Pacific Northwest
NATIONAL LABORATORY

PNNL-31127

The Value of Distributed Wind: A Valuation Framework

April 2021

Kendall Mongird
Sarah Barrows

U.S. DEPARTMENT OF ENERGY

Prepared for the U.S. Department of Energy
under Contract DE-AC05-76RL01830

PACIFIC NORTHWEST NATIONAL LABORATORY
operated by
BATTELLE
for the
UNITED STATES DEPARTMENT OF ENERGY
under Contract DE-AC05-76RL01830

Printed in the United States of America

Available to DOE and DOE contractors from the
Office of Scientific and Technical Information,
P.O. Box 62, Oak Ridge, TN 37831-0062;
ph: (865) 576-8401
fax: (865) 576-5728
email: reports@adonis.osti.gov

Available to the public from the National Technical Information Service
5301 Shawnee Rd., Alexandria, VA 22312
ph: (800) 553-NTIS (6847)
email: orders@ntis.gov <https://www.ntis.gov/about>
Online ordering: http://www.ntis.gov

PNNL-31127

The Value of Distributed Wind: A Valuation Framework

April 2021

Kendall Mongird
Sarah Barrows

Prepared for
the U.S. Department of Energy
under Contract DE-AC05-76RL01830

Pacific Northwest National Laboratory
Richland, Washington 99354

Acronyms and Abbreviations

BCR	benefit-cost ratio
BTM	behind-the-meter
DER	distributed energy
FTM	front-of-the-meter
GHG	greenhouse gas
MIRACL	Microgrids, Infrastructure Resilience, and Advanced Controls Launchpad
NSMP	National Standard Practice Manual
PV	solar photovoltaic

Contents

Figures

Tables

1.0 Introduction

The U.S. electric power distribution grid is transforming as increasing amounts of distributed energy resources (DERs) are being deployed (FERC, 2018; Payne & Monast, 2019). However, despite this increase in DER adoption, distributed wind deployment is currently just over 1 GW, in comparison to the over 30 GW of non-utility solar photovoltaic (PV) deployment in the United States (Orrell, Preziuso, Foster, Morris, & Homer, 2019; SEIA, 2020b). Despite relatively low deployment levels, there is significant growth potential for behind-the-meter distributed wind. In fact, one study estimates that there is up to 37 GW of economically feasible distributed wind deployment by 2050 (Lantz, Sigrin, Gleason, Preus, & Baring-Gould, 2016).

Distributed wind can add value to the energy system in multiple ways. In addition to providing energy generation, distributed wind has the ability to improve resource diversity and resilience in high-DER grid systems (Reiman, Homer, Bhattarai, & Orrell, 2020). This makes distributed wind particularly useful in achieving ambitious state or utility policy goals as many states attempt to produce cleaner energy. Additionally, wind is capable of providing a wide variety of ancillary services, such as frequency response, reserves, voltage support, inertial response, and potentially even black start services (Denholm, Sun, & Mai, 2019).

In order to make decisions about DER deployment, including distributed wind, it is important to identify, characterize, and (to the extent possible) quantify the value elements of DERs to all stakeholders affected by the DERs. These stakeholders include policymakers, system developers, DER-owners, customers, individuals living near where DERs are sited, and utilities. By considering all affected entities, it is possible to make more equitable decisions regarding DER deployment.

Many states have recently been scaling back their net energy metering requirements or introducing replacement programs, such as value-of-resource-based compensation which attempts to capture the value of the different services that DERs can provide (Austin Energy, 2019; Cory, 2014; Flores-Espino, 2015; NC CETC, 2019; Norris et al., 2015; OPUC, 2015; Rábago, Libby, Harvey, Norris, & Hoff, 2015). The net benefits that a DER can provide, often referred to as the ‘value stack’, are used to inform the rates for value-of-resource-based compensation, and are therefore increasingly important to state public utility commissions and public service commissions.

While some peer-reviewed studies looked at the value of small-scale wind projects (Ackermann, Andersson, & Söder, 2001; Allan, Eromenko, Gilmartin, Kockar, & McGregor, 2015; Bush, Jacques, Scott, & Barrett, 2014; Kaldellis, 2003; Olatayo, Wichers, & Stoker, 2018), we found no studies providing a framework for the valuation of wind in distributed energy systems. Several valuation frameworks exist which describe the value elements (the costs or benefits experienced by various stakeholders) available from DERs in general (Frick, Schwartz, & Taylor-Anyikire, 2018; Larsen & Jerndon, 2017; NESP, 2020; Woolf, Whited, Malone, Vitolo, & Hornby, 2014). However, most applied studies have only been conducted for solar PV (Dsouza et al., 2020; Fine et al., 2018; Harari & Kaufman, 2017; SEIA, 2020a). Additionally, these studies vary widely in what they include and/or in their calculation methods (Dsouza et al., 2020). None of these frameworks have been specifically applied to distributed wind, to our knowledge, though they could theoretically do so.

There is therefore a need for a consistent framework for investigating distributed wind’s value in the most common use cases for distributed wind, as well as demonstration of this framework’s applicability to real distributed wind projects. As part of the U.S. Department of Energy's project, Microgrids, Infrastructure and Resilience, and Advanced Controls Launchpad (MIRACL), we develop a valuation framework for distributed wind that considers the main use cases and stakeholders for distributed wind but is flexible in nature. This framework provides a consistent way to demonstrate the net benefits of an existing distributed wind project or a proposed distributed wind project, which can help stakeholders better understand distributed wind's value in a particular scenario. Ongoing work in MIRACL includes applying this valuation framework to two distributed wind projects.

The use cases included in this framework are behind-the-meter (BTM), front-of-the-meter (FTM), in isolated grids, or in grid-connected microgrids. Stakeholders included in this framework are transmission and balancing authorities, utilities, customers, and society. However, the overall structure used for analysis in the framework can be applied to other scenarios as appropriate. For example, a specific stakeholder group could be added to address the energy equity and environmental justice aspects of a given use case.

In the following sections in this report, we describe our distributed wind valuation approach and key concepts, as well as the overarching framework for valuation which is presented in Costs/Revenue Requirements. In Valuation Concepts we outline several important valuation concepts that must be taken into account when finding the net benefits of distributed wind. In Distributed Wind Valuation we describe the main use cases for distributed wind, the most common categories of value elements, and then present several charts that describe the value elements that are possible for each stakeholder in each distributed wind use case. In Conclusions, we give our conclusions.

2.0 Valuation Concepts

DERs, including distributed wind, can provide a variety of services to the electric power distribution grid and add significant value to the grid and to society. Accounting for the benefits and costs of these services, or the value elements of the DER, can be a complex process. In order to provide an accurate, useful, and comprehensive valuation of distributed wind, or any DER, there are several concepts that must be considered. This section details these concepts.

2.1 Co-Optimization

Co-optimization is a mathematical procedure to ensure that limitations and constraints are adhered to and the estimated stack of values are those that can realistically be achieved (CEC, 2017). Co-optimization of services is used to ensure accurate accounting of benefits. Failing to co-optimize could lead to double counting of benefits that cannot, in reality, be achieved simultaneously and could impact important project decisions.

The energy generated by distributed wind may be competed for on a per-benefit basis (i.e., it can only provide value in so many directions at once). For example, a distributed wind asset providing islanding services will not necessarily be able to simultaneously pick up benefits for regulation or other ancillary services which require fluctuations in generation. There may be potential for some of both benefits to be gained simultaneously through the operation of the asset, but the feasibility of this opportunity should be evaluated, not assumed outright.

In order to properly co-optimize services, a valuation model that simulates generation or dispatch over time must be used that can mathematically account for the limitations and constraints of the distributed wind project. Depending on the model used, a time-series dispatch optimization or a quasi-steady state analysis could be conducted. Depending on the technology, various capabilities may be required to ensure optimal dispatch on an individual time-step basis that can account for changes in availability and conditions (EPRI, 2020).

