Commission (CEC) as systems between the individual and utility scales that are owned and operated collectively, or by some entity designated and supported by the system's users.[2,3] Thus, identification of appropriate sites for community scale systems requires consideration of not only practical and technological constraints, but also factors limiting the size of the "energy community" that may be served by such systems. These factors include land use patterns, the presence and condition of energy transmission infrastructure, and system ownership.

1.1 General Considerations for Identifying Energy Communities

This study will begin with a qualitative discussion of how the constraints listed in Table 1 affect the size and location of energy communities and their solar water heating systems.

Table 1: Constraints for Community Scale SWH System in Los Angeles County

Constraints	Issues
Existing Infrastructure	- Heat Transmission Network - Solar Energy Storage - Retrofit Requirements
System Ownership	- System Financing & Maintenance - Qualification for Incentives
Property Ownership	- Land Use Patterns

[1] California Center for Sustainable Communities. (2018). *About the LA Energy Atlas.* Retrieved from: http://www.energyatlas.ucla.edu/about/overview

[2] California Energy Commission. (2017). *Renewable Energy Secure Communities.* Retrieved from: http://www.energy.ca.gov/research/renewable/community.html

[3] U.S. National Renewable Energy Lab. (2010). *A Guide to Community Solar: Utility, Private, and Non-profit Project Development.* Retrieved from: https://www.nrel.gov/docs/fy11osti/49930.pdf

The *Selection of Community Sites for Case Studies* will include an analysis of how these factors help identify potential solar water heating communities in Los Angeles County. The analysis will draw on available geospatial data as well as input from private sector firms that currently retrofit existing properties with solar thermal systems.

1.2 Existing Infrastructure for Community Scale SWH in Los Angeles County

The scale and design of a community scale energy systems is heavily dependent on the condition and degree of connectivity exhibited by existing energy infrastructure. This is especially important for thermal systems, which require non-trivial quantities energy to deliver energy (in the form of hot water) to users, and suffer from much greater transmission losses than electrical systems.

Los Angeles County has very limited thermal energy transmission infrastructure, due to the popularity of natural gas as a heating fuel and land use patterns favoring single family residences in the region. The *Selection of Community Sites for Case Studies* will include a discussion of how investments in building and parcel level heat transmission infrastructure may help encourage the adoption of solar water heating and expand the number of potential solar thermal energy communities.

2 Screening and Selection of Potential Community Scale Sites

The general considerations identified in the previous section are essential for the screening and selection of sites appropriate for the construction of community scale SWH systems. The following section explains how a pool of community scale sites will be identified using geospatial data.

2.1 Community Scale Site Screening Filter

This study will construct a set of criteria based on the general constraints identified in the previous section to identify parcels or sets of parcels appropriate for community scale SWH system installation. The filter will take use geospatial and building data from the CCSC's Energy Atlas, the Los Angeles Regional Imagery Acquisition Consortium (LARIAC) and LA County GIS.

Data from the aforementioned sources will be used to create a map of potential energy communities from which case studies will be selected using ArcGIS. The *Selection of Community Sites for Case Studies* will contain a full explanation of selection criteria.

2.2 Data Sources

Selection of candidate sites for community scale solar water heating systems are drawn from the following sources:

Table 2: Data Sources for Screening and Selection of Candidate Sites

Source	Data	Source
Energy Atlas – California Center for Sustainable Communities	**LA County Parcel Data** - Tax Assessor ID - Parcel Usecodes - Number of Buildings	http://www.energyatlas.ucla.edu/

	- Number of Residential Units - Parcel Area	
Los Angeles Regional Imagery Acquisition Consortium (LARIAC)	**2017 LA County Building Footprints**	https://egis3.lacounty.gov/dataportal/tag/buildings/
Los Angeles GIS Portal	**CDC Public Housing Sites (Polygons)** - Public Housing Parcel Outlines - Affordable Housing Parcel Outlines - Parcel Area	https://egis3.lacounty.gov/dataportal/tag/public-housing/

Data from the sources above will be used to construct a map of potential sites for community scale SWH systems.

3 Gas Consumption for Residential Water Heating

The calculation of energy savings requires the estimation of residential gas consumption based on parcel and building-level data. This analysis develops a method to estimate the gas consumed to heat water by residential parcels on a daily basis for one year based on ASHRAE water consumption tables.[4] Monthly gas consumption data from the Energy Atlas was not used to estimate energy demand due to the inaccuracy inherent in disaggregating by end-uses. Daily hot water consumption calculated for the parcels in an energy community will then be used in simulations of community scale SWH system performance.

3.1 Limitations of Signal Processing Parcel-level Gas Consumption Data

This study calculates daily hot water demand based on ASHRAE guidelines instead of using consumption data from the Energy Atlas because of the difficulty of disaggregating end-uses from one another. While residential appliance surveys provide estimates of gas consumption for water heating relative to total consumption (Figure 1), there is little data aside from small-scale studies of hot water usage to help decompose monthly consumption totals into separate end-uses. Patterns of hot water usage and total hot water consumption also vary greatly depending on the demographics of the people who inhabit the structures on a particular residential parcel.[5]

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[4] Handbook, A. S. H. R. A. E. (2007). Fundamentals. *American Society of Heating, Refrigerating and Air Conditioning Engineers, Atlanta*, *111*.

