A Valuation-Based Framework for Considering Distributed Generation Photovoltaic Tariff Design

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Owen R. Zinaman
National Renewable Energy Laboratory

Naïm R. Darghouth
Lawrence Berkeley National Laboratory

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Owen R. Zinaman, M.S.E
21st Century Power Partnership
National Renewable Energy Laboratory
Golden, Colorado, USA
owen.zinaman@nrel.gov

Naïm R. Darghouth, Ph.D.
Environmental Energy Technologies Division
Lawrence Berkeley National Laboratory
Berkeley, CA, USA
ndarghouth@lbl.gov

Abstract— **Distributed generation photovoltaic (DGPV) cost-benefit analyses (CBAs) can provide substantive insights into understanding the potential flows of value among stakeholders that grid-connected DGPV programs might induce. Tariff design has a significant impact on the level and accrual of such value – thus, a cost-benefit analysis is a robust starting point for stakeholder engagement and discussion on DGPV tariff design. To that end this paper outlines a holistic, high-level approach to the complex undertaking of DGPV tariff design, the crux of which is an iterative cost-benefit analysis process. We propose a multi-step progression that aims to promote transparent, focused, and informed dialogue on CBA study methodologies and assumptions. When studies are completed, the long-run marginal avoided cost of the DGPV program should be compared against the costs imposed on utilities and non-participating customers, recognizing that these can be defined differently depending on program objectives. The results of this comparison can then be weighed against other program objectives to formulate tariff options. Potential changes to tariff structures can be iteratively fed back into established analytical tools to inform further discussions.**

Keywords—tariff design, ratemaking, distributed generation, photovoltaic, solar valuation, value of solar, cost-benefit analysis

I. Introduction

Stakeholders contributing to ongoing discussions over distributed generation photovoltaic (DGPV) tariff design will often have different perspectives on how export tariffs should be structured. This divergence of perspectives may at some level stem from disparate stakeholder interests and assessments of the net costs and benefits (C&B) of DGPV programs, as well as the distribution of how and to whom those C&B accrue. As Indian regulators look to emulate recent progress in certain states in India and quickly accelerate DGPV growth, a common analytical framework, which hinges on a transparent cost-benefit analysis process, might be employed to encourage more open, informed, forward-looking discussion over tariff design. A number of Indian states, including Gujurat, Tamil Nadu, Uttarakhand, Andhra Pradesh, West Bengal, Kerala, Karnataka, among others, have set up forms of net energy metering for DGPV, and many more are in the process of designing regulatory structures to compensate DGPV. It is by applying frameworks such as the one proposed in this paper that Indian policymakers can gain a system-wide understanding of the C&B of DGPV programs given their objectives, ensuring a sustainable solar market as DGPV penetration grows in India. This framework can make use of existing evaluations of the technical issues that will need to be addressed in Indian states (such as those found in Magal et al., 2014 [1]) to quantify the C&B of DGPV.

This paper offers a high-level approach to the complex undertaking of a DGPV tariff design process, the crux of which is a program cost-benefit analysis (CBA) study.

In the context of a larger regulatory framework, we choose to focus on tariff design because of the significant impact this DGPV program design component has on the various flows of value (benefits, costs, and risks) among power sector stakeholders. In that context, this paper is organized into a series of steps that can be taken during the design of a DGPV tariff. These steps are intended to serve as a roadmap of iterative or cyclical activities rather than an explicit, linear schedule.

II. Step 1: Declare the Objectives of the Program

The energy regulator and other relevant government bodies should consider publicly declare their objectives with respect to the DGPV program, as informed by public policy mandates and other goals. Objectives typically take the form of either desired aspects or desire outcomes of the program – they range not only in importance but in tangibility and measurability. Establishing such objectives ex-ante enables tariff design discussions and options to be appropriately assessed for alignment with a transparent set of values. Table I lists examples of potential objectives of a DGPV program.