Prior to and/or during co-optimizing services from a distributed wind project, one can also optimize the resource diversity benefits from differing DER technology types as part of the system designing process. Having a diverse set of resources, such as solar PV and distributed wind in the same system, can enhance the capabilities of the system as a whole. This is especially applicable for assets that are weather dependent, and their capabilities may be enhanced by co-locating them with technologies with different dispatch or operating timelines. The resource diversity benefits of DERs can be technically quantified and used to inform project and policy decisions (Reiman, Homer, Bhattarai, & Orrell, 2020).

2.2 Locational Value

The available value elements to a distributed wind project, defined in Section 3.2, will vary based on its location, grid constraints, market accessibility, and other factors. For example, available services and benefits will differ greatly whether the project is located in front of or behind the meter; whether it exists within a market territory and has the ability to participate; the size of the asset; and the configuration of the system around it and its capability to provide grid services. In addition to locality on the grid, geographic location is important. An FTM deployment located in California will have different opportunities than one located in Massachusetts, for example, and therefore will have different revenue streams. This is due to energy market accessibility, local energy demand, or a multitude of other factors. Additionally, for customer-owned assets, the compensation from programs, such as net-metering and other state-wide programs, can vary widely across regions (Trabish, 2018).

Equally important to market, regulatory, and benefit availability considerations are the terrain and siting components of locational factors. Wind assets may face complications in the sense that not all available locations for interconnection will provide an adequate environment for optimum generation due to differences in wind resource and terrain. For this reason, and especially in scenarios in which the valuation effort is intended to compare multiple potential localities for future deployments, information and data on expected generation output based on geography and landscape constraints are critical to determining potential project value. Additionally, the impacts on residents who will be located near the wind assets are important to take into account. This helps ensure these residents also have a voice in the decision-making process.

2.3 Quantitative vs. Qualitative Value Elements

Benefits and costs exist that may be difficult to apply quantitative valuation to, but they can still be valuable to discuss qualitatively. Examples of difficult-to-monetize benefits and costs include avoided greenhouse gas (GHG) emissions and the associated health benefits of reduced pollution, economic and jobs impacts, viewshed and comfort impacts, and potential property value impacts. The respective importance of externalities, such as these in valuations will vary greatly between projects and may also fluctuate based on policy goals and other factors. If these or other impacts are considered both relevant and material to a given DER valuation, then it is important to account for them. In fact, the National Standard Practice Manual (NSPM) for DERs states that “[u]sing best available information to approximate hard-to-quantify impacts, or accounting for impacts qualitatively, is preferable to assuming that the relevant benefits and costs do not exist or have no value (NESP, 2020).”

There is a broad range of approaches and procedures for attempting to place value on these types of externalities and much discussion about the correct approach. The NSPM lists several methods are possible, including performing jurisdiction-specific studies of the benefits and costs of DERs to that jurisdiction. These studies can be done using studies from *other* jurisdictions to estimate the value of DER impacts, using proxies to increase or decrease the benefits of a DER by a specific percentage (i.e. an adder or multiplier, as done in Oregon’s Order No. 94-590 to account for reduced risk and uncertainty), or using alternative thresholds for project approval besides a benefit-cost ratio (BCR) of 1.0 (OPUC, 1994). If all these methods fail, the NSPM suggests relevant qualitative information can be given simultaneously with monetized results so that this evidence can be considered in decision-making.

When performing a jurisdiction-specific study, it is often necessary to use non-market valuation methods. These methods include stated preference methods that utilize surveys to directly ask stakeholders how they value impact, avoid damage cost methods (which estimate value of the impact by the cost of the avoided damage), and revealed preference methods (which use observations of various purchasing decisions and other behaviors to estimate impact value) (NRC, 2005). Examples of such studies done by and for utilities and states to value non-energy jurisdictional impacts are given in Appendix A of a report by Lawrence Berkeley National Laboratory (Sutter, Mitchell-Jackson, Schiller, Schwartz, & Hoffman, 2020).

As shown later in Section 3.3, if benefits and costs cannot be accounted for quantitatively, then the approach should be similar to that given in the NSPM. Namely, evidence for these qualitative impacts should be accounted for but included separately from the quantifiable benefit streams for projects. These qualitative impacts should be presented at the same time as monetary impacts so they can be fully considered.

2.3.1 Resilience Value

Resilience is one value element that is often difficult to quantify in monetary terms. The resilience of an electrical system, as defined by Idaho National Laboratory, is a characteristic of the people, assets, and processes that make up the electrical system and its ability to identify, prepare for, and adapt to disruptive events and recover rapidly from any disturbance to an acceptable state of operation (Bukowski et al., Forthcoming). It is important to note that under this definition, reliability is similar to resilience, but the two concepts are not the same. Reliability focuses on low-impact, high-frequency events and not on system failure or catastrophic events. Resilience, on the other hand, deals with high-impact, low-frequency events, such as outages caused by natural disasters (NAS, 2017).

There are a variety of value elements that can contribute towards resiliency in both preventative and responsive manners. These can include the more obvious benefits, such as outage mitigation—ensuring access to electricity in the event of a power disruption event—or ancillary services that enable a system to maintain grid stability (Goggin, 2017). A DER that is capable of providing primary frequency response, for example, may be able to prevent a power disruption event before it occurs. Which resiliency-focused benefits elements apply will be dependent on location specific factors and what resiliency looks like for a specific distributed wind project.

Value elements associated with resiliency are typically valued on an avoided-cost basis, and can therefore contain some uncertainty, since they are scenario-based values. For example, for a DER-powered load during a grid outage, the value provided from the outage mitigation would be the avoided cost of the disruption event (e.g., lost industrial production or commercial operation) (IREC, 2016; Sullivan, Schellenberg, & Blundell, 2015).

There are other cases, however, where resiliency-based value elements could be monetized in a market or contract setting whereby the DER is providing the resiliency value as a product (FERC, 2020). For example, the Bonneville Power Administration sells excess primary frequency response reserves to other balancing authorities within the Western Interconnection after satisfying Pacific Northwest needs (BPA, 2015). As energy markets continue to adapt and offer more products there will likely be more opportunities for asset owners that produce excess value elements to obtain direct compensation.

2.4 Stakeholder Perspective

When conducting analyses to determine overall economic viability of a project, such as a benefit-cost calculation, it is very important to consider the perspective of the analysis when co-optimizing and stacking benefits and costs. This can include utility customers, the utility itself, the balancing authority, and other impacted groups. Each will have a separate list of available benefits and costs for a given project.

Benefits may also exist as positive externalities to entities other than the owner of the distributed wind project or those facing the costs and should be accounted for under the appropriate stakeholder perspective. For example, a utility may own a distributed wind asset that is capable of providing islanding services to customers and it would be incorrect to include the avoided cost of lost load for those customers as a benefit to the utility. Instead, it should be counted as a benefit to the customers.

2.5 Market Value vs. Avoided Cost

A majority of value elements considered in an analysis are evaluated either through direct market compensation or through avoided cost mechanisms. Depending on configuration, generation capacity of the asset(s), and whether or not they exist within a market area, there may be opportunities for asset owners to obtain revenue by offering specific services and products in the market (EPA, 2018; FERC, 2020). Market value varies based on supply and demand and differs significantly across regions of the United States. Market procedures vary significantly; for example, some ancillary services are offered in one market and not in another (Zhou, Levin, & Conzelmann, 2016). However, compensation for services (e.g., ancillary services, capacity) will be dictated based on the amount that the asset owner bids into the market, whether the bid is accepted, and their ability to procure the offered service. It is measured as a direct transaction of generation for compensation by the receiving party. Which market, interconnection, or state-level retail energy market a distributed wind project exists within can determine the availability of a variety of value elements (EPA, 2020). When considering market services, there are important considerations that should be observed with regards to participation requirements. Oftentimes, markets will have size minimums, technology restrictions, or must-run requirements which make sure the assets are available when they have agreed to be available. Penalties oftentimes exist that punish assets for not meeting the market availability or product supply that was bid into the market. It is important to understand all of these factors and the various opportunities that may or may not be available prior to assigning value.