[5] Parker, D. S., Fairey, P. W., & Lutz, J. D. (2015). Estimating Daily Domestic Hot- Water Use in North American Homes. *ASHRAE Transactions*, *121*(2). Retrieved from http://www.ashrae.org

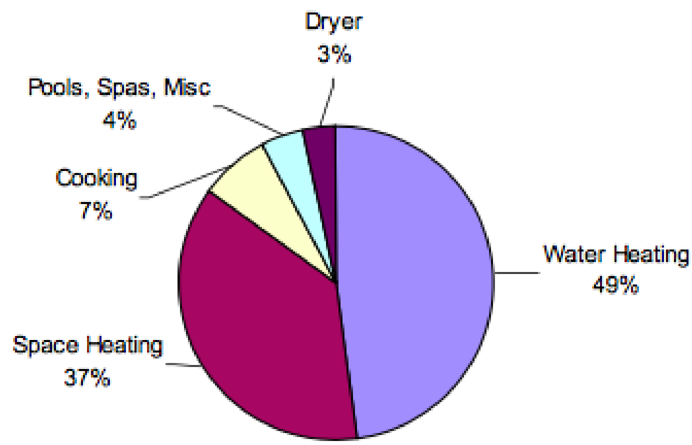
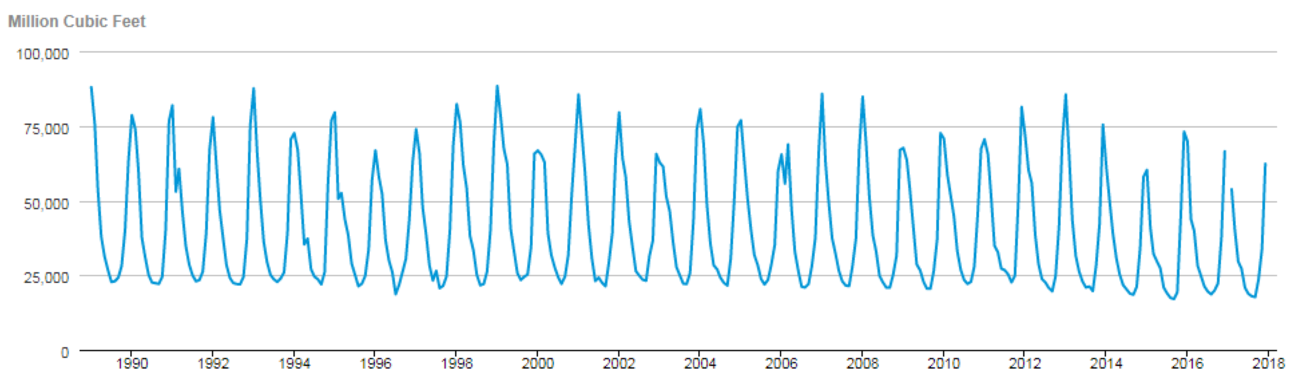


Figure 1: California Residential Gas Consumption by End-use[6]

The focus on one end-use among many complicates the estimation of energy savings; it is necessary to remove the contribution of other end uses from to accurately estimate the energy consumed by water heating. Unfortunately, the structure of the Atlas's gas consumption data (monthly billing data for parcels and individual accounts) limits the potential disaggregation to seasonal and non-seasonal end uses. Residential gas consumption in California displays as strong seasonal trend due to the popularity of natural gas for space heating and the state's mild climate.[7]



[6] Palmgren, C., Stevens, N., Goldberg, M., Bames, R., & Rothkin, K. (2010). 2009 California residential appliance saturation survey.

[7] *Ibid.*

Figure 2: California Total Residential Gas Deliveries (1989-2018)[8]

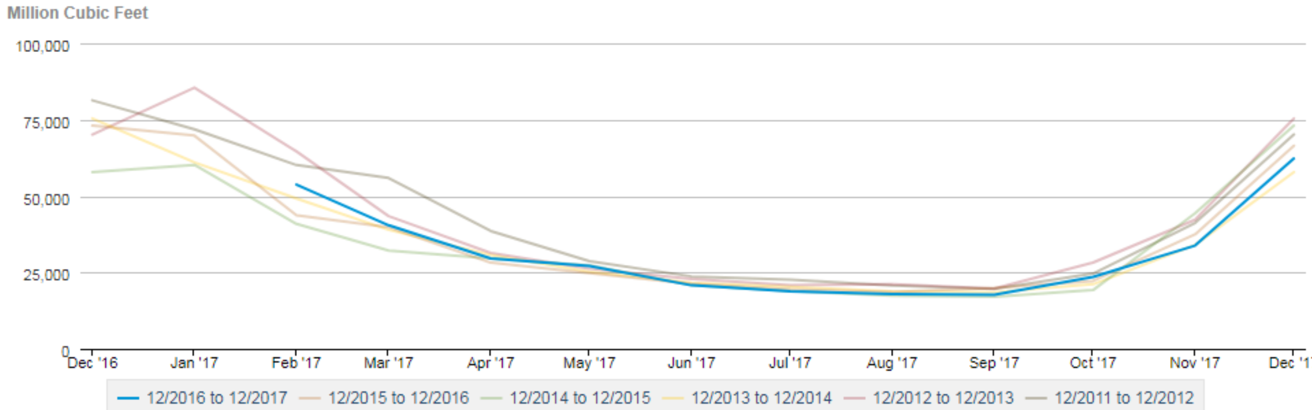


Figure 3: 10-Year Monthly Residential Gas Consumption (2007-2017)[9]