TABLE I. POTENTIAL OBJECTIVES OF A DGPV PROGRAM

Focus Areas	**Taxonomy of Potential Objectives**
	Example Objectives
Utility	preserve financial health of utility; ensure fair recovery of administrative and network infrastructure costs; establish new utility investment opportunities; efficient rate-making to ensure proper price signals to customers
PV Owner	simplicity and attractiveness of DGPV value proposition; ease of application process; incentivize deployment; responsiveness to consumer demand and financibility
Ratepayer	protection from unjust rate increases or allocation of risk; mitigation of cross-subsidization impacts among participants and non-participants; protection of low-income customers
Grid / Technical	deployment goals and timeframes; alleviation of supply shortfalls, network congestion reduction, inducing of

Focus Areas	Taxonomy of Potential Objectives
	Example Objectives
	load-shifting behavior; implementation feasibility; discourage illegal interconnections
Society	economic development and job creation; empowerment of small- or medium-size enterprises; energy security; address environmental justice concerns
Environment	global and local emissions reductions; water use and quality impact reduction

a. Some of the listed example objectives could be classified under more than one focus area

III. Step 2: Consider Program Costs and Benefits to be Analyzed

DGPV exhibits a range of C&B to various stakeholders. Table II lists a summary of those C&B, as synthesized from [2] [3] [4]. The costs and benefits of DGPV are highly dynamic quantities, changing with time and location of energy production, local (i.e. feeder) and global (i.e. system) penetration levels, as well as the performance attributes of the system (e.g. reactive power support). The methodologies employed to valuate these C&B (see Step 3) range in the granularity and accuracy for which they characterize this dynamism [5]. Furthermore, they accrue in a distinct manner to a diverse set of stakeholders.

TABLE II. Costs and Benefits of a DGPV program

Aspect	Range of DGPV Costs and Benefits
	Example C&B
Benefits	avoided utility energy costs; reduced consumer electricity bills; avoided ancillary service costs; reduced line losses; deferred/reduced utility generation, transmission, and distribution capacity investments; fuel price hedging; emissions reductions and air quality improvements; water use reductions; water quality improvements; grid security and reliability; economic development; regulatory compliance benefits
Costs	cost of DGPV system; cost of metering infrastructure; program administration; reduced utility fixed cost recovery; interconnection cost; lost margin on power re-sale; changes to conventional generator operations; distribution system upgrades; cost of enabling information and communication technology systems

In Step 2, the presence of the various DGPV costs and benefits in a prospective CBA study (see Step 4) can be publicly deliberated among relevant stakeholders and evaluated against the backdrop of the program objectives established in Step 1. Furthermore, such deliberation should be informed by the relative difficulty to robustly assess various metrics (see Step 3).

IV. Step 3: Choose Study Assumptions and Methodologies to Assess Costs and Benefits

Upon selecting which set of C&B will be included in a valuation exercise, a multi-stakeholder dialogue can then be focused on *how* selected costs and benefits are assessed, and what underlying assumptions will be used to serve as a foundation for that assessment. *C&B quantification and cost-effectiveness analyses can vary significantly based on the methodologies and input assumptions employed* – thus, careful consideration of these aspects is key to producing credible valuation estimates. For example, when quantifying the economic value of DGPV, should it displace the costs of a marginal or average generator? Will DGPV be incorporated in integrated resource planning, or will it be layered on top of already-planned systems? At what level of spatial and temporal granularity will DGPV be valuated? What stakeholder perspectives will be considered? If included, how will societal benefits such as the health impacts of reduced particulate emissions from conventional generation or improved water quality be quantified?

Denholm et. al [6] discusses the range of methodologies and tools that can be employed to generate estimates of various DGPV costs and benefits from the system perspective. For each C&B covered, approaches are described in increasing order of difficulty, with discussion focused on the relative accuracy of the approach and tools required.

Keyes and Rábago [7] outlines key study assumptions where initial discussions might be focused, such as discount rates, demand and fuel price projections, stakeholder perspectives considered, and geographic and system boundaries. They emphasize that developing a robust set of base assumptions is critical to any study, and that transparency in both methodology and assumptions is key for fostering stakeholder buy-in and program success. Non-disclosure agreements may be a necessary tool to circumvent sensitivities with utilities.

Overall, stakeholders must balance a desire for theoretical accuracy against practical considerations. Table III outlines key questions for stakeholders to consider while evaluating a particular methodology as part of the CBA process. These considerations may change as they are revisited in more mature DGPV markets. For example, the value of accuracy may not be paramount when cumulative DGPV levels are still low, but may gain importance as with increased DGPV capacity.