In regions where markets do not exist, or where an asset is ineligible to participate, many of the services it can provide are monetized on an avoided cost basis and not on direct compensation for generation services. That is, the benefit (typically to a utility or balancing authority) of providing a grid service is the avoided cost of using a more expensive or less desirable asset to provide it (e.g., using a fossil-fuel asset to provide needed ancillary services) or other costs that would be faced if the service was not provided (e.g., interruption cost in the case of outage mitigation) (EPA, 2018). The avoided cost and how it’s calculated will differ based on the distributed wind project and value element details.

3.0 Distributed Wind Valuation

This section presents the main use cases for distributed wind and the value elements, both benefits and costs, that distributed wind can provide in these use cases to different stakeholders.

3.1 Use Cases

Distributed wind has several use cases, and these use cases can affect what value elements are available to the stakeholders. A use case is a term that refers to the configuration of assets and their location on or off the grid. Use cases can be sorted by their technical, financial, market, or resilience similarities and are a way of grouping projects together. Technical aspects of a use case can include how and where project assets are interconnected to the grid system. Financial components can depend on funding or cost structure. Market characteristics are typically associated with developer and ownership constructs. Lastly, resilience can be framed by what vulnerabilities the project is aiming to prevent and/or respond to.

Main use cases for distributed wind are defined in the Department of Energy's MIRACL project and are used in this valuation framework to categorize which value elements may or may not be applicable to a given distributed wind project. We use these use cases in order to inform distributed wind valuation for the most likely distributed wind scenarios. The MIRACL use cases include the following (Reilly, 2020):

1. **Isolated Grids –** This use case includes areas that are disconnected from outside transmission systems and only have access to energy generated within their own system. These areas are typically located in rural, low population, or island communities that are unable to procure energy from outside sources due to lack of transmission infrastructure connecting them.
2. **Grid-Connected Microgrids –** A microgrid is a group of interconnected loads and DERs within defined electrical boundaries that can operate either connected or disconnected ("islanded") from an external grid.
3. **Behind-the-Meter (BTM) Deployments –** BTM deployments are customer-owned and typically located in residential households or at commercial or industrial facilities. They are BTM in the sense that benefits obtained are typically aimed at reducing or shifting consumption of energy purchases (read via the meter) from their energy provider rather than by providing grid services, such as ancillary services or similar.
4. **Front-of-the-Meter (FTM) Deployments –** An FTM deployment is an asset that is connected to a distribution line that serves load and can be as simple as an individual turbine or as complex as a microgrid.

3.2 Value Element Categories

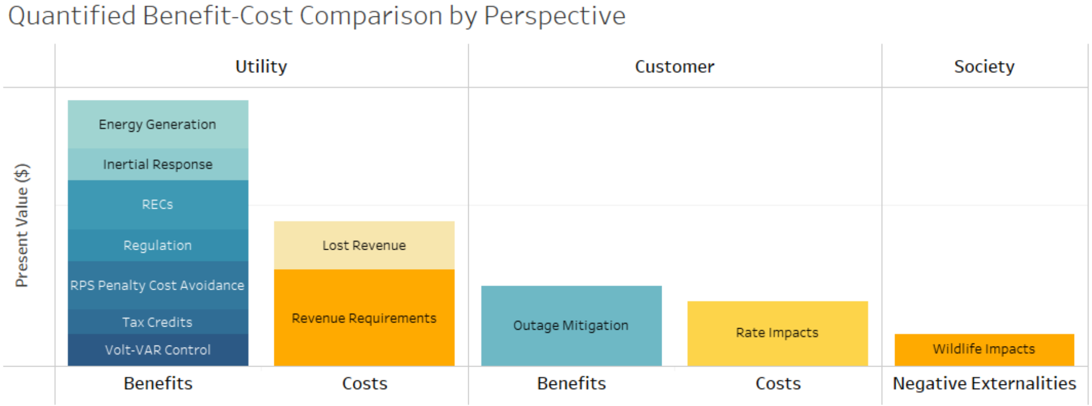
A reference system is a real example of a particular use case, and each reference system will have a unique set of value elements, or benefits and costs, that are available. Reference systems have available technical, financial, and other information that can be used for valuation analyses. Available value elements can vary significantly on a case-by-case basis; however, the overarching categories include the following, some of which have been adapted from Akhil et al. (2015):

- **Bulk Energy Services –** Includes services related to the production of energy and/or reducing the need for alternative generation capacity.
- **Ancillary Services –** Ancillary services typically involve applications intended to maintain a balanced grid. This can include balancing fluctuations in supply and demand of energy, providing black start services necessary to energize transmission and distribution lines in the event of a grid failure, providing voltage support to maintain voltage within specified limits, and others. Typically, in order to provide these services, adequate controls must be part of the system. Though assets may provide some ancillary services naturally through general operation, in order to purposefully react to an event or provide a service, the ability to dispatch a technology in a specified way is required. Distributed wind may also be able to follow a dispatch signal with adequate control capabilities (Denholm et al., 2019).
- **Transmission Services –** This category includes services that support the transmission of energy and provide value by either delaying investment in additional transmission infrastructure or providing energy in congested areas, avoiding the use of higher cost generation resources.
- **Distribution Services –** This category encompasses benefit elements associated with support of the distribution of energy and typically provides value by delaying investment in new distribution systems.
- **Customer/Energy Demand Management Services –** Services within this category typically include those that incorporate bill savings from shifting or reducing energy demand or other customer-facing services, such as the mitigation of power outages. In addition to the avoided costs in the form of bill savings or lost load, tax credits, renewable energy credits, and voluntary demand shifting programs (e.g., demand response) would also fall within this category.
- **Economic/Societal Impacts** – This last category is intended to encapsulate positive externalities that benefit society at large and may or may not be difficult to quantify, In some cases, such as resilience, benefits may only be partially quantifiable. They can include environmental and health benefits, such as avoided GHG production from non-renewable resources and meeting policy or other goals. Some societal impacts, such as the associated health benefits of avoided pollution, can also be considered equity benefits or services for historically disadvantaged communities. It should be noted that, depending on how societal impacts are represented, there could be associated benefit elements that appear within other categories. For example, if there are penalties that a utility will owe to the state if they do not procure enough renewable generation sources in their portfolio, the avoided cost of that penalty will be a direct benefit to the utility and fall within the customer/energy demand management category, while any avoided GHG emissions will remain with the economic/societal impact category. Specific services and value elements exist within each of these categories and are shown in higher detail in Figure 2 and Figure 3. The above categories outline applicable benefits, for costs that may apply, see Costs/Revenue Requirements.

3.3 Value Stacking

Oftentimes DER investments, such as distributed wind projects, can offer more than one value element over their usable life. These value elements can be evaluated in an aggregated manner when looking at the value over the usable life of a project and discounted back to calculate the total present value. These “stacked” value elements are each monetized or evaluated in a consistent manner and co-optimized so that the end result procures a thorough representation of the expected value an asset (or in some scenarios, multiple assets) can provide based on operational capabilities and the available value elements. An example of a potential value stack for a utility owned FTM distributed wind project is given in Figure 1. The stacked benefits would typically be measured in present value dollars where the size of each stacked benefit shows its contribution to the total value stack. Present value costs are similarly calculated and the cost and benefit stacks from a single perspective can be used to generate a BCR. The columns in the figure displaying the positive and negative externalities to society in this example are not quantied and included to demonstrate the appearance of qualitative elements.

The example stack of value elements seen here is not intended to show all benefits and costs that would be available to all assets and all perspectives, but rather those that would apply to a given project. Figure 1 demonstrates a hypothetical end result of applying the distributed wind valuation framework.