While the seasonal nature of space heating in California may allow for and estimation of its relative share of total residential consumption, the remaining gas consumption signal will contain non-seasonal end-uses, such as cooking, pool heating, gas-powered clothes dryers, etc.[10] Inclusion of these end-uses will produce inaccurate estimates of natural gas consumption for water heating. Because of the difficulty and inaccuracy inherent in estimating residential gas consumption from disaggregated monthly data, daily consumption is instead estimated based on building occupancy and standard residential water demand consumption.[11]

3.2 Hot Water Demand per Residential Unit, and Gas Consumed for Residential Water Heating

Daily hot water demand and the volume of gas required to meet it (i.e. energy demand) will be calculated for each community scale SWH case study. These calculations will use data parcel occupancy from the LA County Tax Assessor's database (included in the Energy Atlas) and water consumption and water heater efficiency assumptions listed in the ASHRAE *Handbook of Applications*.

<u>Water Demand per Energy Community Parcel</u>

Daily water demand for energy communities are calculated according to Equation 1:

Equation 1: Daily Hot Water Demand per Community Parcel[12]

$$V_{hot} = N_{unit} V_{unit}$$

Where:

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[8] U.S. Energy Information Administration. (2018). *California Natural Gas Residential Consumption, 1989-2017* [Data Set]. Retrieved from: https://www.eia.gov/dnav/ng/hist/n3010ca2m.htm

[9] *Ibid.*

[10] Palmgren, C., Stevens, N., Goldberg, M., Bames, R., & Rothkin, K. (2010). *2009 California residential appliance saturation survey*. Retrieved from http://www.energy.ca.gov/2010publications/CEC-200-2010-004/CEC-200-2010-004-ES.PDF

[11] *Ibid.*

[12] Kalogirou, S. A. (2013). *Solar energy engineering: processes and systems*. Academic Press.

V_{hot}= Volume of hot water per parcel per day

N_{unit} = Number of residential units per parcel

V_{unit} = Volume of hot water consumed per unit per day

The volume of hot water consumed per unit per day (V_{unit}) depends on the number of units in a residential structure.[13] Values of V_{unit} are estimates of maximum daily hot water consumption in gallons per day (GPD).[14] The volume of hot water is assumed to be seasonally invariant.

Energy Demand per Energy Community Parcel

The energy demand per parcel per day is then calculated using a parcel's daily volumetric consumption (V_{hot}).

Equation 2: Daily Energy Demand per Community Parcel[15]

$$D = V_{hot}\rho c_p(T_w - T_m)$$

Where:

D = Daily energy demand per community parcel

T_w= Delivery temperature of hot water

T_m = Cold water mains temperature

This study assumes a delivery temperature of 120 ^oF (49 ^oC). Cold water mains temperature varies seasonally and geographically. A mains temperature profile for Los Angeles is available in through the National Renewable Energy Laboratory's System Advisor Model Software (NREL SAM).

Equation 3: Daily Natural Gas Consumption per Community Parcel

$$V_{Gas} = \frac{D}{\rho_E} EF_{heater}$$

Where:

V_{Gas}= Daily volume of natural gas consumed for water heating

ρ_E = Energy density of natural gas

EF_{heater} = Energy Factor of the extant water heater

Estimating the energy factor of the extant heater or heaters on a community parcel will require communication with building managers/ property owners. Equation 3 may be modified if electric heaters are installed.

[13] California Public Utilities Commission. (2017 June). *California Solar Initiative – Thermal Program Handbook*. Retrieved from: http://www.gosolarcalifornia.ca.gov/documents/CSI-Thermal_Handbook.pdf
[14] Handbook, A. S. H. R. A. E. (2007). Fundamentals. *American Society of Heating, Refrigerating and Air Conditioning Engineers, Atlanta*, *111*.
[15] Kalogirou, S. A. (2013). *Solar energy engineering: processes and systems*. Academic Press.

4 Calculation of Community Scale SWH System Performance

Numerous methods exist for the estimation of SWH system performance and energy output. Performance calculation methods also vary widely with respect to computational complexity, underlying mathematical structure, assumptions, and flexibility. This study's choice of performance calculation method was determined by the aforementioned considerations, and well as input from the study's Technical Advisory Committee.[16, 17]

Methods for predicting the performance of solar thermal systems may be classified as either regression or simulation methods.[18] Regression methods correlate the parameters of a given system (collector area, storage volume, fluid flow rates, etc.) with thermal performance using empirical relationships derived from the performance data of existing systems.[19] The f-Chart Method, approved for the estimation of minimum annual solar fraction under Title 24, is one such method.[20] Regression methods are computationally inexpensive compared to simulation methods, and in many instances provide accurate predictions of long term system performance. However, regression methods like the f-Chart are not dynamical, and thus cannot be used to calculate hourly system performance. Thus, this study will use one of the publically available simulation programs to model community scale SWH system performance.

Simulation methods model the flow of energy and mass through virtual systems at a user-specified time step.[21] Simulation programs for modeling solar thermal systems differ with respect to their flexibility and complexity; selection of an appropriate simulation program depends on the requirements of a particular study. Because this analysis estimates hourly energy output from community scale SWH systems using a relatively small set of assumptions about system design and physical parameters, simulation programs with intermediate flexibility and computational complexity are most suitable.

