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IDAHO PUBLIC
UTILITIES COMMISSION

BEFORE THE IDAHO PUBLIC UTILITIES COMMISSION

IN THE MATTER OF IDAHO POWER COMPANY'S APPLICATION TO INITIATE A MULTI-PHASE COLLABORATIVE PROCESS FOR THE STUDY OF COSTS, BENEFITS, AND COMPENSATION OF NET EXCESS ENERGY ASSOCIATED WITH CUSTOMER ON-SITE GENERATION	)	**CASE NO. IPC-E-21-21** **IDAHO CONSERVATION LEAGUE** **INITIAL COMMENTS ON STUDY FRAMEWORK**

The Idaho Conservation League (ICL) submits the following Initial Comments on the proposed customer on-site generation study framework, hereinafter the Value of Solar or VOS study. ICL's comments begin with two overarching recommendations that will create a credible and fair study - use avoided cost principles and retain a neutral third party to conduct the study. We then provide recommendations to reorganize and clarify the contents of the study in order to create a more useful basis to consider future customer-owned generation program options.

I. Scope and Objectives

The "Primary Objective" in the proposed framework is a good start towards determining the appropriate method of valuing these exports is the appropriate scope for this solar study and a critical step for developing a credible and fair study. The scope of the study should focus on the exports from on-site generation onto the electric system because this is the key feature that distinguishes customer-owned generation from how other customers use the electric system. The Commission recognized this customer distinction when it created the new customer-generator classes of Schedules 6 & 8[1] and when it approved Idaho Power's request to allow non-exporting customer generators to remain on the same rate schedules for consuming utility service as other customers of the same class.[2]

Building upon this distinction recognized by the Commission, the scope of this solar study should acknowledge and respect the unique relationship between the utility and its generator customers. Customers, including ICL, invest in self-generation systems primarily to control their own energy bills, as the Commission heard in the 13 hours of public testimony regarding the prior solar study settlement.[3] Customer-owned generation is unique in that some portion of the generation serves the customer's own needs and some portion flows beyond the customer's meter onto the grid. At other times, customers consume utility-provided energy. This two-way relationship between the customer and utility implicates distinct areas of the Commission's jurisdiction and regulatory practices.

The scope and sub-objectives for the study, proposed by Idaho Power, confusingly mixes the distinct concepts of consumption and generation and their relevant regulatory tools. The Company's Application asserts that "recommendations to modify the existing offering should focus on cost-of-service principles, while identifying the value of excess net energy to ensure equitable compensation for on-site generation."[4] The sub-objectives in the proposed framework continue this theme by focusing on "the Company's ability to recover costs from self-generating customers."[5] This proposal applies regulatory concepts applicable to consumption - cost of service and revenue requirement - to the question of valuing generation. The more appropriate

[1] Order No. 34046, Case No. IPC-E-17-13, pp. 15 -19 (May 9, 2018).
[2] Order No. 34955, Case No. IPC-E-20-30 (Mar. 9, 2021).
[3] Order No. 34509, Case No. IPC-E-18-15, pp. 3 - 4 (Dec. 20, 2019).
[4] Application, Case No. IPC-E-21-21, p. 6 (June 25, 2021).
[5] Study Framework for Party Comments, Case No. IPC-E-21-21, p. 5 (Sep. 30, 2021).

concept for valuing the service that customer-generators provide to the system is Idaho Power's avoided costs that result from the locally produced energy that flows directly to neighboring properties.

Because there are unique characteristics of customer-generators that distinguish them from all other utility customers, the scope of this solar study should not include either the portion of customer generation that serves the customer's own needs or the customer-generator's consumption of utility service.[6] Consumption of the customer's own solar generation is not a public use and therefore not within the Commission's jurisdiction. Therefore, how on-site customer-generation impacts consumption of utility service is outside the scope of this study.

In addition, although the solar customer's consumption of utility-provided energy is within the Commission's jurisdiction to establish "just, reasonable, or sufficient rates"[7] that issue is appropriately addressed in a general rate case where the Commission holistically considers how all customers consume utility service. Because the customer-generator's consumption of utility supplied service is not the key distinguishing feature of this class of customers, the issues of cost of service and rate designs for consumption are outside the scope of this study.

The unique issues related to customer generation are only relevant when an extra bit of energy flows across the meter onto the electric system. At this point, the Commission's jurisdiction takes on a new flavor because the customer-generator is providing a product for public use. Like other generation resources, the value of the service customer-generators provide to the system is appropriately captured by the concept of avoided costs.

[6] I.C. § 61-501
[7] I.C. § 61-502

Accordingly, ICL's comments on the solar study framework will focus on the appropriate methods to value generation using avoided cost principles and we will leave issues of customer consumption, measured by cost of service and revenue requirement, to the next general rate case. By clearly distinguishing between consumption and generation, and applying the correct tool to each, the study is more likely to be "understandable to an average customer, but its analysis must be able to withstand expert scrutiny."[8]

II. Use a Neutral Third-Party to Conduct the Study

ICL recommends that the Commission direct Idaho Power to use a neutral third-party to conduct the study. In our experience of several years of net-metering dockets, we have consistently heard from the public that it does not trust Idaho Power to conduct a fair study for two primary reasons. First, the nature of the rate of return on invested capital regulatory model creates a strong incentive for utilities to discourage any non-utility generation. To be clear, ICL is not imputing any nefarious actions onto Idaho Power, rather we are just observing the obvious incentive structure. Using a neutral third-party to conduct the study would show the public and stakeholders that Idaho Power also understands this inherent incentive structure and is taking credible steps to address this issue.

Second, Idaho Power's Application continues the long trend of making unsubstantiated assertions about subsidization, cost shifts, and customer-generators not paying their fair share and ICL worries that a solar study conducted by Idaho Power will be unfairly biased against customer-generators. Idaho Power has yet to provide a comprehensive cost of service study that documents how customer-generators' consumption of utility power results in cost shifts that are any more impactful than the normal variation of consumption among members of a rate class.

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[8] Order 34509, supra at 9.

The Company's attempt to address potential cost shifts through a fixed cost study in IPC-E-18-16 did not result in any greater understanding among customers, the public, or the Commission.[9] Further, the Commission has consistently recognized that the "benefits that on-site generation provide to the Company's infrastructure and resource allocation, once quantified, may well prove to outpace any alleged costs, increases in fixed-cost responsibility or decreases in net excess energy compensation credit".[10] In 2019, the Commission also clearly stated that the prior solar settlement that attempted to value customer-generator exports was not based on substantial and competent evidence.[11] Nevertheless, Idaho Power continues to assert the need to "limit subsidies by implementing a more equitable pricing and compensation structure."[12] This statement evidences a clear bias against customer-generators and ignores the Commission's prior orders to study this issue in a credible and fair manner so as to build a substantial and competent record upon which to assess whether any subsidy exists. As the Commission heard in the public testimony in IPC-E-18-15, Idaho Power's repeated unfounded assertions about customer-generators shirking their responsibilities undercuts the Company's credibility to produce a fair study. Using a neutral third party would break this cycle and build a higher level of credibility and fairness into the process.

Utilities and public utility commissions around the country have opted to commission third-party studies of the value of solar rather than conduct the study in-house. Two utilities, Austin Energy and Arizona Public Service Company, have solicited multiple VOS studies from Clean Power Research and SAIC, respectively, to determine the value of solar for utility

[9] Order 34608, Case No. IPC-E-18-16, pp. 6 - 7 (Mar. 31, 2020).
[10] Order 34046, supra at 19.
[11] Order 34546, Case No. IPC-E-18-15, p. 4 (Feb. 6, 2020).
[12] Application, supra at 6; Study Framework supra at 6.

customers.[13] In Minnesota, the Minnesota Public Utilities Commission relied on a third-party study completed by Clean Power Research when it set the value of solar for Minnesota utilities.[14] Finally, in its most recent proceeding to update the net metering tariff in California, the California PUC not only commissioned a third party to conduct a study and issue a tariff proposal, but also asked intervenors in the case to comment on the third-party proposal and provide their own proposals.[15] Idaho Power should follow this precedent by soliciting a neutral third party to conduct its VOS study.

III. Study components

After describing the goals and objectives, the proposed framework turns to the actual contents of the solar study. This section uses terms that are unnecessarily confusing and proposes a sequence of issues that places excessive weight on Idaho Power's interests, such as revenue requirement, rather than the broader public interest, such as the credible and fair calculation of the value of customer-generator exports. ICL's comments below recommend reorganizing and clarifying the study framework so it is more understandable to the public and more likely to result in a useful basis to consider future changes to the customer-generator program.

The framework should begin with defining the range of measurement intervals applied to each category in the VOS as well as the criteria to assess the accuracy of, and ability to implement, each measurement interval option. The second step is to identify all relevant

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[13] Clean Power Research, 2014 Value of Solar Executive Summary, p. 3 (Dec. 12, 2013), http://www.austintexas.gov/edims/document.cfm?id=202758 (last accessed Oct. 11, 2021); SAIC, 2013 Updated Solar PV Value Report, p. 7 (May 10, 2013), https://www.azsolarcenter.org/images/docs/reports/SolarValueStudy-SAIC-2013-05.pdf (last accessed Oct. 11, 2021).
[14] Minn. Pub. Utilities Comm'n, Order Approving Distributed Solar Value Methodology, Docket No. E-999/M-14-65, p. 9 (Apr. 1, 2014).
[15] Cal. Pub. Utilities Comm'n, Order Instituting Rulemaking to Revisit Net Energy Metering Tariffs Pursuant to Decision 16-01-044, and to Address Other Issues Related to Net Metering, Rulemaking No. 20-08-020, p. 4 (Nov. 19, 2020).

categories for the value of solar and assess them in regards to each measurement interval and at various levels of cumulative customer-generation on the system. The third step of the framework should address program implementation issues including the method to return value to customers and options for future updates to the customer-generator program. The fourth step should consider program participation issues including the size of eligible systems and how to enable multi-family housing residents to access the on-site generation program.

1. Measurement Interval

The concept of net exports, and respect for the appropriate scope of the study, requires establishing a time period to compare a customer's consumption with any generation that crosses onto Idaho Power's system. The length of the measurement interval is likely the most important concept to establishing a credible and fair study design that is understandable to the public because it influences both the value of the exports as well as the ability for a customer to understand their investment decision. We support the proposal to study a range of measurement intervals in order to build a complete record and foster understanding.

The study framework, however, identifies inapplicable criteria to assess the appropriate time interval - the "class revenue requirement", the "export credit payments", and the "bill impacts."[16] These criteria have little meaning to the public and do not assist in understanding how the value of the components of the value of solar change in regards to the measurement interval. For example, revenue requirement commonly refers to the revenue Idaho Power should collect to compensate for providing service to customers. The concept of revenue requirement is not relevant until the study determines the amount of exports, when they occur, the value they provide, and the method customers will be credited for providing this value.

[16] Study Framework, supra at 7-8.

The proposal includes the confusing term "credit payments" which mixes two distinct methods of compensation - a credit, as is the current method, and a payment, which is an old method Idaho Power specifically asked to end in 2013.[17] Considering the bill impacts to customer-generators is important, but is appropriately done after assessing the value of exports and various program implementation issues. Finally, the focus on "existing customers" ignores the fact that existing customer generators are protected from future program changes due the Commission's determination that they can remain in the legacy net metering program through 2045.

To produce a more credible and fair solar study that properly focuses on exports, is understandable to the public, and can withstand expert scrutiny, we recommend the solar study apply the following criteria to assess which measurement interval is most appropriate to inform the future design of the customer-generation programs:

1. ability to accurately match generation exports with the value to the system
2. ability for customers to understand how the program rules and credits influence their investment decision
3. ability of system-providers to give clear and reliable forecast of performance to potential system buyers
4. ability of each measurement interval to support the implementation of a range of crediting options

The solar study should apply these criteria to examine the impact on export value in different time intervals - monthly, hourly, as well as a sub-hourly option - as discussed in more detail below.

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[17] Order 32846, Case No. IPC-E-12-17, p. 15 (July 3, 2013).

Monthly: This is the current program design and can serve as a benchmark against which a different interval is assessed according to the criteria above.

Hourly: This is an appropriate time measurement as utility system costs vary by the hour as does the output of the customer-generation system. Based on our conversations with customers and system-providers, the study should address methods and tools available to implement this interval in a manner that allows for customer understanding of the long-term performance of their system and impact on their energy bills. As the Commission recognized in IPC-E-18-15, moving to hourly netting is a significant change to the economic value of customer-owned generation and something that must be supported by a robust record.[18] Studying the change to hourly netting in relation to the criteria above is a key step in developing this record.

"Separate Channel": This term is a measurement method, not an interval. The study framework filed by Staff does not accurately represent ICL's position. ICL did not suggest "Instantaneous Net Energy Measurement" because that collection of words mixes a measurement interval with a measurement method. We note Idaho Power's Application appears to really suggest they meant an instantaneous time interval: "separate channel, which is sometimes referred to as instantaneous."[19]

Referring to Idaho Power's wording, we recommended in our September 22 informal comments to use the term "instantaneous," but noted this concept could undercut a fundamental tenet of customer-generation, the ability to self-supply energy. In that meeting we were relieved to learn Idaho Power is not proposing to study a program design whereby the Company would

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[18] Order 34546, supra at 6 - 7.

[19] Application, supra at 7.

separately measure all customer-owned generation as an export distinct from customer consumption. That possible program design would frustrate a fundamental concept of customer-owned generation, the ability to meet your own energy needs through independent investments.