Quantified Benefit-Cost Comparison by Perspective

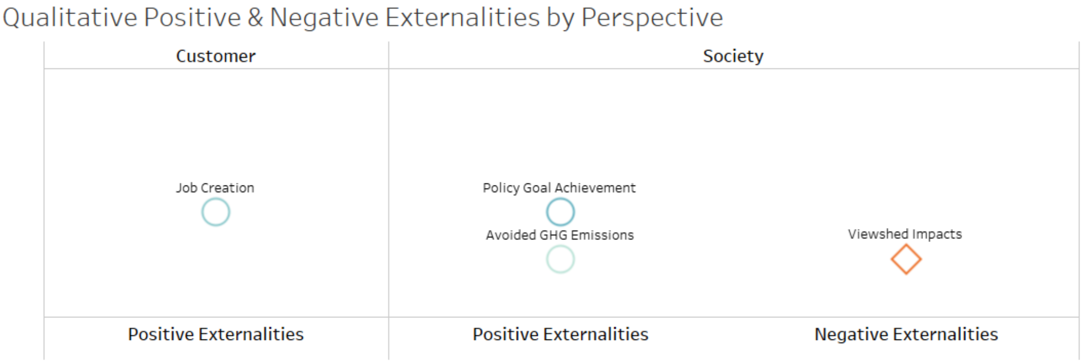

Qualitative Positive & Negative Externalities by Perspective

Figure 1: Example presents value cost, benefit stacks, and externalities by perspective for a utility-owned FTM project.

Value stacks are useful for conducting financial analyses, such as BCRs where the accumulated benefits are compared against the similarly stacked costs. If the present value benefits outweigh the costs over the lifetime of the asset(s), the project is considered to have a positive return. BCRs and similar calculations are useful both to determine whether a project should move forward, to obtain financial backing from third-party investors, compare multiple potential projects to determine the highest return, or help to inform the dispatch schedule for an already constructed asset.

Oftentimes an existing project may not be pursuing the full range of possible benefits. These scenarios may be leaving value on the table that can be captured through informed operation and improving the overall BCR of the project. Techno-economic analysis and thorough valuation efforts can generally improve efforts to obtain more value from an existing project.

The valuation charts we present in Valuation Charts begin this process by enumerating potential value elements in various use cases to different stakeholders. These charts represent a map, or blueprint, for a more detailed techno-economic analysis.

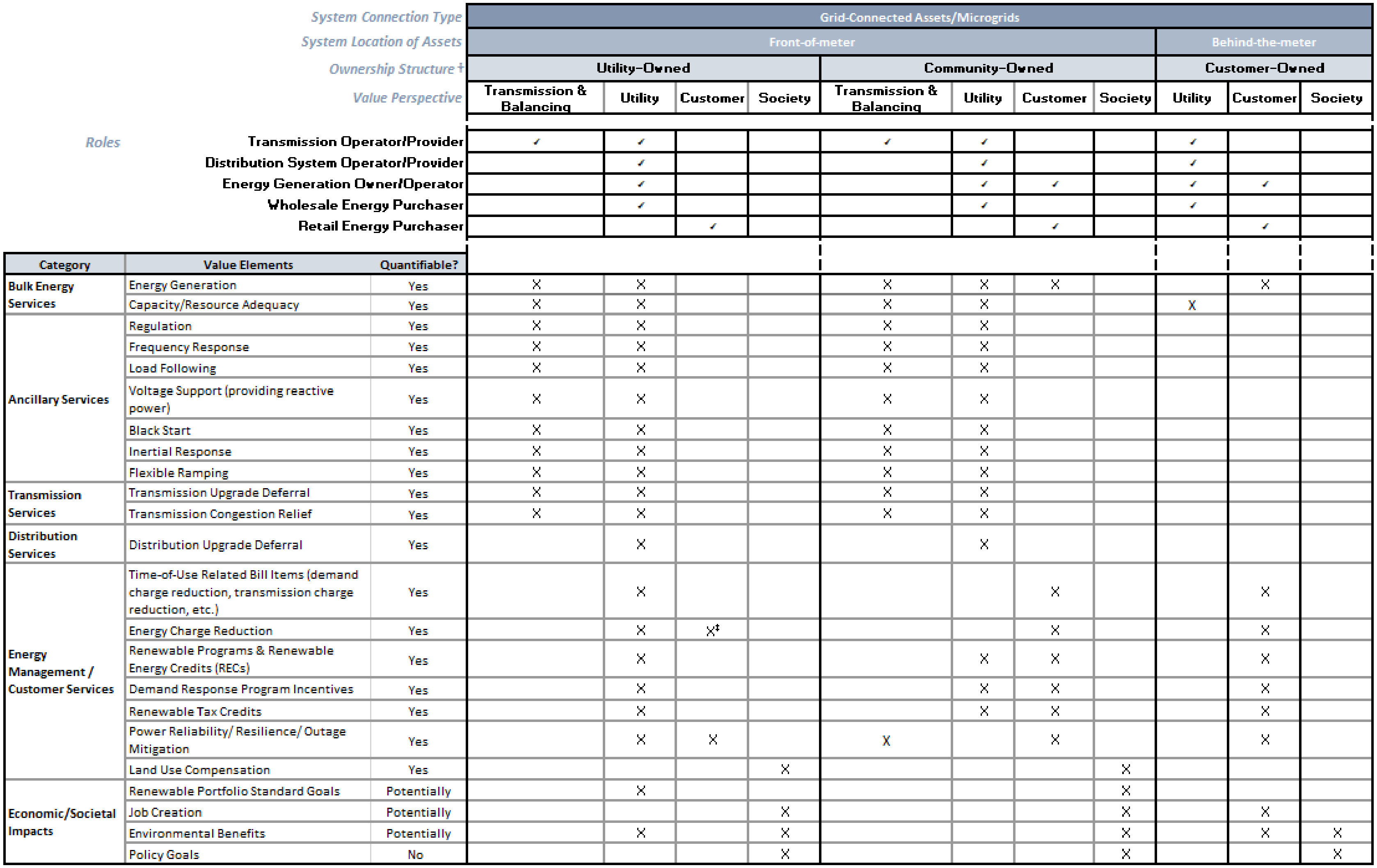
3.4 Valuation Charts

Benefits are presented in Figure 2 and Figure 3, and costs are presented later in this document in Figure 4 and Figure 5. In Using the Valuation Framework, we explain how both benefits and costs are stacked in order to find the net benefits of the distributed wind project. Figure 2 and Figure 3 below show lists of benefits within each of the value element categories previously described, the former for grid-connected systems and the latter for isolated systems. The charts are intended to encapsulate the various use cases described earlier including whether it is a connected or isolated system and where it is located within that system. Under each of those categories are a number of perspectives to which specific benefits can apply, as well as different roles that those perspectives play in a given scenario (represented by check marks in a particular role). For example, under the utility owned FTM scenario, if a distributed wind asset is able to supply capacity, the benefits from that application will accrue to either the utility, the power authority, or, in some cases, both. Under this scenario, the checked boxes towards the top of the table indicate who is potentially responsible for providing energy generation, purchasing energy at wholesale or retail rates, or providing transmission and distribution services. This is intended to provide clarity around the various roles and how they guide applicable benefits.

The ‘X’ in each box should not be interpreted as implying that the benefit gained by that party is absolute and applicable in every reference system but rather that there is a possibility that it could exist. Where benefits accrue (i.e., to which stakeholder) will vary project to project and often depend on ownership, contracting, and other factors that can shift how benefits are assigned. Additionally, it is important to note that in some projects, various benefits might exist under the same category but are valued differently. For example, there may be multiple line items on an energy bill structure that are simultaneously categorized as time-of-use related bill items even if they differ in their specific details.

The purpose of displaying the value elements in Figure 2 and Figure 3 is to demonstrate the importance of perspective in valuation and value stacking. While a utility-owned project may have the ability to provide outage mitigation and supply energy during power disruption events to utility customers, the avoided cost of lost load from doing so will not accrue to the asset owner (i.e., utility) in this case. To do a fair comparison of benefits and costs or calculate other financial metrics, it is important that benefits and costs be accurately sorted, and the analysis be conducted from a specific perspective.