This study uses NREL's System Advisor Model to calculate the hourly energy output from community scale SWH systems. The following section describes the simulation assumptions, input parameters, output, and accompanying cost calculations.

4.1 NREL System Advisor Model Software

NREL SAM is a free transient energy simulation program developed for modeling renewable energy systems. NREL SAM will be used to calculate the daily performance for community scale solar energy systems over the course of a year.

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[16] Anderson, K. (2017, January 17). Personal Communication.
[17] Chen, W. (2017, January 17). Personal Communication.
[18] Duffie, J. A., & Beckman, W. A. (2013). *Solar engineering of thermal processes*. John Wiley & Sons.
[19] *Ibid.*
[20] California Energy Commission. (2016). *Title 24 – 2016 Residential Compliance Manual.*
[21] Lisboa, P., & Fonseca Costa, M. (n.d.). A Software for Performance Simulation of Solar Water Heating Systems. Retrieved from http://www.wseas.us/e-library/conferences/2012/Istanbul/FLUHE/FLUHE-39.pdf

4.1.1 Assumptions and Simulation Method

NREL SAM uses the implicit-Euler method to solve a series of differential equations at each time step. SAM makes two fundamental assumptions about the design of SWH systems[22]:

- SWH systems are indirect (closed collection loop with a heat exchange fluid)
- Auxiliary heat is provided by an electric resistance heater.

4.2 Community Scale SWH System Siting and Design Considerations

Each case study includes the siting of solar water heating systems on the parcel or parcels of an energy community. Collector arrays, storage tanks, and the pipe lengths must be located in space so that system parameters required for heat loss and other performance calculations may be entered into the System Advisor Model. The siting of system components will be conducted as follows:

4.2.1 Collector Arrays

<u>Collector Location</u>

Solar thermal collectors will be located on rooftops where possible to minimize shading of collector apertures and within each building rooftop's Solar Zone[23], as defined in Section 110.10 of California's Title 24.[24] Structures considered part of an energy community are those building outline polygons contained within energy community parcel polygons.

Within each solar zone, polygons representing individual solar collectors will be bin-packed into a building's solar zone to maximize collector area.

The structures closest to storage tanks, and those with flat roofs are prioritized for collector array placement. Roof characteristics will be confirmed with LARIAC oblique imagery search. However, all structures within an energy community's case study's parcel or parcels are considered as potential sites for collector arrays.

<u>Collector Orientation</u>

NREL SAM requires collector tilt and azimuth angles are specified for simulation. Collector plates are assumed to lie flat on roof surfaces and face due south, giving tilt and azimuth angles of 0^{o}.

<u>Collector Physical Parameters</u>

[22] Burch, J., Christensen, C., DiOrio, N., & Dobos, A. (2014 March 14). *Technical Manual for the SAM Solar Water Heating Model*. National Renewable Energy Laboratory. Retrieved from: https://sam.nrel.gov/system/tdf/SimpleSolarWaterHeatingModel_SAM_0.pdf?file=1&type=node&id=69521

[23] Definition of Solar Zone for Low Rise and High Rise Multi-Family Buildings: "The Solar Zone shall be located on the roof or overhang of the building or on the roof or overhang of another structure located within 250 ft. of the building or on covered parking installed with the building project. The Solar Zone will have a total area no less than 15% of the total roof area of the building excluding any skylight area"

[24] California Energy Commission. (2015 June). *2016 Building Energy Efficiency Standards for Residential and Nonresidential Buildings.* Retrieved from: http://www.energy.ca.gov/2015publications/CEC-400-2015-037/CEC-400-2015-037-CMF.pdf

NREL SAM contains a library of commercially available glazed flat-plate collectors and performance data derived from testing.[25] This study will use the Heliodyne Gobi 410 Model Solar Collector. This collector model is manufactured domestically and is OG-100 certified.[26] Selection of a collector model from the SAM library automatically specifies the performance parameters listed in the table below.

Table 3: SAM Collector Performance Parameters for the Heliodyne 410 Solar Collector

Parameter	Value
Collector Area	2.98 m^2
FRta (Hottel-Whillier-Bliss Equation – Optical Gain Coefficient)	0.689
FRUL (Hottel-Whillier-Bliss Equation – Thermal Loss Coefficient)	3.85 W/m^2 C
Incidence Angel Modifier Coefficient	0.2
Test Fluid	Glycol
Test Flow	0.0455278

4.2.2 Storage Tanks

Storage Tank Siting

Standby losses from solar storage tanks may be minimized by locating them within existing structures.[27] Central solar storage tanks will be located within the structure closest to the centroid of an energy community's parcel or parcels.

Storage Tank Physical Parameters

SAM's Solar Water Heating model assumes a two tank indirect system with an electric auxiliary heater, with glycol as a heat transfer fluid.[28] These assumptions are consistent with the SWH system design details required by state and county regulatory regimes identified in the *Solar Water Heating Report.*

SAM requires that users specify the ratio of tank height to width. Vertically oriented and thermally stratified tanks increase the performance of solar water heating systems.[29] This analysis assumes a height to width ratio of 2:1 for solar thermal and hot water tanks. SAM's assumes two-node stratification without thermal exchange.[30]

[25] Burch, J., Christensen, C., DiOrio, N., & Dobos, A. (2014 March 14). *Technical Manual for the SAM Solar Water Heating Model*. National Renewable Energy Laboratory. Retrieved from: https://sam.nrel.gov/system/tdf/SimpleSolarWaterHeatingModel_SAM_0.pdf?file=1&type=node&id=69521

[26] Heliodyne. (2017). *Heliodyne Gobi 410 Specifications Sheet*. Retrieved from: http://www.heliodyne.com/industry_professionals/downloads/GOBI%20Spec%20Sheet.pdf

[27] Duffie, J. A., & Beckman, W. A. (2013). *Solar engineering of thermal processes*. John Wiley & Sons.