TABLE III. Key Considerations for Valuation

Aspect	Key Considerations for C&B Valuation Methodology Selection
	Questions
Accuracy of Estimate	How accurate will the methodology be, relative to more simple or more complex approaches?
Value of Accuracy	How much value will additional accuracy yield for the process?
Cost of Estimate	How much will it cost (in time and money) to execute the methodology in question, relative to other approaches?
Execution Feasability	Is there technical capacity available to implement this methodology? Are adequate models and data sets publicly available in acceptable timeframes?
Implementation Feasability	How equipped and willing are relevant government bodies to implement complex study results?

Facilitating a focused, transparent, and pragmatically grounded multi-stakeholder discourse will help to establish methodological transparency when CBA studies are conducted. While consensus may never be reached among stakeholders, allowing for periods of public comment, addressing concerns, and encouraging focused discussions on study assumptions and methodologies will help to articulate areas of disagreement, leaving room for consensus-building in other areas.

V. Step 4: Conduct Cost-Benefit Analysis Study

The crux of the proposed framework is the DGPV CBA study – the results of which will be used to inform not only tariff design discussions (Step 5), but continued stakeholder dialogue over CBA methodologies and input assumptions (Step 3) as study results are assessed. An iterative process is envisioned where periodic updates to study assumptions, valuation methodologies and tariff design are conducted, as informed by continued stakeholder discussions.

Depending on the scale of the geographical and temporal resolution chosen for the analysis, a variety of approaches, spanning operations and planning models to power flow simulations to financial analysis tools, can be integrated to conduct a DGPV valuation study. No one tool is capable of accurately characterizing the range of potential technical and financial impacts of a DGPV program over various timeframes and system boundaries. Thus, utilizing a combination of tools and analytical techniques is likely key for conducting a robust valuation. As a matter of process, outputs from power sector simulation tools (e.g., bulk planning or operations models, transmission or distribution power flow simulations) are often used as inputs to financial analysis tools that assess utility rate and revenue impacts, as well as stakeholder cost-effectiveness metrics such as the Utility Cost Test, Ratepayer Impact Metric, or the Societal Cost Test.

In formulating a DGPV program, regulators may also consider whether subsidies for DGPV are appropriate, and if so, the levels, types, and sources of subsidization. To this end, CBA studies can be used to understand how potential incentives and subsidies induce different levels and patterns of deployment or mitigate inequities.

A key question to explore is who will be designated to conduct the CBA study. An appropriate balance can be struck between the desire for study transparency and practicalities around capabilities and data availability. In some contexts, it may be appropriate or desirable to enroll a third party consultant, or to install an independent monitor with the utility modelling teams. Utilities typically hold the grid data necessary to perform system-perspective valuation studies but may be perceived as biased towards promoting a lower value for DGPV.

VI. Step 5: Propose Tariff Structure

Understanding various flows of value among stakeholders will enable regulators to allocate costs during a tariff design process in a manner that is aligned with their stated objectives (see Step 1). Table IV lists key components of a DGPV tariff that can be considered.

TABLE IV. Key Tariff Components

Components	**Key Tariff Components** — ***Examples***
Compensation Structure	NEM; avoided cost compensation; FIT[a] [8]; net FIT [9]; value-of-solar [9]
Import/Export Tariff Building Blocks	variable energy charges; fixed/variable network and administrative charges; time-varying rates [11]; demand-based rates; standby charges; bi-directional distribution charges [3]; minimum bills [12]
Export Tariff Level	fixed rate; degression rate; inclining block rates
Export Tariff Contract Terms	term length; credit reconciliation terms and limits; generation limits; exit clauses
Purchasing Arrangements	utility offtaker; independent buyer office

[a] Many FIT structures exist, including fixed rate FITs, degression rate FITs, and FIT premiums.

For any proposed tariff structure, the long-run marginal avoided cost of the DGPV program can be compared against the costs imposed on non-participating customers. This will yield insight into the amount of cross-subsidization, if any, that would be expected to occur between non-participants, the utility and DGPV system owners. In the event that cross-subsidization is occurring, the terms of the tariff or program might be adjusted, via e.g., increases to fixed charges, minimum bills, limits on system size, or program caps. Potential changes to tariff structures can be fed back into established analytical tools to inform decisions and stakeholder discussions. On the other hand, some level of cross-subsidization may be tolerable if it results in a simple and easy-to-implement program (e.g., NEM), or even desirable if incentivizing deployment using ratepayer funding is an objective. CBA studies will likely show a diverse range of value flow and accrual among customer classes which change with grid location and time of energy production. Table V lists potential incentives and pricing mechanisms that can be explored during ratemaking which may help tariffs better reflect the various value dimensions of DGPV.