Not all benefits will be directly quantifiable or monetizable, though they may be of high interest. For example, a distributed wind asset will likely reduce the need for additional fossil-fuel generation assets, however, the overall GHG emission reduction from the project may be difficult to quantify and even more difficult to assign monetary value to. In some projects there may be penalties for non-compliance with renewable standards or for emission levels, however, this will not be true for every project. For this reason, some benefits in Figure 2 and Figure 3 have been described as potentially quantifiable.

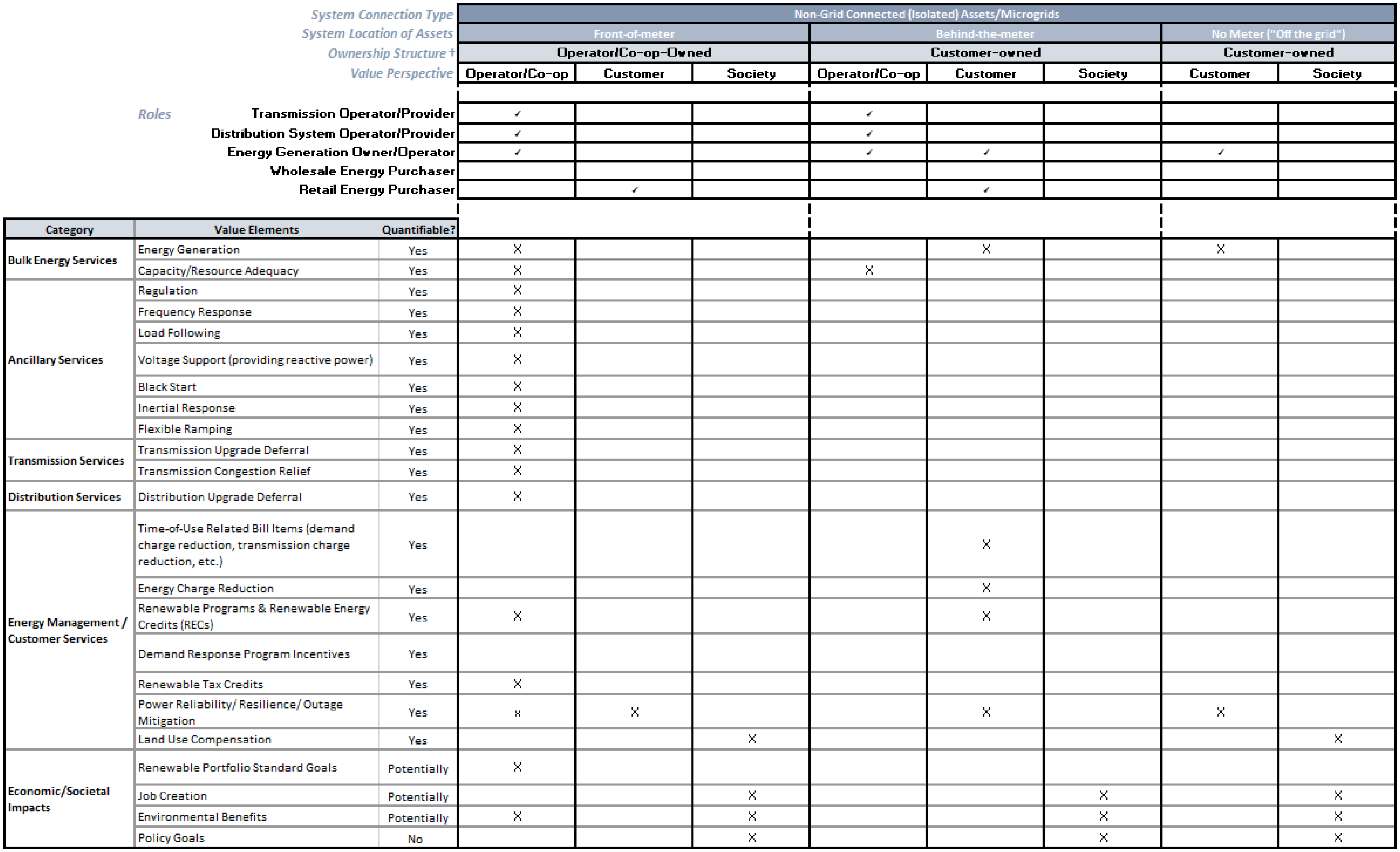


System Connection Type			Grid-Connected Assets/Microgrids										
System Location of Assets			Front-of-meter								Behind-the-meter		
Ownership Structure †			Utility-Owned				Community-Owned				Customer-Owned		
Value Perspective			Transmission & Balancing	Utility	Customer	Society	Transmission & Balancing	Utility	Customer	Society	Utility	Customer	Society
Roles	Transmission Operator/Provider		✓	✓			✓	✓			✓		
	Distribution System Operator/Provider			✓				✓			✓		
	Energy Generation Owner/Operator			✓				✓	✓		✓	✓	
	Wholesale Energy Purchaser			✓				✓			✓		
	Retail Energy Purchaser				✓				✓			✓	
Category	Value Elements	Quantifiable?											
Bulk Energy Services	Energy Generation	Yes	X	X			X	X	X			X	
	Capacity/Resource Adequacy	Yes	X	X			X	X			X		
Ancillary Services	Regulation	Yes	X	X			X	X					
	Frequency Response	Yes	X	X			X	X					
	Load Following	Yes	X	X			X	X					
	Voltage Support (providing reactive power)	Yes	X	X			X	X					
	Black Start	Yes	X	X			X	X					
	Inertial Response	Yes	X	X			X	X					
	Flexible Ramping	Yes	X	X			X	X					
Transmission Services	Transmission Upgrade Deferral	Yes	X	X			X	X					
	Transmission Congestion Relief	Yes	X	X			X	X					
Distribution Services	Distribution Upgrade Deferral	Yes		X				X					
Energy Management / Customer Services	Time-of-Use Related Bill Items (demand charge reduction, transmission charge reduction, etc.)	Yes		X					X			X	
	Energy Charge Reduction	Yes		X	X‡				X			X	
	Renewable Programs & Renewable Energy Credits (RECs)	Yes		X				X	X			X	
	Demand Response Program Incentives	Yes		X				X	X			X	
	Renewable Tax Credits	Yes		X				X	X			X	
	Power Reliability/ Resilience/ Outage Mitigation	Yes		X	X		X		X			X	
	Land Use Compensation	Yes				X				X			
Economic/Societal Impacts	Renewable Portfolio Standard Goals	Potentially		X						X			
	Job Creation	Potentially				X				X		X	
	Environmental Benefits	Potentially		X		X				X		X	X
	Policy Goals	No				X				X			X

† In many cases, rather than a utility, co-op, or customer owning the asset themselves, it may be owned by a third-party and energy is sold through a power purchase agreement or similar. Despite this configuration, many of the value elements listed under utility-owned, community-owned, or customer-owned will still apply. What does differ between the ownership structures is the cost framework, wherein the asset owner may be responsible for operations & maintenance costs, major overhauls, and other factors. The available value elements and the structure of costs will depend on the contract.

‡ The presence of this value element will depend heavily on the structure of the system. If a utility deploys a large amount of renewable assets, this could offset enough fossil-fuel or more expensive generation assets that customer rates could be lowered. This would typically be shown as a rate structure change, however, it has been included in energy charge reduction here for brevity.