To better clarify our recommendation: The study should examine a measurement interval that is shorter than hourly, but must maintain the fundamental concept that customer-owned generation first serves the customers' energy needs. Because Idaho Power knows the technical abilities of its metering system, we suggest the Commission direct Idaho Power to document the appropriate time-interval that allows customers to plainly see what portion of their system serves their needs and what portion is exported to the grid. Then the study can assess this sub-hourly time interval in regards to the three criteria we suggest above.

2. Categories for the Value of Solar

To fully capture all of the benefits that customer-owned generation provides to the utility and its customers, the study design should include as many categories as possible within the value of solar (VOS) analysis. For each category, the study should address monthly, hourly, and sub-hourly intervals as described above. Also for each category and each time interval, the study should assess the value at various levels of growth in the customer-generation program ranging from current levels to 10 times current and 25 times current.

Researchers Koami Soulemane Hayibo and Joshua M. Pearce at Michigan Technological University recently compiled a review of several VOS studies across the country to identify a generalized model for calculating the true value of distributed solar generation. As indicated in their 2021 paper, the best practice to evaluate the dollar value of solar per kilowatt-hour of electricity produced is to sum up the calculated avoided costs, or solar benefits, and then divide that sum by the total amount of energy produced during the analysis period discounted by the associated discount factor.[20]

The researchers found that the most common components included in a value of solar study as avoided costs are: energy production costs (operation and maintenance), electricity generation capacity costs, transmission capacity costs, distribution capacity costs, fuel costs, environmental costs, ancillary costs including voltage control benefits, solar integration costs, market price reduction benefits, economic development value or job creation, health liability costs, and value of increased security.[21] Out of these component categories, Hayibo and Pearce argued that avoided O&M fixed and variable costs, avoided fuel cost, avoided generation capacity cost, avoided reserve capacity cost, avoided distribution cost, avoided environmental cost, and avoided health liability cost are the minimum categories necessary to calculate the true value of solar. Please refer to ICL Exhibit 501, the Hayibo and Pearce study, for further details on the methods to calculate each component of the VOS.

ICL also recommends that, in order to represent fully the entire value of distributed solar generation, the solar study must include values associated with the resilience and reliability of the grid, health benefits including those from reduced carbon dioxide emissions and air pollution, and local economic benefits such as job creation from thriving solar markets.

In addition, ICL makes the following recommendations: In each category in the VOS, the study should include a time horizon for the avoided costs. Solar systems are the vast majority of customer-generation resources and typically last for 20 years or more. Regarding the vague concept of "firmness" and the system level concept of integration, the study should assess

[20] Koami S. Hayibo & Joshua M. Pearce, *A Review of the Value of Solar Methodology with a Case Study of the U.S. VOS*, 137 Renewable and Sustainable Energy Reviews (2021).
[21] Id. at 2.

whether distribution circuits with some meaningful amount of customer-generator exports show an overall variability that adds to or avoids costs for Idaho Power. Because customer-generation systems sit on the distribution circuits and are unlikely to reach the bulk transmission system, we recommend the study focus on avoiding distribution level costs and line losses distinct from transmission costs and line losses. This necessarily requires focusing on the specific locations on the distribution system the exports occur and recognizing this location value in any export credit rate. Lastly, the category of environmental benefits that arise from customer-generator exports and accrue to the utility system should include the utility's reduced costs associated with compliance with Clean Air Act requirements at its fossil fuel generation facilities as well as the utility's reduced costs associated with future greenhouse gas regulation. Because these environmental benefits impact rates for all customers, the environmental and health benefits category should be moved in the framework from a side issue to a core component of the VOS.

3. Program Implementation Issues

Implementing the customer-owned generation program will affect Idaho Power differently than the program participants. The Company's proposed framework already covers issues like collecting revenue associated with customer credits and accounting for these credits in the billing system. The public interest primarily focuses on basic rules governing how customers can participate in the customer-generation program which is not yet well represented in the framework. Therefore, ICL's comments in this section are structured as common questions we have consistently heard that the study should answer.

a. How will customer-generators be fairly compensated for their exports?

The proposed framework includes a section "Billing Structure" and proposes to "explain how potential customer-generators and on-site system installers will have accurate and adequate data and information". Explaining an outcome is not the same as studying options. ICL recommends the solar study examine the options for providing credits for exports to customers. Those options should address issues such as: which bill components the credits can offset, whether credits can be used to offset other accounts held by the same customer, and the ability of customers to donate credits to other customers.

b. Do the credits expire?

The framework includes a section covering the potential for customer credits to expire, which is a distinct change in policy from the current program. ICL believes that credits are the property of the customer and not Idaho Power. Therefore, any regulatory mechanism that would take away the value of a customer's credits could raise thorny legal questions. The study should assess options that preserve the customer's value in any accumulated credits including the ability to transfer them to other accounts, whether held by the customer or not.

c. How will the program change from the current net metering program to a successor?

ICL appreciates the careful attention the Commission gave this issue when adopting the criteria for existing customers to remain in the legacy net metering program. Customers who invest in generation systems make a significant financial investment to meet their own energy needs. And due to the exclusive service territory allocated to Idaho Power by state law, customers are limited to only one program that could enable them to enjoy the benefits of their personal investment. The study should examine options to allow for a predictable and fair transition between the current program and any successor program. The Utah Public Service Commission recognized this dynamic and created three categories of customer-generators[22]: "Net-Metered Customers" who remain in the legacy net metering program over the long-term, "Transition Customers" who interconnected during the years-long process to adopt a successor to

[22] For a simple description of the Utah transition structure please see this website: https://rooftopsolar.utah.gov/

net metering and are subject to transitional rates and program rules, and "Post-Transition Customers" who interconnect after the Commission adopted a successor program and are immediately subject to the new rates and rules. While Idaho will need different rates and rules than those adopted in Utah, ICL recommends the solar study include options to address transitional and post-transition customer-generators.

d. How will the successor program change in the future?

The proposed framework presupposes a biennial or annual update to the export credit rate.[23] ICL submits that this is an overly restrictive framing of this critical issue. Instead of assuming a one- or two-year update period, the study should first assess whether establishing a timeline for in this one area is fair, just, and reasonable when there is no similar timeline for updating the Company's overall electric rates. The study should consider how the timing of updates impacts the ability of customers to make informed decisions about a product that lasts for 20 years or more. The study should consider how the timing of updates impacts the providers of customer-owned system ability to give rigorous information and informed forecasts to their potential customers. Once the study considers the propriety of frequent updates unique to this one customer-facing program, the study should examine the variety of processes available to make these updates. For example, it should examine whether the updates should align with the resource planning cycle even though that process is merely an acknowledgment of a process and not a decision on any of the contents. Another option is to connect any updates to objective criteria such as changes to the costs Idaho Power avoids by receiving exports from customer-generators. Because any changes to the customer-generation program have historically caused

[23] Study Framework, supra at 20.

enormous public interest, ICL recommends the Commission pay close attention to these issues of fundamental program credibility and fairness.

4. Participation Rules

a. System Cap

The eligibility cap for participants in the customer-generator program is an important issue, but not one that needs to be studied as part of the value of solar study. Rather, this issue can and should be addressed immediately in a separate docket. The question is straightforward: should the program limit customers to a somewhat arbitrary system size, or should customers be able to invest in systems that match their own energy needs? To help reduce the size and complexity of the solar study, ICL encourages the Commission to direct Idaho Power to initiate a separate docket to consider this issue. We note that the Commission's previous decision to separate out other system eligibility issues from the previous value of solar proceeding, like interconnection standards in IPC-E-20-26 and smart inverter settings in IPC-E-20-30, enabled a quick and non-controversial resolution of those issues that did not directly impact the value of exports from customer-generation.

b. Multifamily Housing

The solar study should examine potential program designs that will facilitate multifamily solar installation. Residents of multifamily buildings face unique participation challenges for customer generation. Residents who own their units may not own the rooftop space and thus must rely on the building owner or similar entities to manage the solar installation and distribute the value produced by the on-site generation system. Residents who rent their units have little to no control over landlord decisions to install solar and landlords have little incentive to pay for solar installations because renters generally pay their own utility costs. Even if landlords choose to install solar, renters are unlikely to see any financial benefits unless there exists an avenue for renters to subscribe to the solar production. The solar study should explore options to address this market failure so that residents of multi-family housing have an equal opportunity to participate in a customer-generation program,

One program structure that will facilitate multifamily customer-generation for both owner- and renter-occupied buildings is a subscribership program where residents can purchase a subscription to a particular number of rooftop solar panels.[24] A subscribership program will allow building developers/owners to recoup the installation costs of the panels while still permitting residents to benefit financially from the solar production. A subscribership program for renters will also benefit low-income customers who are more likely to live in rented units and are less able to afford individual home solar installations. The study should examine program designs that ensure that multifamily solar participants receive a value for exports that is equivalent to the value received by individual system owners.

IV. Other issues

The proposed study framework includes several other issues raised by parties. ICL takes no position at this point on those issues and perspectives. Rather, we look forward to reviewing parties' formal initial comments before responding.

Similarly, the Commission made it crystal clear in Orders 34509 and 34546 that stakeholders must listen to and incorporate the public input and perspectives in this process. ICL looks forward to learning from the public about what issues are important to them. In particular, we look forward to learning if this proposed framework is understandable to the general public.

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[24] The Virginia State Corporation Commission recently adopted a similar program where multifamily residents can subscribe to shared solar. *See Commonwealth of Virginia, ex rel. State Corporation Commission, Ex Parte: In the matter of establishing regulations for a multi-family shared solar program pursuant to § 56-585.1:12 of the Code of Virginia, Case No. PUR-2020-00124, Order Adopting Rules, p. 12 (Dec. 23, 2020).*

It could be the case that the parties will need to reassess the entire approach to this issue and develop a framework that is less reliant on technical jargon and complex regulatory concepts. At the end of the day, the framework could be reduced to answering some simple questions:

1. How will potential solar owners know the program is fair and predictable?
2. What are the rules potential solar owners need to follow to participate in the program?
3. How can program participants continue to engage in any future updates to the program?
4. How does the customer-generation program align with and support Idaho Power's commitment to 100% clean energy?

V. Conclusion

ICL appreciates the Commission's phased approach to addressing this program that enables customers to make personal investments to meet their own energy needs. We look forward to working collaboratively with all stakeholders to develop a credible and fair solar study.

Respectfully submitted this 13th day of October, 2021.

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Exhibit 501

Koami S. Hayibo & Joshua M. Pearce, *A Review of the Value of Solar Methodology with a Case Study of the U.S. VOS*, 137 Renewable and Sustainable Energy Reviews (2021).

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A review of the value of solar methodology with a case study of the U. S. VOS

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ABSTRACT

Distributed generation with solar photovoltaic (PV) technology is economically competitive if net metered in the U.S. Yet there is evidence that net metering is misrepresenting the true value of distributed solar generation so that the value of solar (VOS) is becoming the preferred method for evaluating economics of grid-tied PV. VOS calculations are challenging and there is widespread disagreement in the literature on the methods and data needed. To overcome these limitations, this study reviews past VOS studies to develop a generalized model that considers realistic future avoided costs and liabilities. The approach used here is bottom-up modeling where the final VOS for a utility system is calculated. The avoided costs considered are: plant O&M fixed and variable; fuel; generation capacity, reserve capacity, transmission capacity, distribution capacity, and environmental and health liability. The VOS represents the sum of these avoided costs. Each sub-component of the VOS has a sensitivity analysis run on the core variables and these sensitivities are applied for the total VOS. The results show that grid-tied utility customers are being grossly under-compensated in most of the U.S. as the value of solar eclipses the net metering rate as well as two-tiered rates. It can be concluded that substantial future work is needed for regulatory reform to ensure that grid-tied solar PV owners are not unjustly subsidizing U.S. electric utilities.

1. Introduction

Solar photovoltaic (PV) technologies have had a rapid industrial learning curve [1–4], which has resulted in continuous cost reductions and improved economics [5,6]. This constant cost reduction pressure has resulted in a spot price of polysilicon Chinese-manufactured PV modules of only US$0.18/W as of April 2020 [7]. There are several technical improvements, which are both already available and slated to drive the costs further down such as black silicon [8–10]. The International Renewable Energy Agency (IRENA) can thus confidently predict that PV prices will fall by another 60% in the next decade [11]. However, even at current prices, any scale of PV provides a levelized cost of electricity (LCOE) [12] lower than the net metered cost of grid electricity [13] and this will only improve with storage costs declining [14–18]. Specifically, PV already provides a lower levelized cost of electricity [12,19,20] than coal-fired electricity [13,21,22]. In addition, PV technology can be inherently distributed (e.g. each electricity consumer produces some or all of their electricity on site thus becoming 'prosumers'). Distributed generation with PV has several technical advantages, including improved reliability, reduced transmission losses [23,24], enhanced voltage profile, reduced transmission and distribution losses [25], transmission and distribution infrastructures deferment, and enhanced power quality [26]. As PV prices decline, prices of conventional fossil fuel-based electricity production are increasing due to aging infrastructure [27–29], increased regulations (in some jurisdictions) [30–33], fossil fuel scarcity [34–36], and pollution costs [37–41]. Thus, PV represents a threat to conventional utility business models [42] and there is evidence that some utilities are manipulating rates to discourage distributed generation with solar [43], while others are embracing it such as Austin Texas or the state of Minnesota [44]. Rates structures vary widely throughout the U.S [45–48]. and there has been significant effort to determine the actual value of solar (VOS) electricity.