TABLE V. Pricing Mechanism for Capturing DGPV Value

Dimension	**Pricing Mechanisms for Reflecting DGPV Value Dimensions**
Time of production	time-of-use pricing [11], panel orientation incentives [13], hourly or dynamic pricing [11]
Location of production	locational incentives [14], distribution locational marginal pricing [5]
Local- and Grid- Level Penetration	penetration-scaling tariff pricing, system capacity caps
System Performance Attributes	Incentives for allowing system curtailment or encouraging specific inverter functionalities

While these mechanisms can be useful to some extent, it may not be pragmatic to design highly-customized tariff rates to ensure solar C&B are disbursed at a theoretical financial optimum (i.e. one which attempts to reflect all value dimensions fully). Furthermore, if simplicity and feasibility of implementation are identified as key program objectives (as is often the case for early-stage programs), using a single tariff (i.e., NEM or FIT) might be desirable.

While the tariff structure is key in influencing the flow of value among stakeholders, tariffs must be formulated in the context of a larger regulatory framework. For instance, if a CBA study shows that fixed network and administrative costs may not be fully recovered from program participants for a given tariff structure, system or program size limits might be desirable. Frameworks must also select and allocate costs for the required meter technology, considering the metering needs of the proposed tariff and future needs with respect to data collection and advanced distribution system management. Smart meter and smart grid targets might be tied to DGPV deployment to help create new investment opportunity for the utility and promote longer-term DGPV integration. Sanctioned business models should also be identified (e.g., virtual NEM, community NEM, third party leasing, shared utility-consumer ownership, utility ownership), as aligned with objectives.

VII. Discussion

As formal decisions are issued, regulators might bear in mind that regulatory frameworks are not set in stone. While honoring existing contracts helps to preserve investment certainty, new terms can be proposed to steer the market toward desired levels and spatial distributions of deployment, as aligned with established and emerging policy objectives. To begin, and one may design and implement a pilot DGPV program in order to assess effects of distributed solar on the electricity grid (potentially calibrating valuation models), while evaluating and demonstrating new technologies or billing methods, increasing public acceptance, and gaining stakeholder buy-in.

CBAs which holistically consider planning, operational and financial implications of DGPV programs are being explored in various contexts, typically under the purview of a value-of-solar (VoS) tariff formulation process. VoS tariffs are intended to reflect the principle that DGPV owners can feasibly be paid for the costs they incur and be paid for the benefits they contribute to the system, with the understanding that these benefits can change over time with wholesale electricity market conditions. Formulating a tariff to reflect this principal fundamentally necessitates a detailed CBA methodology.

The U.S. State of Minnesota established a VoS tariff formulation process where stakeholders were able to review all aspects of the methodology before a final rate was set [15]. While no true consensus was ever reached on the methodology employed (or the final tariff level, for that matter), the process nonetheless successfully garnered open dialogue and methodological transparency. As well, it will have enabled stakeholders to continue to meaningfully contribute to VoS proceedings as the tariff is periodically reevaluated.

While a VoS tariff formulation process is a sound impetus for conducting a CBA study, we argue that there is nevertheless strong practical utility to conducting such a study even if VoS tariffs are not being actively considered. Provided that time and resources (both financial and technical) are available, establishing the analytical framework to understand the costs, benefits and expected impacts of a program will lead to informed decisions that are aligned with the objectives of the power sector regulator and other relevant government bodies. It also establishes the models, financial analysis tools and other technical capabilities which could eventually inform shifts toward more systematically fair apportionments of DGPV costs and benefits (i.e. a VoS tariff). State Energy Regulatory Commissions in India might consider investing in building such capabilities, either internally, within their regulated utilities, or with a third-party consultant.

VIII. Conclusion

A multitude of objectives and stakeholder perspectives are prioritized and harmonized during a DGPV tariff design process. CBA studies can provide substantive insights toward understanding the various flows of value that a program may create, and can be used directly or indirectly to inform public consultation processes and formal proposals and decisions. The framework presented in this paper strives to promote methodological transparency and active stakeholder participation in the often iterative CBA study process. The extent to which independent decisions must be made by empowered stakeholders (i.e. regulators, utilities) depends on the specifics of the consultation process, the DGPV program objectives, and surrounding institutional and governance arrangements. However, ensuring that stakeholders understand the full range of issues considered will help to enable focused and productive engagement.

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