Figure 2: Grid-Connected Systems Valuation Chart



		System Connection Type	Non-Grid Connected (Isolated) Assets/Microgrids							
		System Location of Assets	Front-of-meter			Behind-the-meter			No Meter ("Off the grid")	
		Ownership Structure †	Operator/Co-op-Owned			Customer-owned			Customer-owned	
		Value Perspective	Operator/Co-op	Customer	Society	Operator/Co-op	Customer	Society	Customer	Society
Roles		**Transmission Operator/Provider**	✓			✓				
		Distribution System Operator/Provider	✓			✓				
		Energy Generation Owner/Operator	✓			✓	✓		✓	
		Wholesale Energy Purchaser								
		Retail Energy Purchaser		✓			✓			
Category	**Value Elements**	**Quantifiable?**								
Bulk Energy Services	Energy Generation	Yes	X				X		X	
	Capacity/Resource Adequacy	Yes	X			X				
Ancillary Services	Regulation	Yes	X							
	Frequency Response	Yes	X							
	Load Following	Yes	X							
	Voltage Support (providing reactive power)	Yes	X							
	Black Start	Yes	X							
	Inertial Response	Yes	X							
	Flexible Ramping	Yes	X							
Transmission Services	Transmission Upgrade Deferral	Yes	X							
	Transmission Congestion Relief	Yes	X							
Distribution Services	Distribution Upgrade Deferral	Yes	X							
Energy Management / Customer Services	Time-of-Use Related Bill Items (demand charge reduction, transmission charge reduction, etc.)	Yes					X			
	Energy Charge Reduction	Yes					X			
	Renewable Programs & Renewable Energy Credits (RECs)	Yes	X				X			
	Demand Response Program Incentives	Yes								
	Renewable Tax Credits	Yes	X							
	Power Reliability/ Resilience/ Outage Mitigation	Yes	x	X			X		X	
	Land Use Compensation	Yes			X					X
Economic/Societal Impacts	Renewable Portfolio Standard Goals	Potentially	X							
	Job Creation	Potentially			X			X		X
	Environmental Benefits	Potentially	X		X			X		X
	Policy Goals	No			X			X		X

† In many cases, rather than a co-op, or customer owning the asset themselves, it may be owned by a third-party with energy sold through a power purchase agreement or similar. Despite this configuration, many of the value elements listed under utility-owned, community-owned, or customer-owned will still apply. What does differ between the ownership structures is the cost framework, wherein the asset owner may be responsible for operations & maintenance costs, major overhauls, and other factors. The available value elements and the structure of costs will depend on the contract.

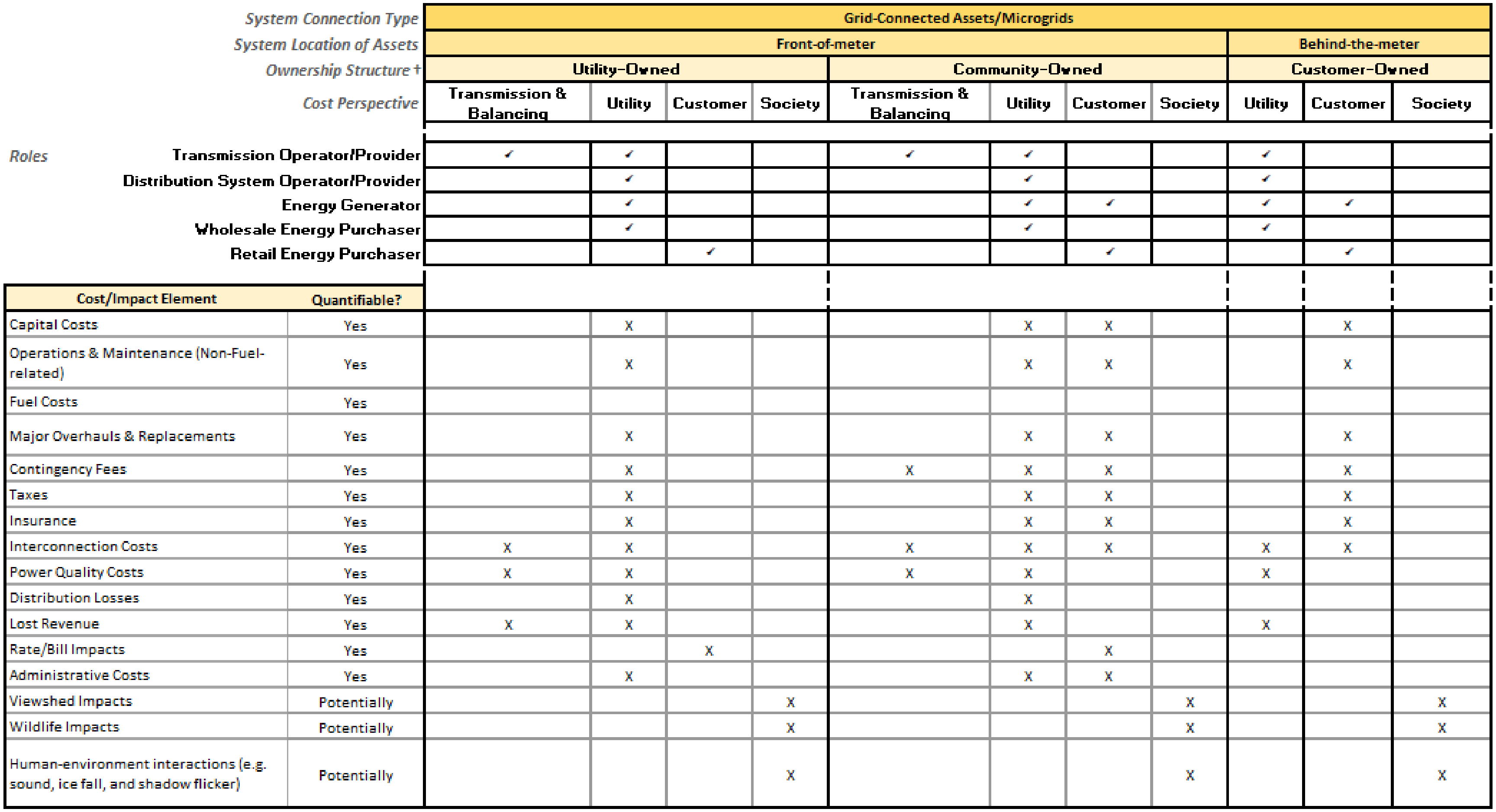
Figure 3: Isolated Systems Valuation Chart

The value elements shown in Figure 2 and Figure 3 describe value elements for typical systems. Oftentimes there will be unique benefits or impacts that vary by reference system, such as a specific electricity bill line item or similar. The tables are intended to be used as a guide for services that may apply.

3.5 Costs/Revenue Requirements

For many projects, the return on investment is an important financial metric that many asset owners prefer to calculate prior to implementation or to compare various deployment options. Just as with the benefits, costs are incurred from various perspectives and calculating a BCR from the perspective of choice requires determining the costs faced by that perspective within that reference system. It is important when conducting such analyses that the full range of costs be included in addition to the capital costs for the asset that should be evaluated over the usable life of the asset. The accumulation of all of these is known as revenue requirements. There are various types of costs that can accrue to a project, such as operations and maintenance, integration, taxes, insurance, and others. Each of the applicable costs must be estimated out across the expected life of the asset to calculate the full present value revenue requirements.