[28] NREL. (2011 December 7). *System Advisor Model – Technology Options: Concentrating Solar Power Systems*

[29] Cruickshank, C. A., & Harrison, S. J. (2010). Heat loss characteristics for a typical solar domestic hot water storage. *Energy and Buildings*, *42*(10), 1703–1710. http://doi.org/10.1016/j.enbuild.2010.04.013

[30] Diorio, N., Christensen, C., Burch, J., & Dobos, A. (2014). Technical Manual for the SAM Solar Water Heating Model. Retrieved from https://sam.nrel.gov/system/tdf/SimpleSolarWaterHeatingModel_SAM_0.pdf?file=1&type=node&id=69521

Table 4: Sam Storage Tank Parameters

Parameters	Description
Solar Tank Volume	Volume in cubic meters. Title 24 requires a storage volume to collector area ratio of 1.5 gallons/ 1 $ft.^2$ of collector area.
Solar Tank Height to Diameter Ratio	Tank aspect ratio (2:1)
Solar Tank Heat Loss Coefficient (U-value)	W/ m^2 C
Solar Tank Maximum Water Temperature	Maximum allowable temperature in solar tank. Bulk tank temperature cannot exceed this value. Equivalent to the opening of a temperature controlled relief valve.
Outlet Set Temperature	Residential hot water temperature set point (48.89^oC)
Mechanical Room Temperature	Used to calculate tank standby loss. $Q_{Loss} = UA_{Tank}(T_{room} - T_{tank})$

Heat Exchangers

In indirect SWH systems, heat exchangers transfer thermal energy from the heated working fluid in the solar tank to water for delivery to end users. SAM requires the following parameters to model heat exchange:

Table 5: SAM Heat Exchanger Parameters

Parameter	Description/ Units
Heat Exchanger Effectiveness (*e*)	$e = (T_{cold\text{-}out} - T_{cold\text{-}in}) / (T_{hot\text{-}in} - T_{cold\text{-}in})$

4.2.3 Pipes and Pumping

SWH System Piping

Indirect SWH systems have two separate piping systems. One circulates working fluid through the collection array and solar tank, and the other delivers heated water from the auxiliary tank to end users. SAM requires information about the length, diameter, and insulation of the pipes used to collect heat and distribute hot water to residential buildings.

Collection network pipe lengths will include the vertical and horizontal distances between collector arrays and solar storage tanks. Transmission network pipe lengths will be the straight line distance from the solar storage tank.

Pumps

SAM assumes that fluid is circulated between the collector array, solar tank, and heat exchangers by an electric pump. The collector pump's peak power rating and efficiency are required to calculate solar fraction and other performance metrics.

Table 6: SAM Piping and Pumping Parameters

Parameters	Description
Total Piping Length in System	Collection Network: Vertical and Horizontal distance between collector arrays (m). Transmission Network: straight line distance plus detours (m).

Pipe Diameter	Average diameter of piping (m)
Pipe insulation Conductivity	W/ m^2 C
Pipe Insulation Thickness	Average insulation thickness
Pump Power	Electric pump's peak power rating (W)
Pump Efficiency	Estimated pump efficiency (0 to 1)

4.2.4 Auxiliary Heat Source

All active SWH heating systems have auxiliary heating units to ensure water is delivered at the appropriate temperature. SAM assumes that electricity is used for auxiliary heating, and calculates the energy required to raise the temperature of water in the storage tank to the set temperature at each time step. The auxiliary energy required to reach set temperature is given by:

Equation 4: Auxiliary Heat[31]

$$Q_{aux} = m_{draw} C_P (T_{set} - T_{deliv})$$

Where:

Q_{aux} = Auxiliary heat

m_{draw} = Mass of water draw

T_{set} = Set temperature for hot water

T_{deliv}= Temperature of water delivered from solar storage

SAM requires local utility rate structures to calculate the cost of auxiliary heating. The Energy Atlas contains LADWP residential rate structure codes for all accounts. These structures will be used to calculate the cost of auxiliary heating.

4.2.5 System Incentive & Operating Cost Calculations

CSI Thermal Incentive

The majority of residential SWH projects require property owners to make an up-front investment in SWH equipment and heat transmission infrastructure which is then partially recouped through government incentive programs. The CSI Thermal Program incentive offsets a significant portion of the capital cost for multifamily structures and apartment buildings (30-70% of capital cost)[32]. This study will use the CSI Thermal Program's TRNSYS-based incentive calculator to estimate the incentives for each energy community's SWH system.