This shift towards VOS is fueled by criticisms of its predecessor [49], net metering, that is misrepresenting the true value of distributed solar generation [50–52]. VOS is more representative of the electricity cost because under a Value of Solar Tariff (VOST) scheme, the utility purchases part of, or the whole net solar photovoltaic electricity generation from its customers, therefore dissociating the VOST from the electricity

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Nomenclature:

B	Burner tip fuel price [$/MMBtu]
C_D	Distribution capacity [MW]
C_G	Utility generation capacity [p.u.]
C_H	Health cost of natural gas [$/kWh]
C_{PV}	PV capacity for year 'n' [kW]
C_T	Transmission capacity [p.u.]
D	Utility Discount rate
D_E	Environmental discount rate
D_H	Heat rate degradation rate
D_{PV}	Degradation rate of PV
E	Environmental cost [$/MMBtu]
F	Utility discount factor
F_E	Environmental discount factor
h	Number of hours in the analysis period
H_C	Heat rate of combined cycle gas turbine [Btu/kWh]
H_{CT}	Heat rate of peaker combustion turbine [Btu/kWh]
H_n	Heat rate for year n [Btu/kWh]
H_P	Heat rate of the plant [Btu/kWh]
H_S	Solar heat rate [Btu/kWh]
i	Number of years in analysis period
I_C	Installation cost of combined cycle gas turbine [$/kW]
I_D	Investment on distribution capacity per year without PV [$]
I_{DP}	Investment on distribution capacity per year with PV [$]
I_P	Installation cost of peaker combustion turbine [$/kW]
K	Growth rate
M	Reserve capacity margin
n	nth year of analysis period
O	Output of the PV [kWh]
$PL1$	1st year load capacity [kW]
$PL10$	10th year load capacity [kW]
Q	Distribution cost [$/kW]
S	PV fleet shape [kW]
S_C	Solar capacity cost [$/kW]
U_C	Utility cost [$]
U_F	Utility fixed operation and maintenance cost [$/kW]
U_P	Utility price [$/kWh]
U_T	Utility transmission capacity cost [$/kW]
U_V	Utility variables operation and maintenance cost [$/kWh]
VOS	Value of solar [$/kWh]
V_x	V_1: Avoided operation and maintenance fixed cost [$]$V_2$: Avoided operation and maintenance variable cost [$]$V_3$: Avoided fuel cost [$]V_4: Avoided generation capacity cost [$]$V_5$: Avoided reserve Capacity cost [$]$V_6$: Avoided transmission capacity cost [$]$V_7$: Avoided distribution cost [$]$V_8$: Avoided environmental cost [$]$V_9$: Avoided health liability [$]

retail price [51,53]. Performing a complete VOS calculation, however, is challenging. One of the main challenges is data availability and accuracy [54,55]. Three data challenges have been identified by Ref. [55] that are: 1) the time granularity of the solar irradiation data, 2) the origin of the data, modeled versus measured, and 3) the data measurement accuracy. Other challenges faced by utilities while assessing the VOS are which components to include in the calculations, and what calculations method to assess the value of each components [56]. The possible components across the literature that are suggested to be included in a VOS as avoided costs and solar benefits are: **energy production costs** (operation and maintenance) [45–47,57–63], **electricity generation capacity costs** [45–47,50,57–63], **transmission capacity costs** [45–47,50,57–61,63], **distribution capacity costs** [45–47,50,57–63], **fuel costs** [45–47,50,57,60–63], **environmental costs** [45,47,57,58,60–63], **ancillary including voltage control benefits** [47,57–59,63], **solar integration costs** [47], **market price reduction benefits** [47,60], **economic development value or job creation** [46,47,57,60,61], **health liability costs** [57,60,64], and **value of increased security** [47,57]. A guidebook has been developed by the United States' Interstate Renewable Energy Council (IREC) for the calculation of several of the VOS components [57]. These methods have been further developed by the U.S. National Renewable Energy Laboratory (NREL) [58]. NREL has provided more detailed calculation methods than the guidebook from the IREC with a different level of accuracy. The methods with a higher level of accuracy are more complicated to implement and require a higher level of data granularity. A qualitative study on VOS performed in 2014 suggested the inclusion of all relevant components in a VOS studies [64]. The calculation of the VOS can be done annually, as in the case of Austin Energy [50,53], or can be fixed for a selected period, as per the case of Minnesota state's VOS (25 years) [45,53]. There are recently an increasing number of studies looking into externality-based components of VOS especially environmental costs and health liability costs [65–67]. This is because a country with high solar PV penetration rate provides a healthy population according to a German study [68]. An estimated average of 1424 lives could be saved each summer in the Eastern United States, and $13.1 billion in terms of health savings if the total electricity generation capacity in the Eastern United States included 17% of solar PV [69]. For the entire U.S. if coal-fired electricity were replaced with solar generation, roughly 52,000 premature American deaths would be prevented from reduced air pollution alone [70]. Not surprisingly, the latest report from North Carolina Clean Energy Technology Center found out that there are policy changes on VOS across the United States with 46 states, in addition of DC considering making significant changes in their solar policies and might be transitioning to a VOS model in coming years [63].

This indicates VOS is the way of the future for grid integrated PV, but how exactly should solar be valued on the modern grid? In this study the VOS literature is reviewed, and a generalized model is developed taking realistic future avoided costs and liabilities into account from the literature. The approach used here is a bottom-up modeling where the final value of solar to a utility system is calculated. This model factors in the existing parameters, that have been identified in VOS studies in different U.S. jurisdictions. The approach starts from the existing formula to calculate the levelized cost of electricity from solar PV technology [12] and updates the formula by adding the avoided and opportunity costs and the effect of different externalities. The costs considered in the study are: avoided plant operation and maintenance (O&M) fixed cost; avoided O&M variable cost; avoided fuel cost; avoided generation capacity cost, avoided reserve capacity cost, avoided transmission capacity cost, avoided distribution capacity cost, avoided environmental cost, and the avoided health liability cost. The value of solar represents the sum of these costs. Each sub-component of the VOS has a sensitivity analysis run on the core variables and these sensitivities are applied for the total VOS. These sensitivities are limited by the best available data on the variables in the literature and future work is needed to quantify the secondary costs that would lead to an even higher VOS. The conservative results developed here are presented and discussed in the context of aligning policy and regulations with appropriate compensation for PV-asset owners and electric utility customers.

2. Methods/theory

2.1. Avoided plant O&M – fixed cost (V_1)

The use of solar energy results in a displacement of energy production from conventional energy sources. The avoided cost of plant operation and maintenance (V_1) [$] depends on the energy saved by using solar PV for electricity generation instead of conventional energy generation processes. Equation (1) describes the calculation of the capacity of solar PV (C_{PV}) [kW] throughout the lifetime of the solar PV system. During the first year of operation, the installed solar PV system is considered to not have suffered any degradation. Therefore, the capacity has a value of one. The degradation of the installed solar PV system is expressed by the degradation rate of PV (D_{PV}) and for a marginal year (n), the marginal capacity of the installed PV system for that year would be:

$$C_{PV} = (1 - D_{PV})^n \tag{1}$$

The fixed O&M cost is directly linked to the need for new conventional electricity generation plants. If the construction of new conventional generators in the location of interest can be avoided, there is no need to include the fixed O&M in the valuation of solar for this location. To calculate the value of the fixed O&M (V_1), the value of the utility cost (U_C) [$] needs to be known first. The utility cost depends on four parameters, the capacity of solar PV (C_{PV}) mentioned above, the utility capacity (C_G) [p.u.], the utility fixed O&M cost (U_F) [$/kW], and the utility discount factor (F). To calculate this utility cost, first the ratio of the capacity of solar to the utility capacity is calculated. This ratio is then multiplied by the utility fixed O&M cost. A discount is applied to the result by multiplying it by the utility discount factor [71]. The discount factor (F) depends on the year and can be calculated by using the discount rate (D). The discount factor for year (n) is [45]:

$$F = \frac{1}{(1 + D)^n} \tag{2}$$

The discount rate used in the formula describes the uncertainty and the fluctuation of the value of money in time. The value of the discount rate differs when considered from a utility point of view or a societal point of view and can highly impact the utility cost. While considering the economics of solar PV systems [57], has suggested the use of a discount rate lower than the value used by the utility.

$$U_C = U_F * \frac{C_{PV}}{C_G} * F \tag{3}$$

The avoided plant O&M fixed cost (V_1) is then calculated by summing the utility cost for all the years included in the analysis period.

$$V_1 = \sum\nolimits_0^i U_C \tag{4}$$

2.2. Avoided plant O&M – variable cost (V_2)

The utility cost for the avoided variable O&M cost (V_2) [$] is calculated by multiplying the utility variable O&M cost (U_V) [$/kWh] by the energy saved by using solar PV systems or the output of the solar PV system (O) [kWh], and the result is discounted by the discount factor (F).

$$U_C = U_V * O * F \tag{5}$$

The avoided variable O&M (V_2) cost is the sum of the utility cost over the analysis period:

$$V_2 = \sum\nolimits_0^i U_C \tag{6}$$

2.3. Avoided fuel cost (V_3)

Additionally, the calculation of the utility price (U_P) [$/kWh] require the knowledge of the equivalent heat rate of a marginal solar. According to Ref. [72], the heat rate [Btu/kWh] describes how much fuel-energy, on average, a generator uses in order to produce 1 kWh of electricity. It is typically used in the energy calculation of thermal-based plants and is therefore misleading for the calculation of solar energy production. Since the method evaluates the avoided cost from thermal-based plants, however, it is applied to solar PV generation. The heat rate (H_S) [Btu/kWh] of solar PV or displaced fuel heat rate during the first marginal year is calculated as:

$$H_S = \frac{\sum_0^h (H_p * S)}{\sum_0^h S} \tag{7}$$

In the equation above, the heat rate (H_p) [Btu/kWh] represent the real value of the utility plant's heat rate during the operation hours of the solar PV systems over the analysis period and the parameter (S) [kW] describes the PV fleet shape that is the hourly PV fleet shape production over the hours (h) in the analysis period.

After the heat rate for the first year has been calculated, the heat rate for the succeeding years in the analysis period can be calculated by the following equation [45]:

$$H_n = H_S * (1 - D_H)^n \tag{8}$$

The primary use of heat rates is the assessment of the thermal conversion efficiency of fuel into electricity by conventional power plants. As a result, it is natural to deduce that the rate at which the heat rate (D_H) decreases corresponds to the efficiency lost rate of the power plant [73].

The utility price (U_P) depends on the heat rates and can be calculated once the heat rate is known as:

$$U_P = \frac{B * H_n}{10^6} \tag{9}$$

Another parameter to account for is the burner tip price (B) [$/MMBtu]. The burner tip price describes the cost of burning fuel to create heat in any fuel-burning equipment [74].

The avoided fuel cost (V_3) [$] is calculated in a similar way as the value of the fixed O&M. First, the utility cost is calculated by multiplying the value of the per unit PV output (O) by the utility price (U_P). The result is then discounted by the discount factor. The discount factor used in the case of the avoided fuel cost depends on the treasury yield [45]. The avoided fuel cost is obtained by summing up the utility cost over the analysis period.

$$U_C = U_P * O * F \tag{10}$$

$$V_3 = \sum\nolimits_0^i U_C \tag{11}$$

2.4. Avoided generation capacity cost (V_4)

The installation of solar systems reduces the generation of electricity from new plants. This is represented by the avoided capacity cost. To calculate the avoided generation capacity cost, the solar capacity cost (S_C) [$/kW] needs to be known. Two variables are essential to evaluate the solar capacity cost, the cost of peaker combustion turbine (I_P) [$/kW] and the installed capital cost (I_C) [$/kW]. The cost of peaker combustion turbine (I_P) is the cost associated with the operation of a turbine that function only when the electricity demand is at its highest. The installed capital cost (I_C) describes the cost of combined cycle gas turbine updated by the cost based on the heat rate. The solar capacity can be calculated as follows [75]:

$$S_C = I_C + (H_S - H_C) * \frac{I_P - I_C}{H_{CT} - H_C} \tag{12}$$

H_{CT} [Btu/kWh] and H_C [Btu/kWh] are respectively the heat rate of the peaker combustion turbine, and the combined cycle gas turbine. After the calculation of the solar capacity cost (S_C), the utility cost can be obtained by first, multiplying the ratio of solar PV capacity (C_{PV}) and utility generation capacity (C_G) by the value of solar capacity cost (S_C). Then, the result is discounted by the discount factor (F) to obtain the final value of the utility cost. And as in the previous cases the value of avoided generation capacity is the sum of the utility cost overs the analysis period.

$$U_C = S_C * \frac{C_{PV}}{C_G} * F \tag{13}$$

$$V_4 = \sum_0^i U_C \tag{14}$$

2.5. Avoided reserve capacity cost (V_5)

The calculation of the avoided reserve capacity cost (V_4) [$] follows the same pattern as the avoided cost of generation capacity. But in this case, the effective solar capacity, that is the ratio of the solar PV capacity (C_{PV}) and utility generation capacity (C_G) is multiply by the solar capacity cost, then the result is multiplied by the reserve capacity margin (M) to obtain the utility costs. After that, the utility cost is discounted as previously described by the discount factor (F). Then, the avoided reserve capacity is calculated by adding up the utility cost over the analysis period [58].

$$U_C = S_C * \frac{C_{PV}}{C_G} * M * F \tag{15}$$

$$V_5 = \sum_0^i U_C \tag{16}$$

2.6. Avoided transmission capacity cost (V_6)

The avoided transmission capacity cost (V_6) [$] calculation is also performed similarly to the avoided generation capacity cost. This cost describes the losses that are avoided when electricity does not have to be transported on long distance because of installed solar systems. It is calculated by first multiplying the utility transmission capacity cost (U_T) [$/kW] by the solar PV capacity (C_{PV}). The result is then divided by the transmission capacity (C_T) [p.u.] and the discount factor (F) is applied to obtain the utility cost for a marginal year. The avoided transmission cost is calculated by the sum, over the years in the analysis period, of the corresponding utility costs [76].

$$U_C = U_T * \frac{C_{PV}}{C_T} * F \tag{17}$$

$$V_6 = \sum_0^i U_C \tag{18}$$

2.7. Avoided distribution capacity cost (V_7)

The two major variables that influence the avoided distribution capacity cost (V_7) [$] are the peak growth rate (K) and the system wide costs. The system wide costs account for several financial aspects of a distribution plant, among which, overhead lines and devices, underground cables, line transformers, leased property, streetlights, poles, towers etc. [77].