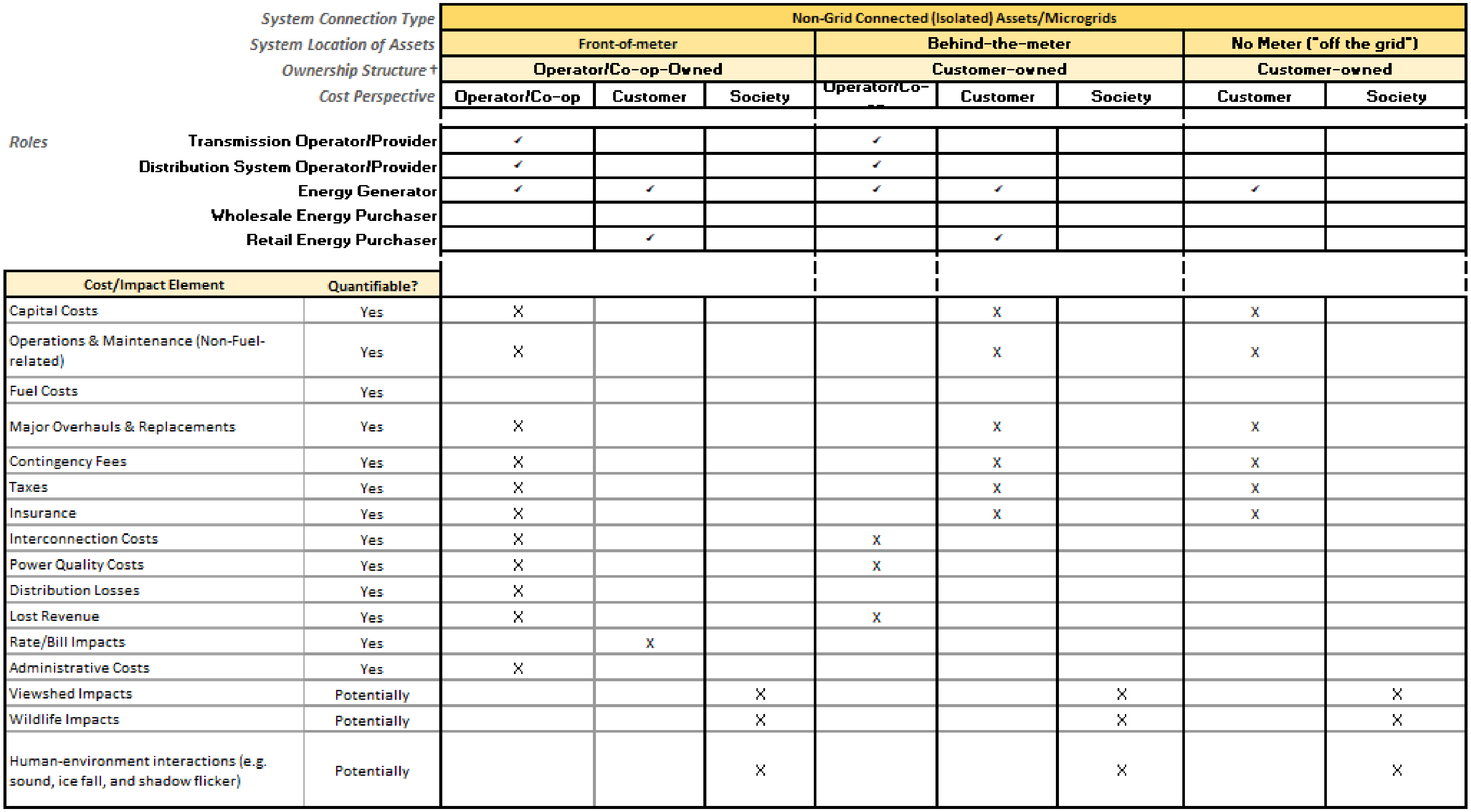
Figure 4 and Figure 5 below show a list of some of the costs that various stakeholders may face in the range of use cases. This list is not intended to be exhaustive, nor will all costs listed under a perspective necessarily apply. As with the value charts (Figure 2 and Figure 3), Figure 4 and Figure 5 are intended to show what costs could potentially accrue.



System Connection Type		**Grid-Connected Assets/Microgrids**										
System Location of Assets		**Front-of-meter**								**Behind-the-meter**		
Ownership Structure †		**Utility-Owned**				**Community-Owned**				**Customer-Owned**		
Cost Perspective		**Transmission & Balancing**	**Utility**	**Customer**	**Society**	**Transmission & Balancing**	**Utility**	**Customer**	**Society**	**Utility**	**Customer**	**Society**
Roles **Transmission Operator/Provider**		✓	✓			✓	✓			✓		
Distribution System Operator/Provider			✓				✓			✓		
Energy Generator			✓				✓	✓		✓	✓	
Wholesale Energy Purchaser			✓				✓			✓		
Retail Energy Purchaser				✓				✓			✓	
Cost/Impact Element	**Quantifiable?**											
Capital Costs	Yes		X				X	X			X	
Operations & Maintenance (Non-Fuel-related)	Yes		X				X	X			X	
Fuel Costs	Yes											
Major Overhauls & Replacements	Yes		X				X	X			X	
Contingency Fees	Yes		X			X	X	X			X	
Taxes	Yes		X				X	X			X	
Insurance	Yes		X				X	X			X	
Interconnection Costs	Yes	X	X			X	X	X		X	X	
Power Quality Costs	Yes	X	X			X	X			X		
Distribution Losses	Yes		X				X					
Lost Revenue	Yes	X	X				X			X		
Rate/Bill Impacts	Yes			X				X				
Administrative Costs	Yes		X				X	X				
Viewshed Impacts	Potentially				X				X			X
Wildlife Impacts	Potentially				X				X			X
Human-environment interactions (e.g. sound, ice fall, and shadow flicker)	Potentially				X				X			X

† In many cases, rather than a utility, co-op, or customer purchasing the asset themselves, it may be owned by a third-party through a power purchase agreement or similar. Despite this configuration, many of the cost elements listed under utility-owned, community-owned, or customer-owned may still apply. Whether or not the asset owner is be responsible for operations & maintenance costs, major overhauls, and other factors will depend on the structure of the contract.

Figure 4: Grid-Connected Systems Cost/Impact Chart



System Connection Type		Non-Grid Connected (Isolated) Assets/Microgrids							
System Location of Assets		Front-of-meter			Behind-the-meter			No Meter ("off the grid")	
Ownership Structure †		Operator/Co-op-Owned			Customer-owned			Customer-owned	
Cost Perspective		Operator/Co-op	Customer	Society	Operator/Co-	Customer	Society	Customer	Society
Roles **Transmission Operator/Provider**		✓			✓				
Distribution System Operator/Provider		✓			✓				
Energy Generator		✓	✓		✓	✓		✓	
Wholesale Energy Purchaser									
Retail Energy Purchaser			✓			✓			
Cost/Impact Element	Quantifiable?								
Capital Costs	Yes	X				X		X	
Operations & Maintenance (Non-Fuel-related)	Yes	X				X		X	
Fuel Costs	Yes								
Major Overhauls & Replacements	Yes	X				X		X	
Contingency Fees	Yes	X				X		X	
Taxes	Yes	X				X		X	
Insurance	Yes	X				X		X	
Interconnection Costs	Yes	X			X				
Power Quality Costs	Yes	X			X				
Distribution Losses	Yes	X							
Lost Revenue	Yes	X			X				
Rate/Bill Impacts	Yes		X						
Administrative Costs	Yes	X							
Viewshed Impacts	Potentially			X			X		X
Wildlife Impacts	Potentially			X			X		X
Human-environment interactions (e.g. sound, ice fall, and shadow flicker)	Potentially			X			X		X

† In many cases, rather than a utility, co-op, or customer purchasing the asset themselves, it may be owned by a third-party through a power purchase agreement or similar. Despite this configuration, many of the cost elements listed under utility-owned, community-owned, or customer-owned may still apply. Whether or not the asset owner is be responsible for operations & maintenance costs, major overhauls, and other factors will depend on the structure of the contract.

Figure 5: Non-Grid-Connected Cost/Impact Chart

3.6 Using the Valuation Framework

This report encompasses a wide variety of key concepts, best practices, and considerations to keep in mind when evaluating the value of a distributed wind project. Though the above figures can be used in a variety of ways, the following steps in Table 1 outline a recommended path and framework for those hoping to use it towards conducting a techno-economic valuation. Note that these steps are outlined for use with an identified reference system with accessible information and project characteristics.