Active, indirect SWH systems with collectors and auxiliary heating apparatuses of the type described in the *Solar Water Heating Report* meet the eligibility requirements for the CSI Thermal incentive.[33]

Residential Renewable Energy Tax Credit

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[31] NREL. (2011). *System Advisor Model –Solar Water Heating Help File*.
[32] Chen, W. (2017 Jan 17). Personal Communication.
[33] GoSolar California. (2014). *CSI-Thermal Multifamily/Commercial Standard-100 Incentive Calculator User Guide*. Retrieved from: https://www.csithermal.com/media/docs/Standard-100_Calculator_User_Guide_20140520.pdf

Property owners installing community scale SWH systems also qualify for the federal Residential Renewable Energy Tax Credit. Taxpayers may claim a credit for qualified expenditures for a system that is installed at a location that can be claimed as a residence. Credits are determined as follows:

- 30% for systems placed in service by 12/31/2019
- 26% for systems placed in service after 12/31/2019 and before 01/01/2021
- 22% for systems placed in service after 12/31/2020 and before 01/01/2022
- No maximum credit for systems placed in service after 2008

Expenditures include labor costs for on-site preparation, assembly or system installation.[34] Properties within energy communities must meet the following criteria to qualify:

- System equipment must be certified by the SRCC or comparable entity endorsed by the state
- At least half of the energy used to heat the dwelling's water must be from solar in order for property expenditures to be eligible.
- The property need not be the taxpayer's principal residence
- Swimming pools and hot tubs are ineligible.

The federal renewable credit will be applied to applicable properties.

Capital & Operating Costs

SAM accepts the following cost data. These costs will be further estimated based on input from engineering firms with experience constructing large scale SWH systems, and the siting considerations discussed in the previous sections.[35] Cost information will subsequently be used to calculate payback periods for community scale SWH systems in each case study.

Table 7: SAM Direct Capital Cost Parameters

Parameter	Description/Units
Collector Cost	Cost of collectors in the system ($/m^2)
Storage Cost	Cost of storage tanks ($/m^3)
Balance of System	Other fixed costs not included in collector or storage costs (mounting/ piping) ($).
Installation Cost	Fixed cost that can be used to account for labor or other costs ($)
Contingency	Percentage of collector, storage, balance of system, and installation costs to account for uncertainty in direct cost estimate (%)
Total Direct Cost	Sum of all direct costs ($)

Table 8: SAM Indirect Capital Cost Parameters

Parameter	Description/ Units
Engineer, Procure, Construct (EPC)	Costs associated with the design and construction of the project ($ and %)

[34] U.S. Department of Energy. (2016). *Residential Renewable Energy Tax Credit*. Retrieved from: https://www.energy.gov/savings/residential-renewable-energy-tax-credit
[35] Chen, W., Anderson, K. (2017 Jan 17). Personal Communication.

Project, Land, Maintenance	Costs associated with land purchases, permitting, and administrative overhead ($ and %)
Sales Tax	State sales tax (%)

Table 9: Total Cost

Parameter	Description/ Units
Total Installed Cost	Sum of total direct cost and total indirect cost ($)
Total Installed Cost per Capacity	Total installed cost divided by total system rated capacity ($/kW)

Table 10: Operation & Maintenance Costs

Parameter	Description/ Units
Fixed Annual Cost	A fixed annual cost applied to each year in the project cash flow ($/yr)
Fixed Cost by Capacity	Fixed annual cost proportional to the system's rated or nameplate capacity ($/kW-yr)
Escalation Rate	Increase in O&M cost above annual inflation rate (%)

4.2.6 Simulation Outputs

SAM output the following variables for each time step of a simulation are listed in Appendix 1.

5 Calculation of Energy Savings from Community Scale SWH Systems

Energy savings will be calculated on a daily basis for each community case study. Figure 4 summarized the calculation of energy savings using the results of community hot water demand calculations and the system parameters chosen for community scale SWH systems.