All the deferrable system wide costs throughout a year have been summed up and the result divided by the yearly peak load increase in kW over a total period of a decade to obtain the distribution cost per growth of demand.

The ratio of the 10th year peak load (PL_{10}) [kW] and the 1st year peak load (PL1) [kW] are used in the calculation of the growth rate (K) of demand. The expression of the growth rate (K) is as follows [45,78]:

$$K = \left(\frac{PL_{10}}{PL_1}\right)^{\frac{1}{10}} - 1 \tag{19}$$

The distribution capital cost (Q) [$/kW] is utility owned data and depends on the utility, and the growth rate (K) that can be obtained by using the previous formula. An escalation factor is necessary to evaluate the distribution cost for deferral consecutive years [79].

After obtaining the distribution cost (Q) from the utility and growth rate (K) calculated, the distribution capacity (C_D) [kW] can be calculated from the growth rate. The result is then multiplied by the distribution cost and discounted by the discount factor (F) to get the discounted cost for a particular year. The discounted cost for the analysis period can in turn be used to calculate the investment during each year (I_D) [$] of the analysis period [45].

$$I_D = C_D * Q * F \tag{20}$$

When there is no other generation system than solar PV that comprised the installed capacity, the investment per year (I_{DP}) [$] in terms of deferred distribution can be calculated from the investment deferred [45].

$$I_{DP} = C_D * Q * DF \quad \text{(in terms of deferred distribution)} \tag{21}$$

After obtaining the yearly investment without PV (I_D) and the yearly investment in terms of deferred distribution (I_{DP}), the utility cost can be obtained by dividing the difference between the yearly investment without PV and the yearly investment with PV by the distribution capacity (C_D). This utility cost can be called the deferred cost per kW of solar. This deferred cost per kW of solar is discounted by the discount factor (F), multiplied by the solar PV capacity, and summed up over the analysis period to obtain the avoided distribution capacity cost.

$$U_C = \frac{I_D - I_{DP}}{C_D} * F * C_{PV} \tag{22}$$

$$V_7 = \sum_0^i U_C \tag{23}$$

2.8. Avoided environmental cost (V_8)

The three major pollutants that are considered in the calculation of the avoided environmental cost (V8) [$] are: greenhouse gases (GHGs), pollutants sulfur dioxide, nitrogen oxide, and hazardous particulates [80].

The two parameters that influences the cost linked to CO_2 and other greenhouse gasses' emission are the social cost of CO_2 and the gas emission factor [81]. With these two variables, the cost of avoided CO_2 can be calculated in dollars and then the real value linked to this cost is obtained by converting the previously calculated value in current value of dollars. This is done by multiplying the externality cost of CO_2 by the consumer price index (CPI) [82]. The obtained result is then multiplied by the general escalation rate for the following years [80]. The cost of CO_2 for every year is obtained by multiplying the previous value by pounds of CO_2 per kWh. The same logic is applied to the other pollutants to calculate the related costs and the cost related to all three categories of pollutant are added up to get the environmental cost (E) [$/MMBtu].

By multiplying the environmental cost by the solar heat rate (H_S), the utility cost (U_C) is obtained. An environmental discount factor (F_E) is applied to the utility factor. The environmental discount factor (F_E) is defined as follows [83]:

$$F_E = \frac{1}{(1 + D_E)^n} \tag{24}$$

Here, D_E is the environmental discount rate taken from the Social Cost of Carbon report [81].

$$U_C = E * H_S * F_E * O \tag{25}$$

$$V_8 = \sum_0^i U_C \tag{26}$$

2.9. Avoided health liability cost (V_9)

The use of solar PV systems prevents part of the emissions of pollutants from getting into the air. This can in turn result in great health benefits. The harmful pollutants that greatly impact human health are NO_x and SO_2. These two chemicals react with other compounds when they are released in the air to form a heavy and harmful product that is called particulate matter $PM_{2.5}$, [84–86]. Particulate matter $PM_{2.5}$, can cause diseases such as lung cancer and cardiopulmonary diseases [87]. It is difficult to evaluate the cost related to the avoided health liabilities and the saved lives. Several works have investigated the calculation of the cost of human health related to electricity production through fossil fuels [88–91]. Nevertheless, the most relevant approach is the work of [91] because the methods accounts for changes of the cost at a regional and plant level. This has been made possible because of data collected by EPA on the emission level of facilities through the Clean Air Markets Program. The result obtained by Ref. [91] is conservative as it does not include environmental impacts over the long term (e.g. climate change) [66,68,69,92]. The calculation of the cost of health liability by Ref. [91] depends on the quantity of pollutants emitted [tons/year] during a year, the cost of a unit mass of emission for each pollutant in [$/tons], and the annual gross load [kWh/year].

The health cost of energy produced by fossil fuel sources (C_H) [$/kWh] obtained by Ref. [91] are used to calculate the utility cost. The utility cost (U_C) is the product of the health cost by the PV systems output (O), that is discounted by the environmental discount factor (F_E).

$$U_C = C_H{*}O{*}F_E \tag{27}$$

The avoided health liability cost (V_9) [$] is then calculated by:

$$V_9 = \sum\nolimits_0^i U_C \tag{28}$$

2.10. Value of solar (VOS)

There are three different ways to represent the value of solar. It can be expressed either as the annual cost [$] over the analysis period or the lifetime of the installed solar photovoltaic system, or as the cost per unit of solar PV power installed [$/kW], or finally as the cost of generated electricity by the solar system [$/kWh] [58]. The most commonly used metric to express the VOS is the cost of electricity generated by the solar system [$/kWh] because it is user friendly and is the same metric used by utilities on electricity bills [58]. To calculate the levelized value of VOS per kilowatt-hour of electricity produced, the sum of the value of all the avoided cost is calculated and then divided by the total amount of energy produced (O) during the analysis period discounted by the discount factor (F).

$$VOS = \frac{V_1 + V_2 + V_3 + V_4 + V_5 + V_6 + V_7 + V_8 + V_9}{\sum_0^i (O{*}F)} \tag{29}$$

where:

V_1: Avoided O&M fixed cost.
V_2: Avoided O&M variable cost.
V_2: Avoided fuel cost.
V_4: Avoided generation capacity cost.
V_5: Avoided reserve capacity cost.
V_6: Avoided transmission capacity cost.
V_7: Avoided distribution cost.
V_8: Avoided environmental cost.
V_9: Avoided health liability cost.
O: Output of the solar PV system.
F: Utility discount factor.

3. Sensitivity

The calculation of VOS requires several parameters that come from different sources. Some parameters are location dependent, while other parameters are state dependent, and there are parameters that are utility dependent. Many of these parameters can also change from one year to another. As a result, there are wide differences in the calculation of VOS across the literature [56]. The utility-related parameters that can change from one VOS calculation to another are the number of years in the analysis period (i), the utility discount rate (D), the utility degradation rate, the utility O&M fixed, and variable costs, the O&M cost escalation rate, the hourly heat rate (H_P), the heat rate degradation rate (D_H), the reserve capacity margin (M), the transmission capacity cost (U_T), the peak load of year 1 (PL_1) and year 10 (PL_{10}), the distribution cost (Q), the distribution cost escalation factor (G_D), and the distribution capacity (C_D). Parameters such as the cost of peaker combustion turbine (I_P), the cost of combine cycle gas turbine (I_C), the heat rate of peaker combustion turbine (H_{CT}), and the heat rate of combine cycle gas turbine (H_C) can be either obtained from the utility or from the U.S. Energy Information Agency. The solar PV fleet (S) can also be obtained from the utility or by simulation using the open source Solar Advisory Model (SAM) (https://github.com/NREL/SAM) [45]. Other variables that can affect the VOS but are not controlled by the utility are the PV degradation rate (D_{PV}), the environmental discount factor (F_E), the environmental cost of conventional energy, the health cost of conventional energy, and the cost of natural gas on the energy market. Table 1 summarizes high and low estimates of the values for the variables that are required to perform a VOS calculation and the VOS component they are used to calculate.

3.1. Number of years in analysis period

The number of years in the analysis period varies and can be as low as 20 years, and as high as 30 years or more [12,57]. The typical warranty provided by solar panels manufacturer is 25 years. As a result, it is reasonable to set the lowest value of the analysis period to 25 years. Also, solar modules have proved to continue to reliably deliver energy 30 years after the installation of the system [57], therefore, 30 years has been set as the higher value of the analysis period in this study. Keyes et al. have pointed out that utility planning is often over shorter time periods (e.g. 10–20 years) [57]. However, economic decisions should be made over the entire life of the physical project not an arbitrary cutoff date [102] and there are existing methods to estimate the load growth on the utility side as it is usually done for conventional energy generators [53].

3.2. PV system degradation rate

The degradation rate of PV panels overtime depends on the location of operation as well as climate conditions (temperature, wind speed, dust, etc.). A statistical study conducted by the National Renewable Energy Laboratory [93] has found the value of the PV system degradation rate to be comprised between 0.5% and 1%. These two values are the boundaries that will be used as low and high values for the sensitivity analysis on the PV system degradation rate.

3.3. Utility discount rate

The discount rate is used to assess the change in money value overtime. This value can change depending not only on the location, but also, on the utility. A discount rate value as high as 9% can be used or a value as low as the inflation rate might be used. The discount rate used by utilities are usually in the high values, but the social discount rate is closer to the inflation rate [57]. As a result, 9% will be considered as the high-end value of the discount rate while the current inflation rate of 2.18% will be considered for the lowest value. It is important to note that the value of the inflation rate changes with time and if this value is chosen as the discount rate it should be updated regularly for new calculations of the VOS. Also, the value of the inflation rate can be subjected to ongoing events. The value of the inflation rate of 2.18% was chosen at a date before the coronavirus outbreak in the United States that is ongoing. The outbreak has brought the inflation rate to as low as

Table 1
Assumptions used for required variables for a VOS calculation.

Variable	High estimate	Source	Low estimate	Source	VOS components
Degradation rate of PV (D_{PV}) [%]	1	[93]	0.5	[57,93,94]	All components
Distribution capacity (C_D) [kW]	429,000	[95]	237,000	[95]	Avoided distribution cost (V_7)
Distribution cost (Q) [$/kW]	1104	[95]	678	[95]	Avoided distribution cost (V_7)
Environment discount rate (D_E) [%]	2.5	[81]	5	[81]	Avoided environmental cost (V_8)
Environmental Cost (E) [$/metric tons of CO_2]	[62–89]	[81]	[12–23]	[81]	Avoided environmental cost (V_8)
Health cost of natural gas (C_H)[$/kWh]	0.025	[91]	0.025	[91]	Avoided health liability cost (V_9)
Heat rate degradation rate (D_H) [%]	0.2	[96]	0.05	[96]	•Avoided fuel cost (V_3) •Avoided environmental cost (V_8)
Heat rate of combined cycle gas (H_C) [Btu/kWh]	7627	[97]			•Avoided generation capacity cost (V_4) •Avoided reserve capacity cost (V_5)
Heat rate of peaker combustion turbine (H_{CT}) [Btu/kWh]	11,138	[97]			•Avoided generation capacity cost (V_4) •Avoided reserve capacity cost (V_5)
Installation capital cost of combined cycle gas turbine (I_C) [$/kW]	896	[98]			•Avoided generation capacity cost (V_4) •Avoided reserve capacity cost (V_5)
Installation cost of peaker combustion turbine (I_P) [$/kW]	1496	[98]			•Avoided generation capacity cost (V_4) •Avoided reserve capacity cost (V_5)
Load Growth Rate (K) [%]	1.17	[99]	−0.94	[99]	Avoided distribution capacity cost (V_7)
Number of years in analysis period	30	[57]	25	PV industry warranties	All components
Reserve capacity margin (M) [%]	36	[100]	13	[100]	Avoided reserve capacity (V_5)
Solar Heat Rate (H_S) [Btu/kWh]	8000	[53]			•Avoided fuel cost (V_3) •Avoided generation capacity cost (V_4) •Avoided reserve capacity cost (V_5) •Avoided environmental cost (V_8)
Transmission capacity cost (U_T) [$/kW]	130.535	[101]	17.895	[101]	Avoided transmission capacity (V_6)
Utility Discount rate (D) [%]	9	[57]	2.18	[57]	•Avoided plants O&M fixed cost (V_1) •Avoided plants O&M variable (V_2) •Avoided generation capacity cost (V_4) •Avoided reserve capacity cost (V_5) •Avoided transmission capacity cost (V_6) •Avoided distribution capacity cost (V_7)
Utility fixed O&M cost (U_F) [$/kW]	18.86	[95]	7.44	[95]	Avoided O&M fixed cost (V_1)
Utility variable O&M cost (U_V) [$/kWh]	0.01153	[95]	0.00216	[95]	Avoided O&M variable cost (V_2)

0.25%. This value will not be used to run a sensitivity analysis because of the special conditions in which it occurred.

3.4. Environmental cost

The environmental cost associated with electricity production through conventional energy sources depends on the cost associated with the pollution from carbon dioxide (CO_2), carbon monoxide (CO), nitrogen oxide (NO_x), and hazardous particulates (PM). The environmental cost of carbon dioxide dominates the cost of the other components. Different estimates of the CO_2 cost are given by the EPA [81]. The cost of CO, NO_x, and PM depends on state laws. The lowest value and highest value used for the cost of CO, NO_x, and PM were chosen from the state of Minnesota [103]. It has been hypothesized that if conventional energy sources are being used to produce electricity in the future, the effects on environment are going to worsen (e.g. lower quality fuel, higher embodied energies, etc.), therefore the environmental cost will be expected to increase. This will be investigated by raising the environmental cost while analyzing the sensitivity of VOS to the environmental cost. This will show the trend of the impact of the environmental cost on the VOS and in the future, the values will need to be updated because the environmental cost is likely to exceed the maximum used value in this study.

3.5. Health liability cost

The health liability cost is a new calculated VOS component introduced by this study. This component has been mentioned by several studies but was not incorporated in the calculation due to lack of data for the evaluation [57,66,67,104]. The health and mortality impacts of coal in particular are so severe an ethical case can be made for the industries elimination [105]. For example, Burney estimated that 26,610 American lives were saved between 2005 and 2016 by a conversion of coal-fired units to natural gas in the U.S [106]. More lives as well as non-lethal health impacts would be avoided with a greater transition from coal to solar [70]. The values used here were obtained from the study of [91] that found the value of health impact cost of natural gas to be $0.025/kWh. As previously hypothesized, the use of fossil fuel energy sources in the future will increase the emissions, and the cost of health care has been escalating faster than inflation [106] thus increasing the cost of derived health liability. Several increase rates will be investigated. Although it should be pointed out the approach taken here was extremely conservative as the potential for climate/greenhouse gas emission liability [107,108] was left for future work as discussed below.

3.6. Other parameters

The other parameters are utility related and in case of absence of utility data, generic values from the U.S. government agencies is used as indicated in Table 1 and run through realistic percent increases or decreases to determine their effect on the VOS components.

3.7. Sensitivity analysis

A sensitivity analysis has been run on each of the nine VOS components as well as on the VOS. For each component, the sensitivity has been analyzed for some of its parameters wherever data was available. The evaluation of the variability of the VOS components has been performed for each parameter. The sensitivity of a component to one of its parameters is determined by maintaining an average value of the other parameters and varying the studied parameter from its lowest value to its highest value. The different values that are obtained for the VOS component are then plotted to show its variation according to the parameter studied. A correlation study between the different parameters has not been conducted because there was no evident relationship between these parameters. Most of the parameters are set by the utilities and is often not disclosed openly. An interaction study between the parameters and how their interaction affects the VOS components would be interesting for future studies where utility data are available.

A similar process has been used for the sensitivity analysis of the main VOS. The main VOS's variability has been studied according to the nine VOS components. For each component for which the sensitivity of the VOS is analyzed, average values of the other components are maintained while the studied component's value is varied from its lowest value to its highest value.

4. Results and discussion

The simulation results are plotted first for each VOS components. For each component, sensitivities on the different input variables have been investigated. Then the sensitivity of the overall VOS to each of the VOS components has been analyzed.

4.1. Avoided O&M fixed cost (V_1)

Fig. 1 shows the results for the avoided O&M fixed cost (V_1). The sensitivity has been plotted for five parameters: the utility O&M fixed cost, the utility O&M cost escalation, the PV degradation rate, the utility discount rate, and the utility degradation rate. According to the results, the avoided O&M cost is highly sensitive to the utility O&M fixed cost and O&M cost escalation. When the utility O&M fixed cost increases, the avoided O&M cost increases accordingly and an increase in the O&M escalation rate obviously increases the avoided O&M cost because it increases the utility fixed O&M cost over the analysis period. V_1 is also sensitive to the utility discount rate and decreases when the discount rate increases. This means that using a discount rate close to the social discount rate while conducting a VOS study will increase the avoided O&M cost while using a higher discount rate will lower the cost. This is in accordance with the recommendation of [57] that is the use of a discount rate lower than that of the utility in a distributed solar generation economic calculation. Also, the avoided O&M fixed cost is not very sensitive to the utility degradation rate or the PV degradation rate. Nevertheless, its value is slightly reduced when the PV degradation rate increases.

4.2. Avoided O&M variable cost (V_2)

The parameters for which the avoided O&M variable cost's (V_2) sensitivity has been studied are: the utility O&M variable cost, the utility O&M cost escalation, the PV degradation rate, and the utility discount rate. The sensitivity of the avoided O&M to its parameters are plotted in Fig. 2. Fig. 2 shows a similar variation trend of V_2 as compared to the case of the avoided fixed O&M cost. It is highly sensitive to the utility variable O&M cost, and the O&M cost escalation. The avoided variable O&M cost increases when the variable O&M, or the O&M cost escalation rate is increased but decreases with the increase of the discount rate, and the PV degradation rate.

4.3. Avoided fuel cost (V_3)

In the case of the avoided fuel cost (V_3), the variable considered for the sensitivity analysis are the heat rate degradation rate, the natural gas price fluctuation rate and the PV degradation rate. While the avoided fuel cost has shown to be not very dependent on the heat rate degradation rate or the PV degradation rate, this value changes very quickly with a change in the natural gas price as in Fig. 3. This is an important factor that should be carefully considered while conducting a VOS study because the price of natural gas is not fixed and varies according to

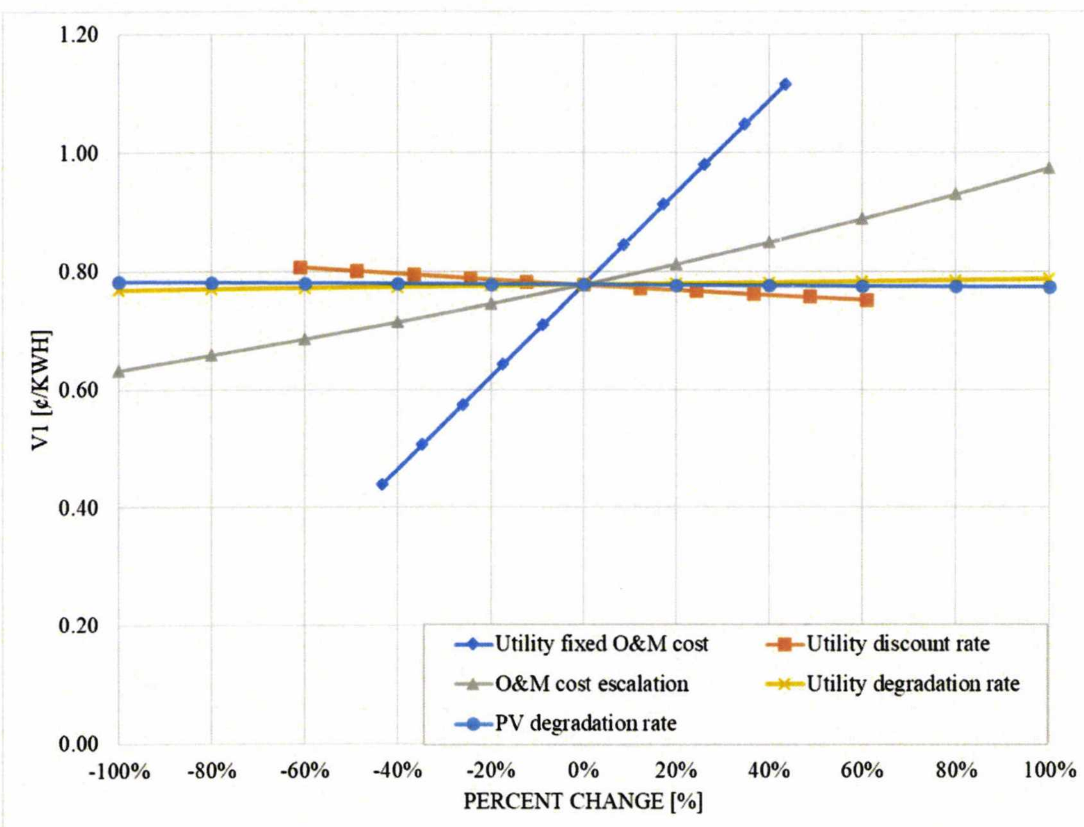

Fig. 1. Sensitivity of avoided O&M fixed cost (V_1) in terms of LCOE (¢/kWh) to its parameters in percent change.

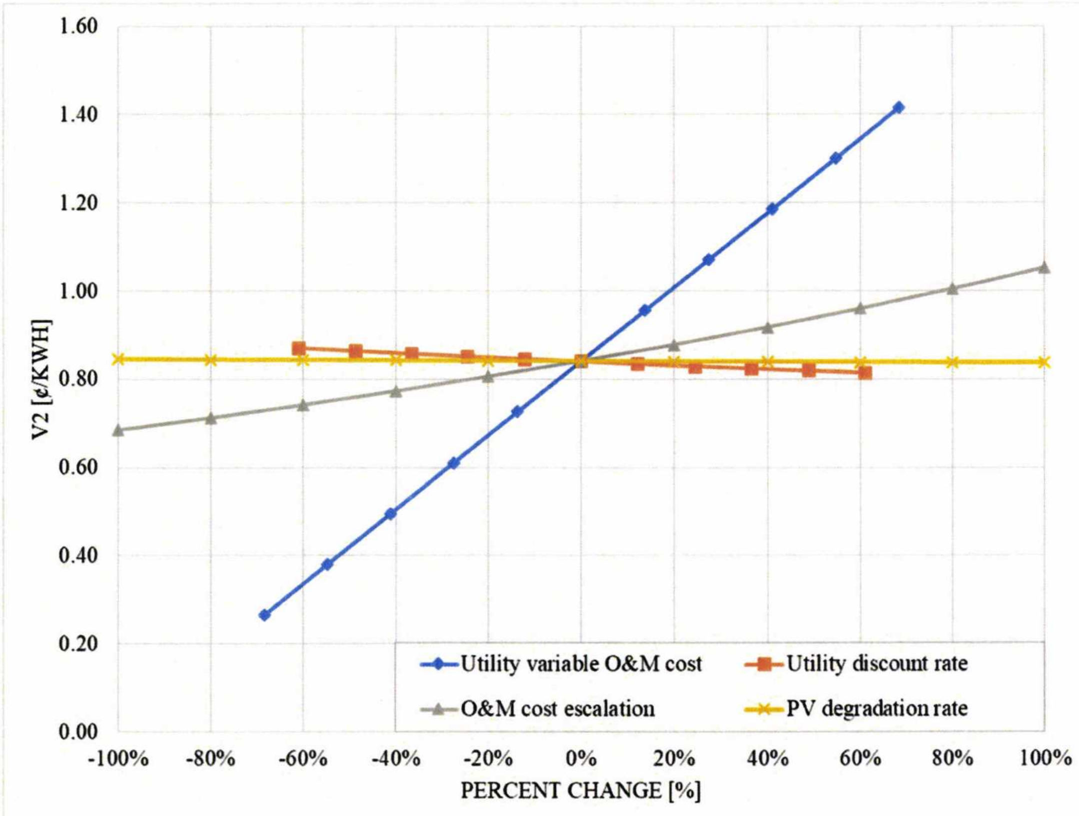

Fig. 2. Sensitivity of avoided O&M variable cost (V_2) in terms of LCOE (¢/kWh) to its parameters in percent change.

several parameters that are not controlled by the utility such as, the economy, the weather, market supply and demand [109,110]. The equivalent heat rate degradation rate expresses the degradation of the utility plant's efficiency over the analysis period and when the efficiency decreases, there is a slight decrease in the avoided fuel cost. Another value for which the avoided fuel's sensitivity could have been studied is the equivalent heat rate for solar, which was not analyzed in detail here because of the lack of utility data. This is left for future work.

4.4. Avoided generation capacity cost (V_4)

The sensitivity of the avoided generation capacity cost (V_4) has been plotted in Fig. 4 for the discount rate, the utility degradation, and the PV degradation rate. The V_4 VOS component does not have a high variability to the PV degradation rate even though it shows a decreasing trend with the increase of PV degradation. But it reacts sharply to the utility degradation rate. This is because the generation capacity of the utility is highly impacted by the utility degradation. Also, as previously observed, when the discount rate grows far from the social discount rate, the avoided generation capacity cost decreases.

4.5. Avoided reserve capacity cost (V_5)

The avoided reserve capacity cost (V_5) expresses the reserve component of the generation capacity; therefore, it can have a value of zero when there is no reserve capacity planned by the utility as shown in Fig. 5. V_5 is highly sensitive to the reserve margin and the result shows that the more generation capacity is reserved, the more the avoided generation capacity cost increases. On the other hand, the avoided reserve capacity cost is not very sensitive to the discount rate compared to its sensitivity to the other parameters. V_5's value goes up when the utility degradation rate increases and goes down when the PV degradation rate increases.

4.6. Avoided transmission capacity cost (V_6)

Three parameters have been analyzed in the sensitivity study of V_6: the discount rate, the transmission capacity cost, and the PV degradation rate. The parameter it is the most sensitive to is the transmission capacity cost. Obviously, when the transmission is low cost in a location, the avoided cost associated will be low. The results shown in Fig. 6 make it clear that the avoided transmission capacity cost does not change with the PV degradation rate or the discount rate. This is because the utility transmission capacity has been assumed to be constant over the analysis period, and the transmission capacity degradation rate has not been considered because utility data on this parameter was not available.

4.7. Avoided distribution capacity cost (V_7)

The avoided distribution capacity cost (V_7) is one of the most complicated VOS components to evaluate. As shown in Fig. 7, its sensitivity has been studied for six variables: the load growth rate, the distribution capacity, the distribution capacity cost, the utility discount rate, the distribution cost escalation, and the PV degradation rate. But it depends on more than six parameters. The growth rate, for example is calculated from utility data, mainly, the load for the past ten years of operation [45,111]. Here, the sensitivity has been analyzed on the growth rate directly to be as widely applicable as possible. Another parameter is the number of deferred years that is also a utility owned data.