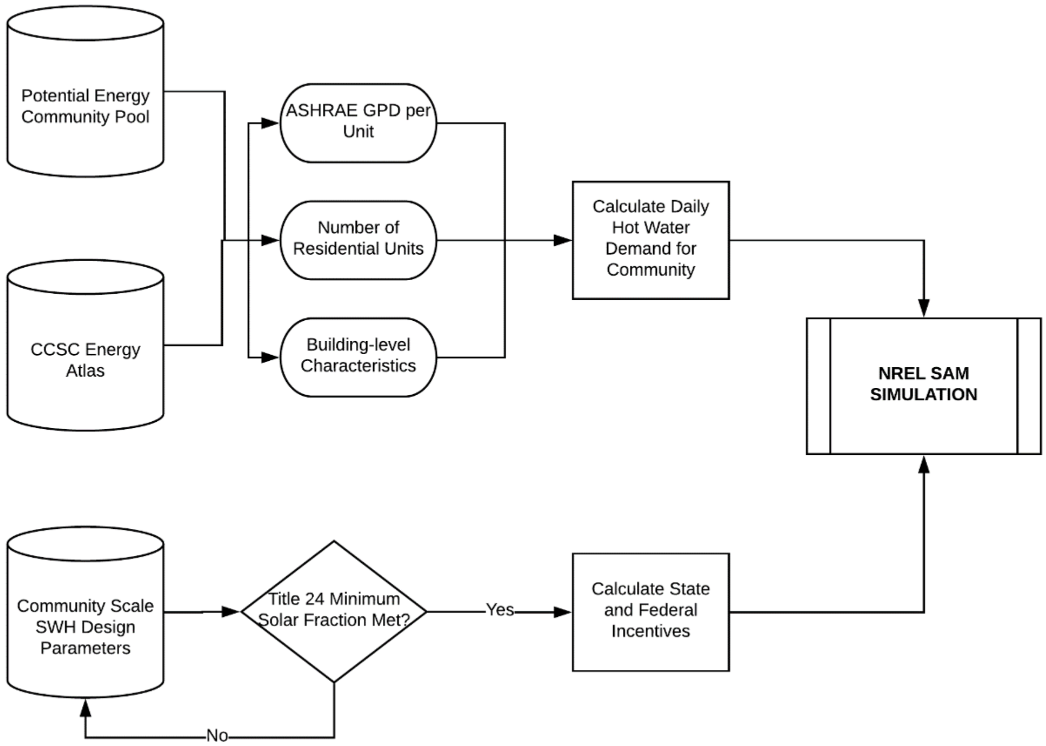

Figure 4: Calculation Flowchart for NREL SAM Simulations of Community Scale SWH System Performance.

6 Analysis of Gas Consumption Pattern in Los Angeles County with Wide & Deep Neural Networks

This study will also explore the power of parcel and supra-parcel characteristics to predict residential gas consumption using a wide and deep neural network.[36] This analytical approach is better suited to explore the relationships between the descriptive variables stored in the Energy Atlas (such as assessor's usecodes or a parcel's belonging to a particular neighborhood) and gas consumption than a series of regressions.[37] The results of this analysis will assist state and local stakeholders in understanding what combinations of characteristics are associated with gas consumption, and how to structure investment in residential energy efficiency measures.

6.1 Artificial Neural Networks vs. Linear Regression – Model Selection

The Energy Atlas database relates account-level monthly gas consumption with a set of variables that describe the physical characteristics of parcels' built environments and the demographics of the people inhabiting those parcels. These descriptive variables are both categorical (such as property usecodes and some census variables) and continuous (such as building square footage). A non-linear approach to explaining variation in gas consumption is favored for two reasons. First, correlation between

[36] Cheng, H.-T., Koc, L., Harmsen, J., Shaked, T., Chandra, T., Aradhye, H., … Shah, H. (2016). Wide & Deep Learning for Recommender Systems. http://doi.org/10.1145/2988450.2988454
[37] *Ibid.*

descriptive variables violates a key assumption of linear regression methods, precluding their use.[38] Secondly, the complexity of some descriptive categorical variables makes implementation of linear models and the interpretation of their results difficult.[39]

Many of the descriptive variables associated with parcels display moderate to high multicollinearity. Linear regression methods require that explanatory variables be uncorrelated or weakly correlated in order to produce accurate estimates of variable coefficients (the estimated effect of a variable on the outcome of interest) and reliable measures of statistical inference.[40]

Linear regression models are also poorly suited for analyzing the effects of complex categorical variables. In order for a categorical variable's effect to have a meaningful interpretation in the context of a linear regression model, its categories must have some sort of meaningful ordinality (i.e. ascending building or income brackets increase consumption of energy), or the different categories may be included as fixed-effects relative to a reference category (i.e. the effect of belonging to a minority group relative to being white on residential energy consumption).[41] A number of categorical variables with potential predictive power, such as assessor's usecodes, neighborhood identifiers, and census classifications are not easily incorporated into linear models because of the number of component categories they contain (there are 1,000+ assessor's usecodes) and in some cases also lack of meaningful ordinality.

6.1 Wide & Deep Neural Networks

Unlike linear regression models, neural networks do not require that input variables be uncorrelated with one another, or that outputs be linearly dependent upon inputs.[42] A wide & deep neural network model will be used to analyze of the relationships between descriptive variables and monthly gas consumption. This class of model is well suited to large-scale classification and regression problems with complex categorical variables.[43]

Wide & deep models have an architecture that captures both simple, specific relationships between inputs and outputs ("wide"), and more complicated dependencies between combinations inputs and outputs ("deep").[44]

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[38] Farrar, D. E., & Glauber, R. R. (1967). Multicollinearity in regression analysis: the problem revisited. *The Review of Economic and Statistics*, 92-107.
[39] Google. (2018). *TensorFlow Programmer's Guide*.
[40] Farrar, D. E., & Glauber, R. R. (1967). Multicollinearity in regression analysis: the problem revisited. *The Review of Economic and Statistics*, 92-107.
[41] Angrist, J. D., & Pischke, J. S. (2014). *Mastering'metrics: The path from cause to effect*. Princeton University Press.
[42] *Ibid.*
[43] Google. (2018). *TensorFlow Wide & Deep Learning Tutorial*. Retrieved from: https://www.tensorflow.org/tutorials/wide_and_deep
[44] Cheng, H.-T., Koc, L., Harmsen, J., Shaked, T., Chandra, T., Aradhye, H., … Shah, H. (2016). Wide & Deep Learning for Recommender Systems. http://doi.org/10.1145/2988450.2988454

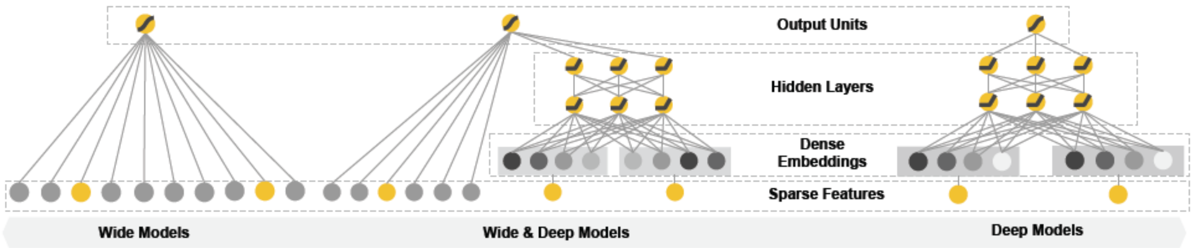

Figure 5: Wide, Deep, and Wide & Deep Neural Network Architectures

Interrogation of the model after training and validation will yield a ranking of what combinations of parcel and supra-parcel characteristics are the most important predictors of gas consumption. The following characteristics will be included in the model.