The avoided distribution capacity cost naturally increases with the distribution capital cost. Fig. 7 shows that the avoided distribution capacity cost does not fluctuate with the distribution capacity at all, but it is highly sensitive to the discount rate, the distribution cost, and the

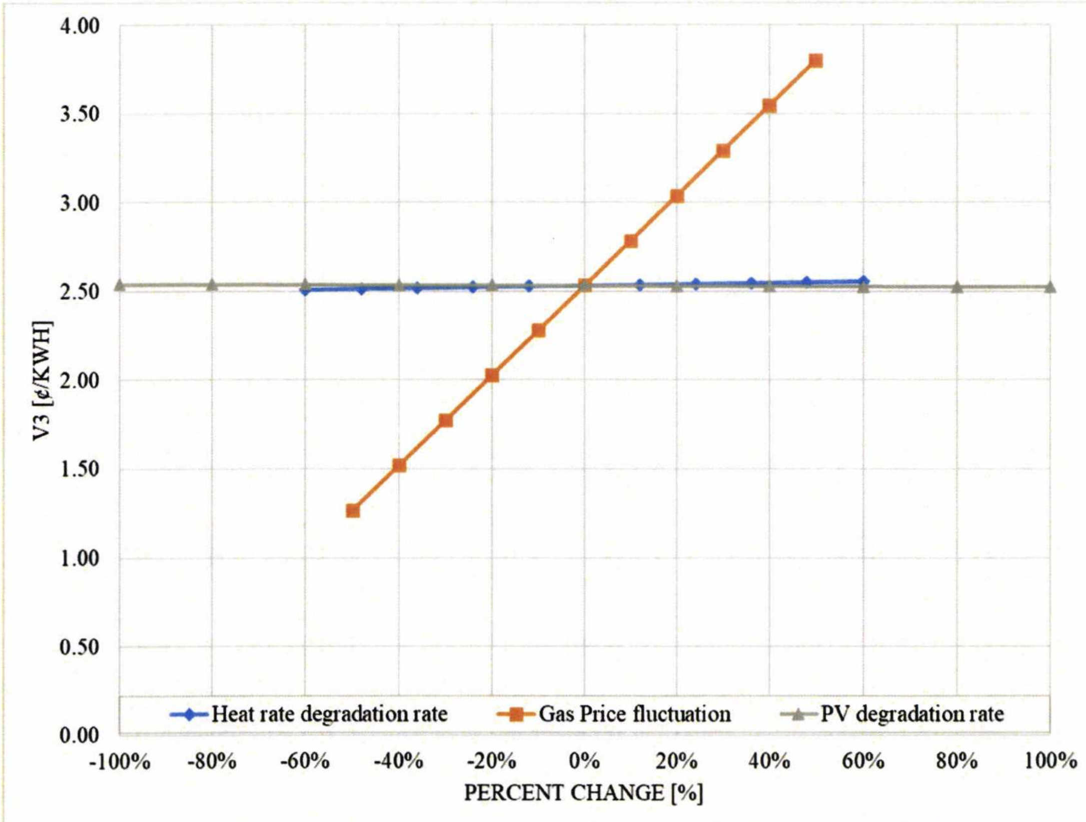

Fig. 3. Sensitivity of avoided fuel cost (V_3) in terms of LCOE (¢/kWh) to its parameters in percent change.

distribution cost escalation rate. It can even shift to a negative value when the discount rate is too low. This shows that choosing the discount during a VOS study must be a trade-off between the social discount rate and the utility discount rate. It is interesting to note that the avoided distribution capacity cost goes down when the distribution cost escalation in increasing. A possible explanation for this observation is that when a utility has enough distribution capacity, it will purchase less power from solar PV systems owners, therefore the price goes down. The same reasoning can be used to explain the decreases of the cost when the load growth goes up. Finally, V_7 shows a slight decrease with the increase of the PV degradation rate.

4.8. Avoided environmental cost (V_8)

The second most complicated component of the VOS calculation is the avoided environmental cost (V_8). The sensitivity has been analyzed for the three environmental discount rate scenarios provided by the EPA [81]. For each scenario, a sensitivity analysis has been conducted on the environmental cost increase rate. V_8 will increase when the chosen environmental discount rate is low but overall, each of the three EPA scenarios show an increase when the environmental cost increase rate goes up as seen in Fig. 8. This is useful to see how the avoided environmental costs might change in the future. Environmental externalities are volatile and changing quickly [66]. If it is assumed that in the future, the environmental impact of conventional energy production technologies will increase, then the costs of the environmental externalities will increase as well [104]. On the other hand, an increase in distributed renewable energy generation could lead to a decrease or stabilization of the avoided environmental cost.

4.9. Avoided health liability cost (V_9)

The avoided health liability cost, V_9, depends on three values, the health cost increase rate, the environmental discount rate, and the PV degradation (see Fig. 9). This cost does not fluctuate with the PV degradation rate but is very sensitive to the other two parameters. The environmental discount rate used here is the same as the environmental discount rate used in the evaluation of the avoided environmental cost's sensitivity study. As a result, the avoided health liability cost decreases when the environmental discount rate goes up as is the case for the avoided environmental cost.

4.10. VOS

After the sensitivity analysis of each VOS component, the main VOS value has been studied to find out how the impact of different components compare to one another and which components have more variability. Fig. 10 shows that the VOS is, in decreasing order, sensitive to the avoided environmental cost (V_8), avoided health liability cost (V_9), avoided transmission capacity cost (V_6), avoided fuel cost (V_3), avoided distribution capacity cost (V_7), avoided O&M variable cost (V_2), avoided reserve capacity cost (V_5), avoided O&M fixed cost (V_1), and avoided generation capacity cost (V_4)

The contribution of each VOS component to the overall VOS depends on the case. The lowest VOS value calculated with the assumptions used in this study in term of LCOE is 9.37¢/kWh while the highest value calculated is 50.65¢/kWh. This variation observed in the VOS value comes from the fact that the parameters values considered from this study are chosen to have the lowest and the highest value of a VOS. The values of calculated VOS using utility data are highly likely to be located within this interval. It is also clear based on the values shown in Fig. 10, that the VOS exceeds the net metering rates (when they are even

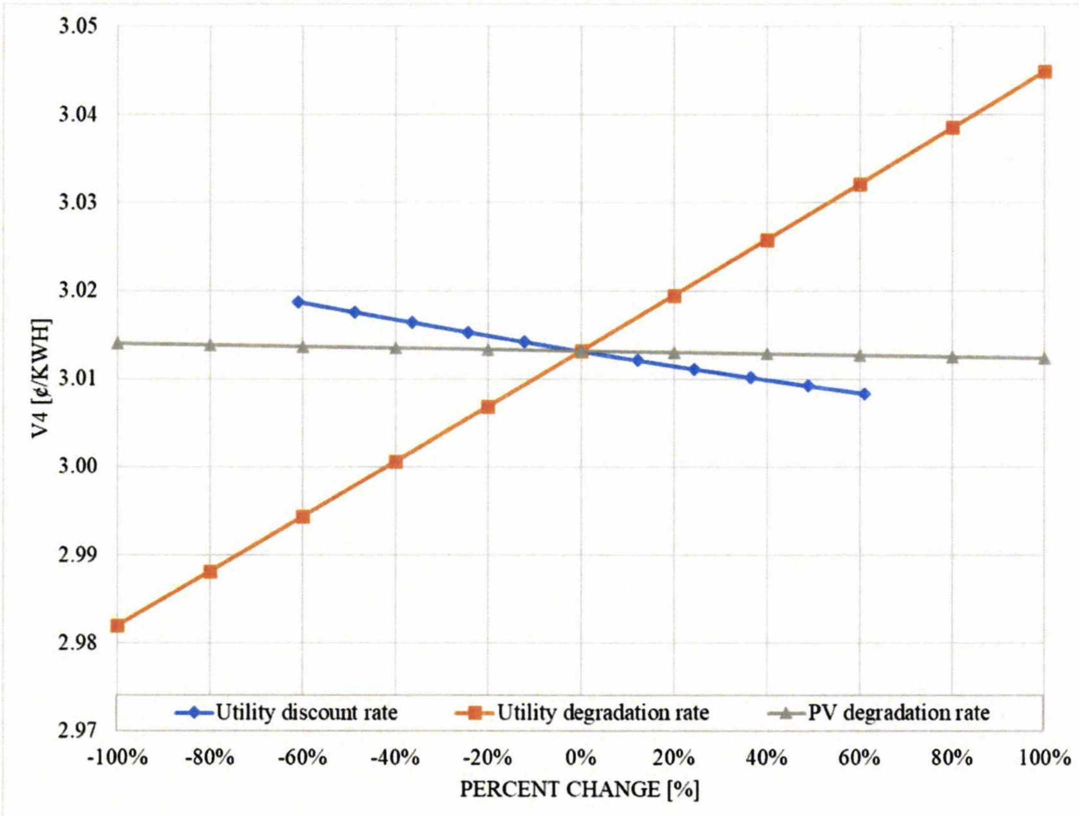

Fig. 4. Sensitivity of avoided generation capacity cost (V_4) in terms of LCOE (¢/kWh) to its parameters in percent change.

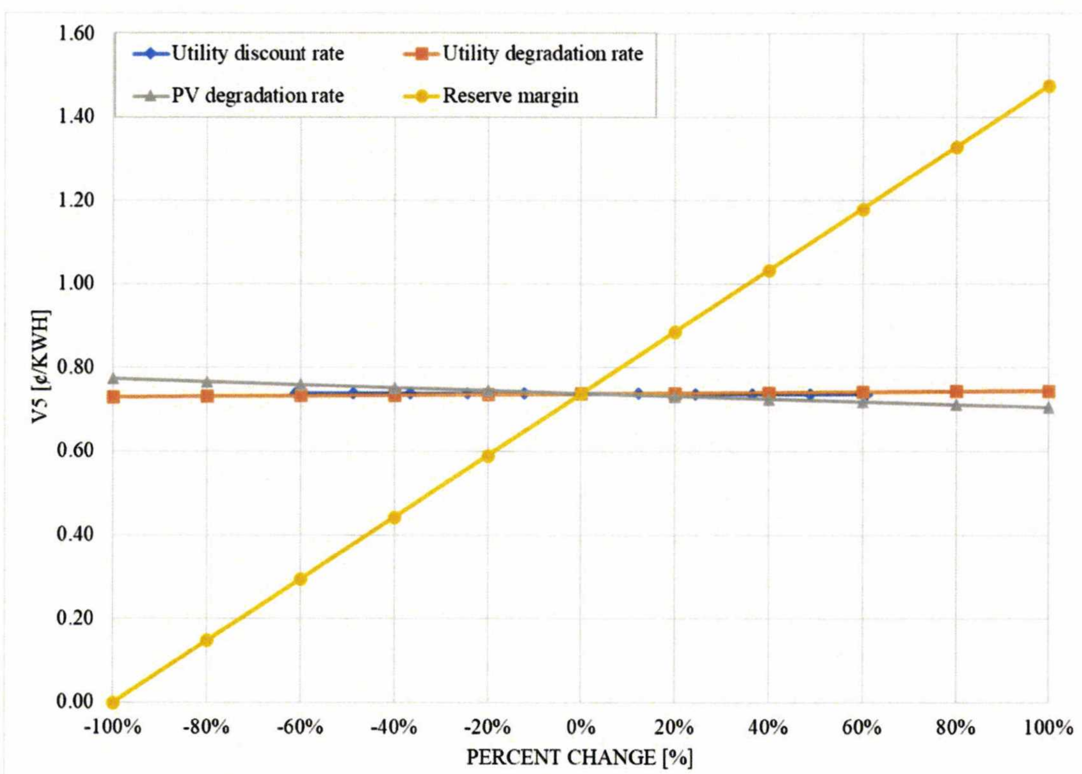

Fig. 5. Sensitivity of avoided reserve capacity cost (V_5) in terms of LCOE (¢/kWh) to its parameters in percent change.

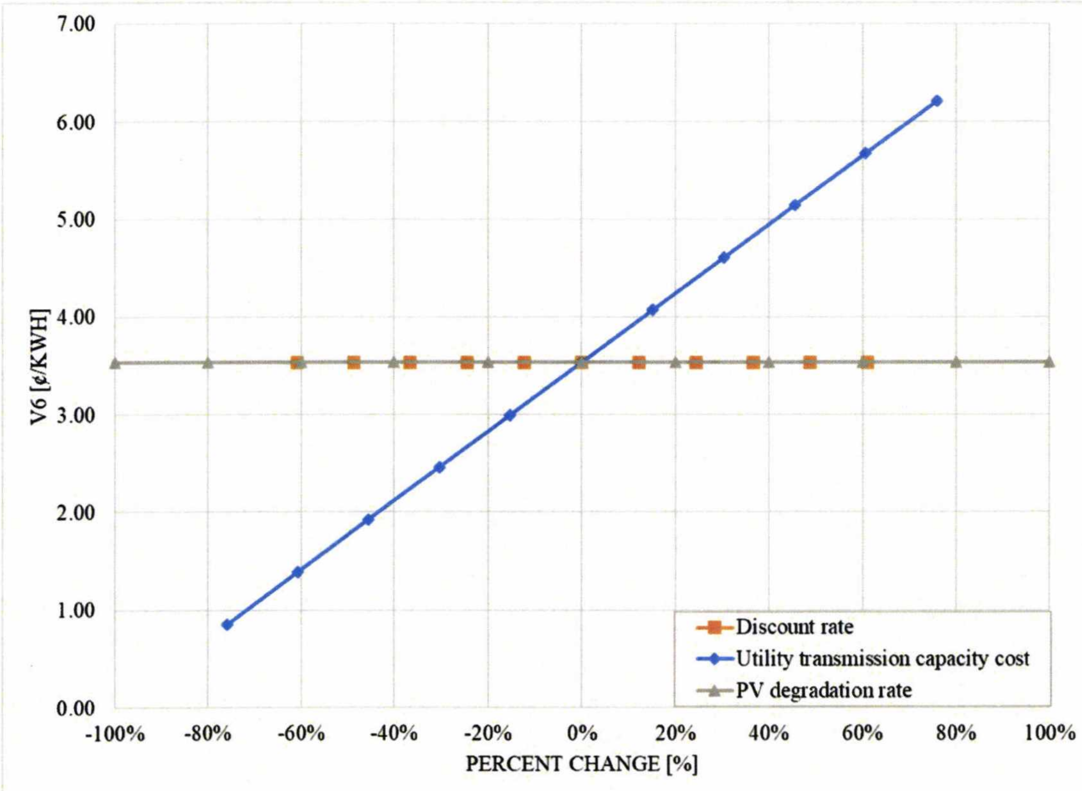

Fig. 6. Sensitivity of avoided transmission capacity cost (V_6) in terms of LCOE (¢/kWh) to its parameters in percent change.

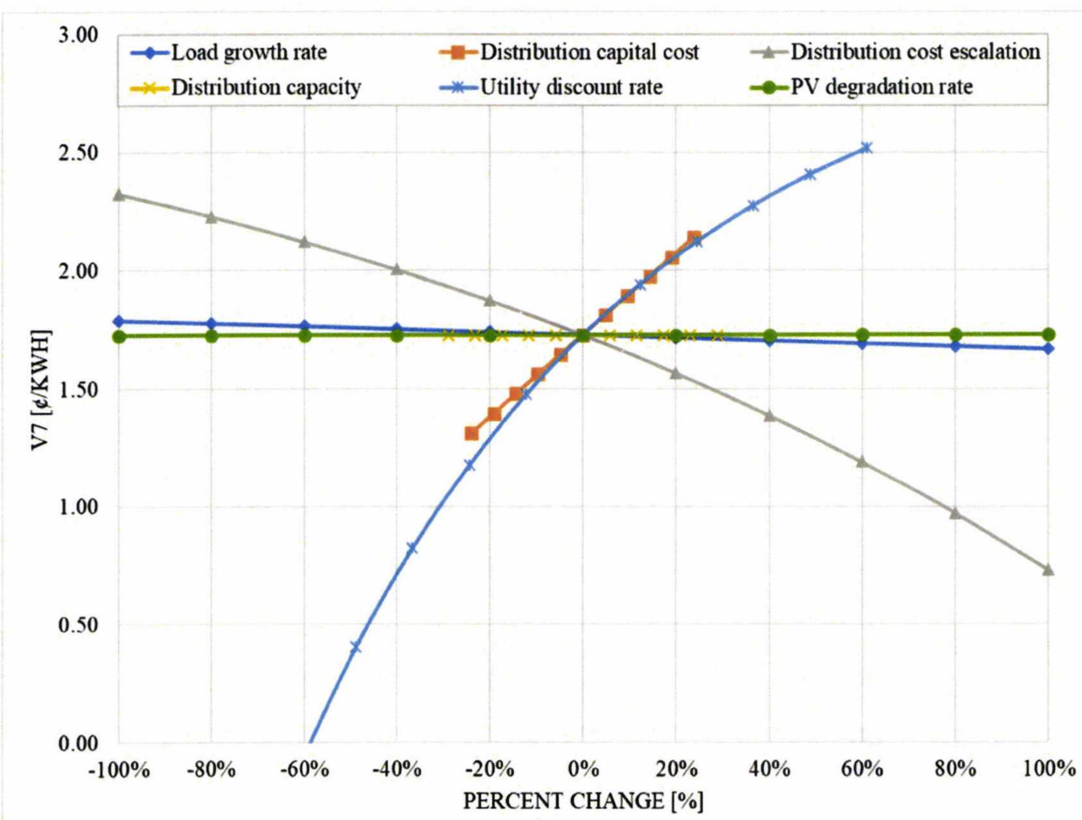

Fig. 7. Sensitivity of avoided distribution capacity cost (V_7) in terms of LCOE (¢/kWh) to its parameters in percent change.

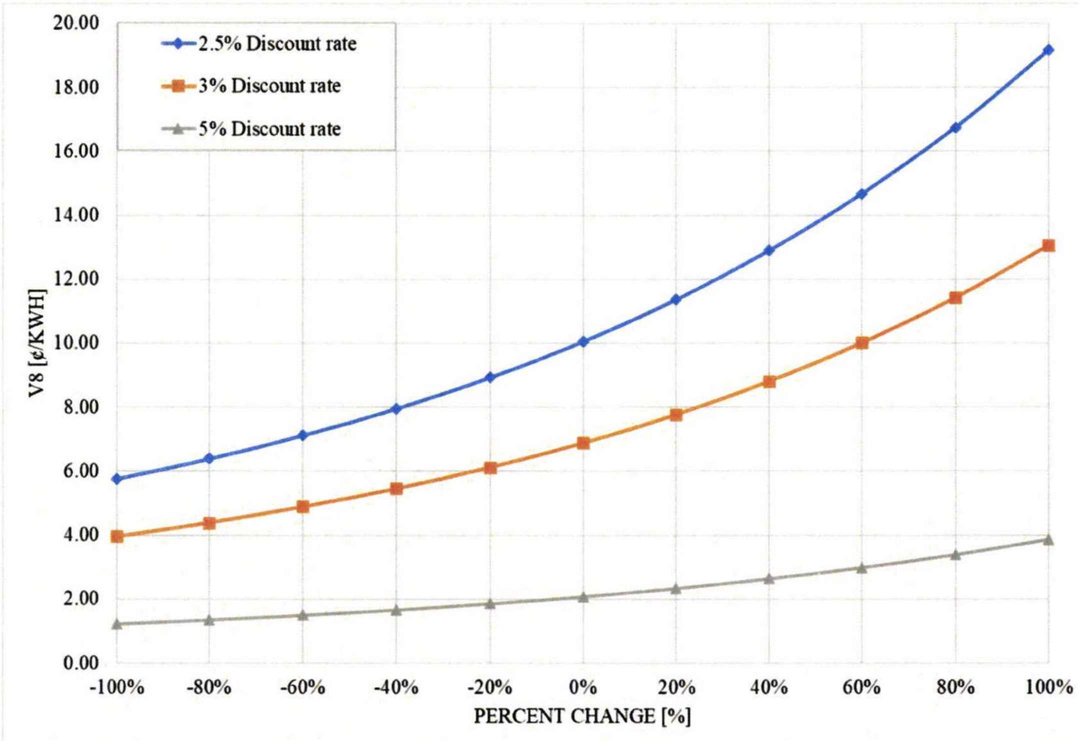

Fig. 8. Sensitivity of avoided environmental cost (V_8) in terms of LCOE (¢/kWh) to its parameters in percent change.

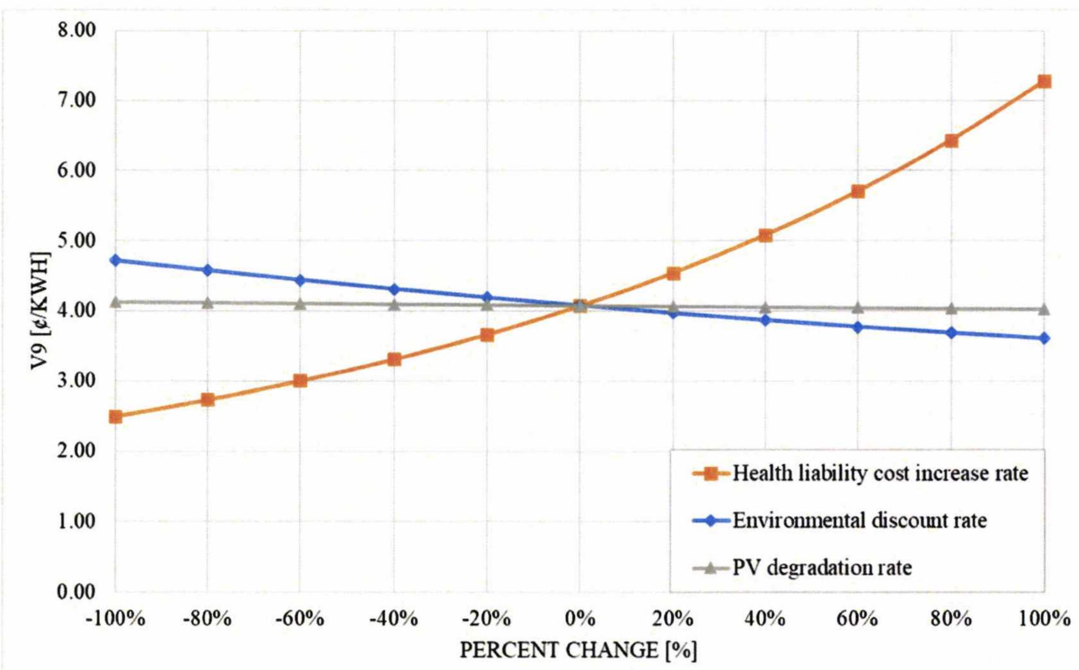

Fig. 9. Sensitivity of avoided health liability cost (V_9) in terms of LCOE (¢/kWh) to its parameters in percent change.

available as shown in Table 2) in the U.S. Thus, it can be concluded that even when grid-tied solar owners are provided with a full net metered rate for electricity fed back onto the grid they are effectively subsidizing the electric utility/other customers.

For the low VOS value case shown in Fig. 11, the avoided distribution cost (V_7), and the avoided reserve capacity cost (V_5) has no contribution in the VOS value. The avoided generation capacity cost (V_4) and the avoided health liability cost (V_9) represent most of the VOS value followed by the avoided environmental cost (V_8) and avoided fuel cost (V_3).

The contribution of the avoided environmental (V_8) cost increases with the VOS value as it becomes the largest contributor to the overall

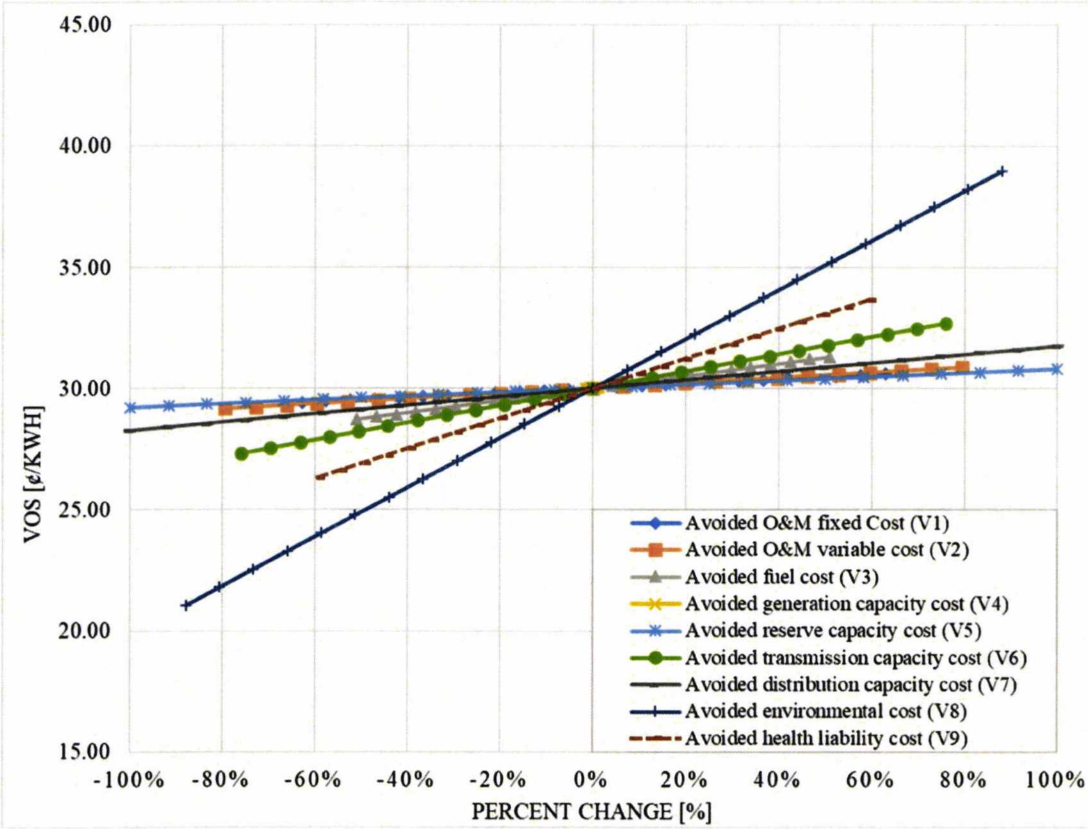

Fig. 10. Sensitivity of VOS LCOE (¢/kWh) to all the components in this study, in percent change.

Table 2
Comparison of VOS rates and net metering rates for some U.S. States.

State	VOS	Net Metering
Minnesota	13.5¢/kWh	
Austin (Texas)	10.7¢/kWh	Approximately 4–5¢/kWh (1.2–1.6$/kWh) [113]
Maine	33.7¢/kWh	12.16–14.66¢/kWh [114]
New Jersey	25.6–28¢/kWh	
Pennsylvania	28.2–31.8¢/kWh	Minimum value of (4¢/kWh) [115]
Washington D. C.	19.4¢/kWh	

value followed by the health liability (V_9) cost as shown in Fig. 12 representing a middle VOS value. The avoided generation capacity cost's (V_4) is reduced as well as the contribution of the avoided fuel cost (V_3).