Table 11: Wide & Deep Model Inputs and Output

Input	Description
Date	Month and Year
Units	Number of residential units per parcel
Sqft	Parcel's square footage
Usecode	Parcel's tax assessor's usecode
Block Group	Parcel's census block group ID
Neighborhood	Parcel' s neighborhood ID
Location	Parcel Latitude/ Longitude
Output	**Description**
Consumption	Monthly Natural Gas Consumption

Appendix 2 contains a diagram of the wide & deep model listing all combinations of model inputs.

7 Conclusion

This study will estimate energy savings realized by implementing community scale SWH systems in energy communities selected from a larger eligible pool. In each case, annual energy savings, the energy produced and consumed by community scale SWH systems will be estimated. Payback periods and reductions in GHG emissions and air toxics from the combustion will also be calculated.

Appendix 1: NREL SAM Outputs

Variable Name	Units	Description
Energy saved	W	Energy saved by the solar water system.
Hot water draw	kg/hr	The hourly usage of hot water specified in the draw profile on the input page.
Irradiance - Beam	W/m^2	Direct normal irradiance value from the weather file.
Irradiance - Diffuse	W/m^2	Diffuse horizontal irradiance value from the weather file.
Irradiance - Incident	W/m^2	The total hourly incident global irradiance incident on the collector.
Irradiance - Transmitted	W/m^2	The total hourly radiation that makes it into the collector. Depends on the optical properties of the collector.
Operation mode		1 – startup mode, useful energy is collected and tank temperature is somewhat stratified. 2 – mixed mode, useful energy is collected and tank temperature is fairly uniform. 3 - stratified mode, no useful energy is collected and tank temperature is very stratified.
P pump	W	Electric pump power required to drive the collector loop and heat exchanger loop.
Power generated by the system	kW	Equivalent to the energy saved by the system, expressed in kW. When you run the solar water heating model with a financial model, this is the value used by the financial model.
Q auxiliary	W	Electric power required by the auxiliary heater to raise the water temperature from the solar storage tank to the set temperature: $Q_{aux} = \dot{m}_{draw} C_p (T_{set} - T_{deliv})$, where T_{deliv} is the temperature of the water delivered from the solar tank. Because solar heat has been added to the water, $T_{deliv} > T_{mains}$, and less power is needed to bring the water to the desired set temperature than would be required without the solar water heating system.
Q auxiliary only	W	Electric power that would be required without the solar water heating system: $Q_{aux,only} = \dot{m}_{draw} C_p (T_{set} - T_{mains})$.
Q delivered	W	Thermal power delivered by the solar water heating system.
Q loss	W	Envelope loss to room: $Q_{loss} = UA_t (T_{tank} - T_{room})$.
Q saved	W	Electric energy saved by the solar water heating system: $Q_{saved} = Q_{aux,only} - Q_{aux} - P_{pump}$. This value is equivalent to the energy delivered by the solar water heating system.
Q transmitted	W	Solar irradiance transmitted through the collector glass, accounting for collector area: $Q_{transmitted} = I_{transmitted} * A_c$, where $I_{transmitted}$ is the transmitted irradiance and A_c is the total collector area.
Q useful	W	Power delivered by the collector to the solar water storage tank.
Shading losses	%	Percent loss of incident beam irradiance due to shading, determined by the shading factors that you specify on the Solar Water Heating page.

T ambient	°C	The mid-hour ambient temperature calculated by averaging the end-of-hour temperature from the previous hour with the end-of-hour temperature from the current hour in the weather file.
T cold	°C	The temperature of the cold portion of the solar storage tank volume in stratified mode. If the tank is not stratified, this value is equal to the previous hour's cold temperature.
T delivered	°C	The temperature of the water delivered from the storage tank.
T hot	°C	The temperature of the hot portion of the solar storage tank volume in stratified mode. If not stratified, this value is equal to the previous hour's hot temperature.
T mains	°C	The temperature of water incoming from the supply source.
T tank	°C	The mean temperature of the solar storage tank.
V cold	m^3	The estimated volume of the cold portion of the solar storage tank, where "cold" is with respect to the hot portion of the tank. SAM models the hot and cold portions as separate nodes. The cold volume increases as users draw water from the tank and mains water replaces it.
V hot	m^3	The estimated volume of the hot portion of the solar storage tank, where "hot" is with respect to the cold portion of the tank. SAM models the hot and cold portions as separate nodes. The hot volume increases from hour to hour as the useful energy from the collector is added until the hot volume is equal to the tank volume (and cold volume is zero).

Appendix 2: Wide & Deep Model Architecture