Fig. 13 represents the contribution of each of the VOS components to the overall value in the case of the highest obtained value in the scope of this study. The avoided environmental cost (V_8), avoided health liability cost (V_9), and avoided transmission capacity cost (V_6) represent 69% of the total cost.

The evolution of the cost percentage contribution of each VOS throughout Figs. 11, Figure 12, and Fig. 13 shows the level of uncertainty of the VOS in respect to the corresponding component.

The lowest and highest LCOE VOS values obtained from the assumptions made in this study are respectively 9.37¢/kWh and 50.65¢/kWh. The existing VOS studies results fall into this interval. The sample calculation made by Ref. [45] for Minnesota is 13.5¢/kWh while [46] calculated a VOS of 10.7¢/kWh for Austin Energy. These values are in the lower spectrum of the result of this study because of the considerations made. They incorporate less VOS components than the present study, and this study focuses on sensitivity, therefore higher values of parameters have been considered. Other results summarized by Ref. [47] have found the VOS to be 33.7¢/kWh in Maine, between 25.6 and 31.8¢/kWh in New Jersey and Pennsylvania [48], and 19.4¢/kWh in Washington DC. In general, the VOS is much higher than the net metering costs as even the highest costs observed at the residential level pay [50,62,112]. The residential net metering rates are also the highest as compared to commercial and industrial rates so the latter two are even more unjustly compensated for installing solar. Overall, this indicates that utilities are under-compensating customers with grid-connected PV systems if they are only paying net metering rates, as displayed in Table 2. Table 2 shows a comparison between VOS rates and net metering rates in the U.S. states mentioned above, wherever data is available. As only a tiny fraction of utilities (3%) are paying full net metering rates anyway [43], there is a need for regulators to ensure that solar customers are being adequately compensated for the value of solar electricity they are sharing with the grid [42]. Substantial future work is needed to ensure that solar PV owners are not subsidizing non-solar electricity customers.

5. Future work

This study has covered a vast number of existing VOS components, but some components were not included in this study due to the lack of a reliable evaluation methodology. These components include the economic development cost, the avoided fuel hedge cost, and the avoided voltage regulation cost. These represent opportunities for future work once the evaluation methodologies have been developed. Also, there are some parameters sensitivities that would provide insights with multiple utility data sets. These parameters include the analysis period, the hourly solar heat rate and solar PV fleet, and the 10-years load profile. Future studies can focus on incorporating the sensitivities of these

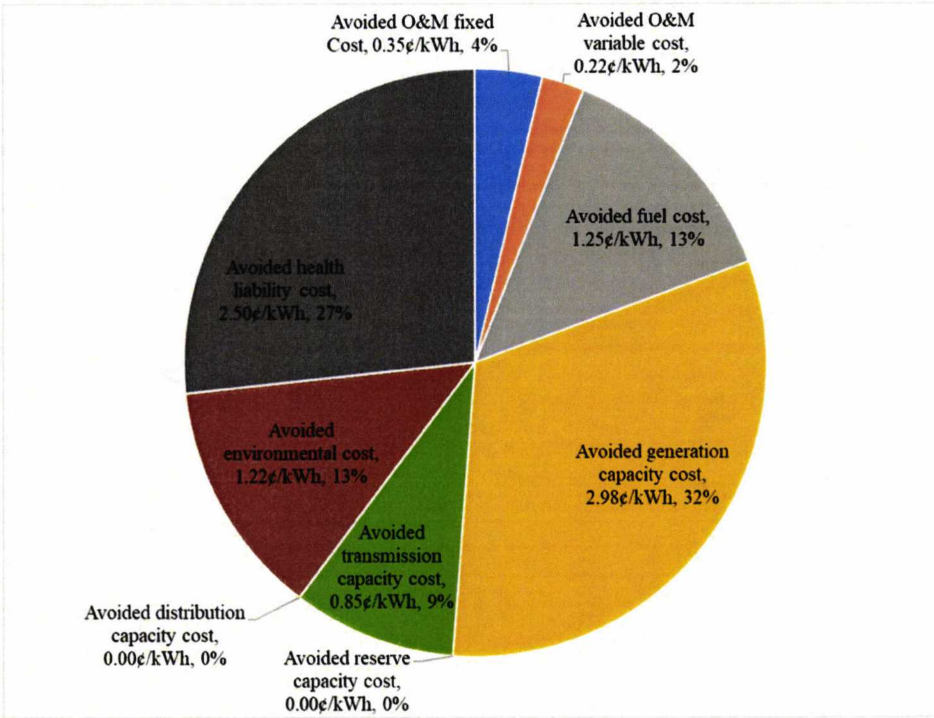

Fig. 11. Contribution of each VOS component to the overall VOS LCOE – Low Cost Scenario.

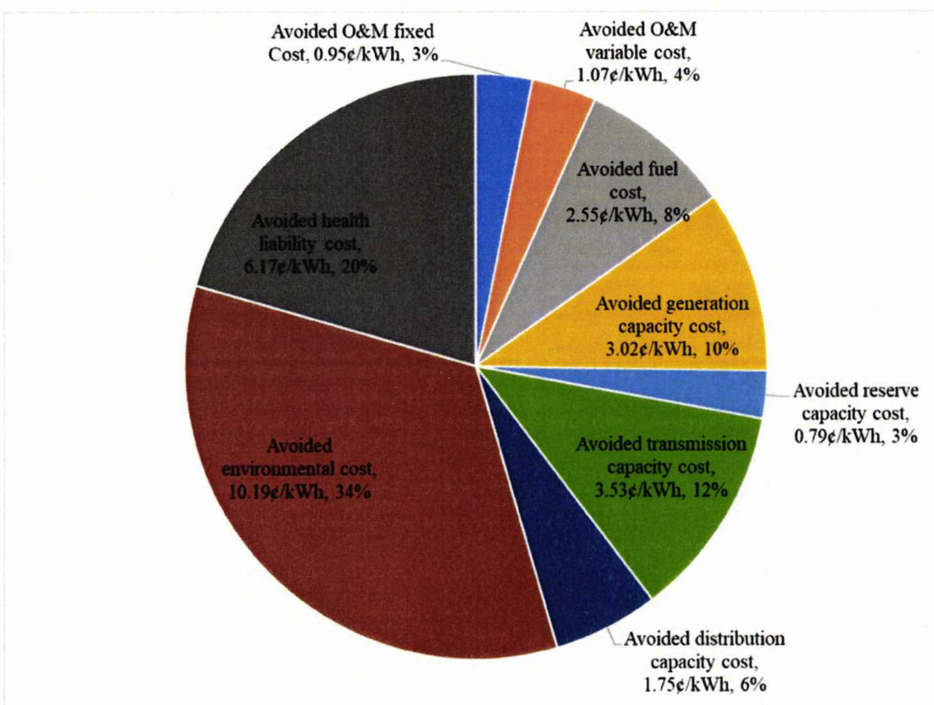

Fig. 12. Contribution of each VOS component to the overall VOS LCOE – Middle Cost Scenario.

parameters into the model or can use the foundation of this model to build on new VOS studies according to a specific location and available data from utilities. Another limitation to this study is that it does not include the effect of the load match factor, and loss saving factor.

As the results show the environmental and health costs can dwarf the technical costs and thereby determine the VOS. There are also second order effects that can be used to obtain a more accurate VOS values. For example, the negative impact of pollution from conventional fossil fuel electricity generation on crop yields [106] as well as PV production could also be considered in future work to give a more accurate V_8. In addition, as greater percentages of PV are applied to the grid the avoided costs will change and there is a need for a dynamic VOS akin to dynamic

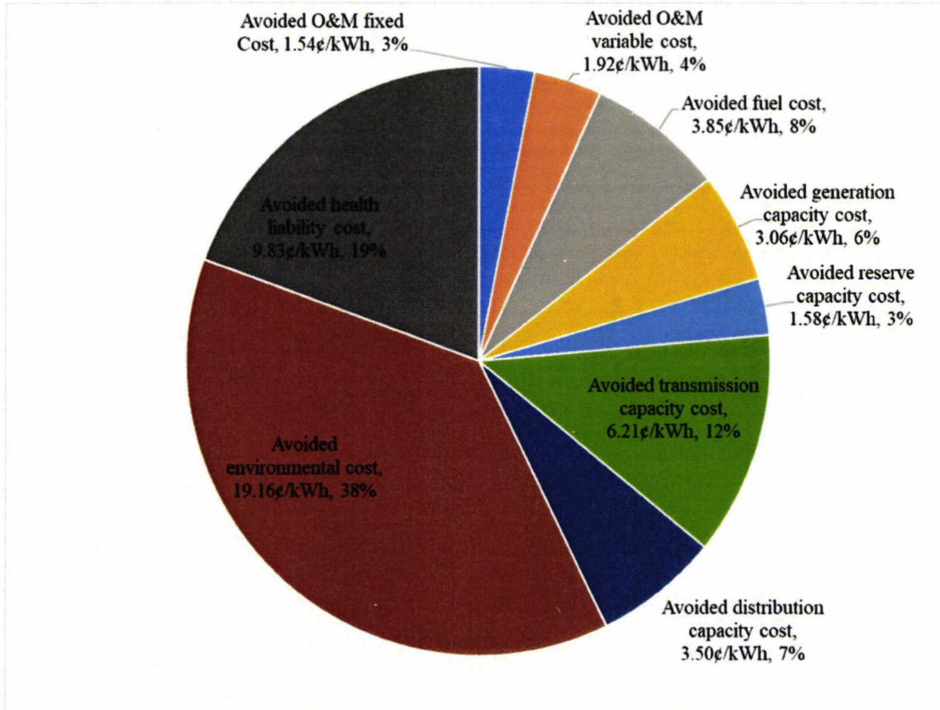

Fig. 13. Contribution of each VOS component to the overall VOS LCOE – High Cost Scenario.

carbon life-cycle analyses needed for real energy economics [116]. This complexity will be further enhanced by the introduction of PV and storage systems [117] as it will depend on size [118] and power flow management and scheduling [119,120].

Perhaps the most urgent need for future work is accurate estimations of the value of avoided GHG liability costs because the magnitude of the potential liability [107,108] could overwhelm other subcomponents of the VOS. This is because as the realities of climate change have become more established, a method gaining traction to account for the negative externalities is climate litigation [107,108,121–131]. For utility VOS analysis this is particularly complex as it is difficult to know where to draw the box around environmental costs. As some studies have concluded there is liability for past emissions as well as for harm done in other nations [122]. Liability for disastrous events is also challenging to predict [126]. Combining both other nations and disaster creates liability potential that could become enormous with prioritization given to victims that are losing their land, culture, and lives due to climate change [127]. Tort-based lawsuits are already possible from a legal point of view [126], but there are other legal methods that could be used to reduce climate change such as public nuisance laws [128]. Some authors have argued a 'polluters pay principle' for carbon emissions [129]. Other studies have concluded that emitters such as conventional fossil fuel power plant operators should be forced to buy long term insurance in order to cover their share of climate change costs for minimizing risks in case of insolvencies [130]. Determining what such insurance premiums should be is another area of substantial future work. Determining what the greenhouse gas liability costs are for conventional electricity generators (as well as potential avoided insurance costs) that can be avoided with PV is extremely challenging. These estimates will become easier with time as climate change impact studies become more granular thereby assigning specific costs to specific amounts of emissions. In addition, realizing these climate liability costs in courtrooms will become more likely. As Krane points out it is clear that as the negative impacts of climate change grow more pronounced, the fossil-fuel based electricity industry faces a future that will be less accepting of current practices and that will increase economic (and maybe even industry existential) risks [131]. Avoiding these risks has real value, which should be included in the VOS in the future.

6. Conclusions

This study demonstrated a detailed method for valuing the incorporation of solar PV-generated electricity into the grid and analyzed the sensitivity of each VOS component to its input parameters, and the overall sensitivity of the VOS to the each of its components. Several components have been found to be sensitive to the utility discount rate, namely the avoided O&M fixed cost; avoided O&M variable cost; avoided generation capacity cost, and the avoided distribution capacity cost. Except for the avoided distribution capacity, the other components' value decreases with the increase of the utility discount rate. The distribution capacity is more sensitive to the discount rate than the other components. It increases with the discount rate and can be negative if the discount rate is very low. This has shown the necessity of carefully choosing the discount rate for VOS studies. Most of the VOS values do not have a high variability to the solar PV degradation rate even though its increase slightly reduces the value of each component, and the overall VOS. The environmental cost and the health liability cost are sensitive to the cost increase rate that can be tied to the emissions impact of the conventional energy sources. These two costs are likely to increase in the future with the worsening of the emission of fossil fuel sources and more information about its effects, which increases potential emissions liability for utilities. Finally, specific case studies could provide additional sensitivities on the few areas of the VOS that were not evaluated in this paper to create better VOS models. Overall the results of this study indicate that grid-tied utility customers are being grossly under-compensated in most of the U.S. as the value of solar eclipses the net metering rate. The implications of this sensitivity analysis demand a reevaluation of the compensation for U.S. PV prosumers as the VOS is much higher than net metering or any lesser compensation schemes. Substantial future work is needed for regulatory reform to ensure that solar owners are not unjustly subsidizing U.S. electric utilities. In addition, future work can obtain an even more accurate (and higher) value of

VOS by evaluating economic development costs, the avoided fuel hedge costs, the avoided voltage regulation costs, secondary health and environmental effects such as increased crop yields from PV-reduced pollution, and accurate estimations of the value of avoided GHG liability costs or avoided GHG emissions liability insurance.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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CERTIFICATE OF SERVICE

I hereby certify that on this 13th day of October 2021, I delivered true and correct copies of the foregoing INITIAL COMMENTS to the following persons via the method of service noted:

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