Table 1: Valuation Framework Guide

Step 1	Define reference system details, such as: grid-connection status (connected vs. isolated), FTM/BTM project, microgrid, ownership/contract structure, etc.
Step 2	Select valuation chart to section that applies to defined reference system.
Step 3	Define project-specific factors (e.g., technology type, market availability, co-located technologies, controls capabilities) to narrow value element availability.
Step 4	Specify valuation perspective for base case analysis.
Step 5	Define valuation methodologies applicable to project (e.g., market participation methods and compensation, applicable penalty avoidance, outage mitigation frequency and associated value of lost load) for selected benefits and reference system characteristics. For services that are not monetizable, discuss potential impacts or externalities.
Step 6	Model operation of asset(s) and co-optimize benefits to determine present value benefits over the course of the asset's useable life, accounting for all technologies included in project.
Step 7	Define revenue requirements/costs associated with reference system considering the appropriate perspective of analysis.
Step 8	Calculate present value revenue requirements/costs for project from chosen perspective
Step 9	Summarize any non-quantifiable impacts for stakeholders, giving relevant qualitative evidence.
Step 10	Compare co-optimized value stack to revenue requirement/cost stack for base case and calculate financial metrics of interest. Simultaneously present qualitative impacts with quantified impacts.
Step 11	Repeat process as desired, conducting additional analyses for other perspectives of interest and/or conduct sensitivity analyses with changes to key parameters or assumptions to determine robustness of results.

If a reference system is not already established, the valuation and cost tables can be used in the following ways:

- As a guide to explore benefit opportunities for a potential project that is not yet established;
- To compare multiple hypothetical reference systems to see how their benefits may compare based on various factors (e.g., location, grid-connection type, ownership structure); and
- To gain an overall understanding of applications and use cases and how benefits accrue.

4.0 Conclusions

This report provided an overview of key concepts in valuation, tables of services, and costs for distributed wind from various stakeholder perspectives, and a recommended framework for conducting valuation of benefits and costs. The framework within this document provides a consistent and comprehensive approach to the valuation of distributed wind and can be used in many different distributed wind use cases. Next steps in this research initiative are to apply the framework to a reference system in order to provide an example of how each step may be applied. These worked examples will provide a roadmap for others to see how to apply this framework to value specific distributed wind projects.

5.0 References

Ackermann, T., Andersson, G., & Söder, L. (2001). Distributed generation: a definition. *Electric Power Systems Research, 57*(3), 195-204. doi: https://doi.org/10.1016/S0378-7796(01)00101-8

Akhil, A. A., Huff, G., Currier, A. B., Kaun, B. C., Rastler, D. M., Chen, S. B., . . . Gauntlett, W. D. (2015). *DOE/EPRI Electricity Storage Handbook in Collaboration with NRECA* (SAND2013-5131). Retrieved from Albuquerque, NM: https://prod-ng.sandia.gov/techlib-noauth/access-control.cgi/2015/151002.pdf

Allan, G., Eromenko, I., Gilmartin, M., Kockar, I., & McGregor, P. (2015). The economics of distributed energy generation: A literature review. *Renewable and Sustainable Energy Reviews, 42*, 543-556. doi:https://doi.org/10.1016/j.rser.2014.07.064.

Austin Energy. (2019). Value of Solar Rate 2019. Retrieved from https://austinenergy.com/ae/rates/residential-rates/value-of-solar-rate

BPA. (2015). Power Products - RFO Notice for Web Posting [Press release]. Retrieved from https://www.bpa.gov/p/Power-Products/Products/RFO_notice-for-web-posting.pdf

Bukowski, S., M.J., C., Gentle, J. P., Bell, J. C., Rieger, C. R., & Smith, J. (Forthcoming). *Distributed Wind Resilience Metrics for Electric Energy Delivery Systems.* . Retrieved from

Bush, R., Jacques, D. A., Scott, K., & Barrett, J. (2014). The carbon payback of micro-generation: An integrated hybrid input–output approach. *Applied Energy, 119*, 85-98. doi: https://doi.org/10.1016/j.apenergy.2013.12.063.

CEC. (2017). *Energy Research and Development Division FINAL PROJECT REPORT: Validated and Transparent Energy Storage Valuation and Optimization Tool*. Retrieved from Sacramento, CA: https://ww2.energy.ca.gov/2017publications/CEC-500-2017-016/CEC-500-2017-016.pdf

Cory, K. (2014). Minnesota Values Solar Generation with New “Value of Solar” Tariff. Retrieved from https://www.nrel.gov/state-local-tribal/blog/posts/vos-series-minnesota.html

Denholm, P., Sun, Y., & Mai, T. (2019). *An Introduction to Grid Services: Concepts, Technical Requirements, and Provision from Wind*. Retrieved from Golden, CO: https://www.nrel.gov/docs/fy19osti/72578.pdf

Dsouza, K., Halbe, S., Thomas, M., Baran, M., Chowdhury, B., Schwarz, P., & Proudlove, A. (2020). *The Challenges of Valuing Distributed Generation*. Paper presented at the 2020 IEEE Power & Energy Society Innovative Smart Grid Technologies Conference (ISGT), Washington, D.C.

EPA. (2018). *Quantifying the Multiple Benefits of Energy Efficiency and Renewable Energy: A Guide for State and Local Governments*. Retrieved from Washington, D.C.: https://www.epa.gov/sites/production/files/2018-07/documents/epa_slb_multiple_benefits_508.pdf

EPA. (2020). U.S. Electricity Grid & Markets. Retrieved from https://www.epa.gov/greenpower/us-electricity-grid-markets

EPRI. (2020). *DER-VET User Guide*. Retrieved from Palo Alto, CA: https://www.der-vet.com/files/DER-VET_User_Guide_v0.1.1.pdf

FERC. (2018). *Distributed Energy Resources: Technical Considerations for the Bulk Power System*. (Docket No. AD18-10-000). Washington D.C.: Federal Energy Regulatory Commission (FERC)

FERC. (2020). Electric Power Markets - National Overview. Retrieved from https://www.ferc.gov/industries-data/market-assessments/electric-power-markets

Fine, S., Kelly, M., Vaidya, S., D'Costa, P., Reddy, P. M., & Hawkins, J. (2018). *Review of Recent Cost-Benefit Studies Related to Net Metering and Distributed Solar*. Retrieved from https://www.energy.gov/sites/prod/files/2020/06/f75/ICF%20NEM%20Meta%20Analysis_Formatted%20FINAL_Revised%208-27-18.pdf

Flores-Espino, F. (2015). *Compensation for Distributed Solar: A Survey of Options to Preserve Stakeholder Value*. Retrieved from Golden, CO: https://www.nrel.gov/docs/fy15osti/62371.pdf

Frick, N. M., Schwartz, L. C., & Taylor-Anyikire, A. (2018). *A Framework for Integrated Analysis of Distributed Energy Resources: Guide for States*. Retrieved from Berkeley, CA: https://eta-publications.lbl.gov/sites/default/files/lbnl_integrated_der_report_20181127.pdf

Goggin, M. (2017). *Renewable Energy Builds a More Reliable and Resilient Electricity Mix*. Retrieved from Washington D.C.: https://www.awea.org/Awea/media/Resources/Publications%20and%20Reports/White%20Papers/AWEA-Renewable-Energy-Builds-a-More-Reliable-and-Resilient-Electricity-Mix.pdf

Harari, S., & Kaufman, N. (2017). *Assessing the Value of Distributed Solar*. Retrieved from https://cbey.yale.edu/sites/default/files/2019-10/Distributed%20Solar_FINAL.pdf

IREC. (2016). *A REGULATOR'S GUIDEBOOK: Calculating the Benefits and Costs of Distributed Solar Generation* (NHSEA-NP-2). Retrieved from https://puc.nh.gov/Regulatory/Docketbk/2016/16-576/TRANSCRIPTS-OFFICIAL%20EXHIBITS-CLERKS%20REPORT/16-576_2017-03-30_EXH_35.PDF

Kaldellis, J. (2003). Feasibility evaluation of Greek State 1990–2001 wind energy program. *Energy, 28*(14), 1375-1394. doi:10.1016/S0360-5442(03)00121-X

Lantz, E., Sigrin, B., Gleason, M., Preus, R., & Baring-Gould, I. (2016). *Assessing the Future of Distributed Wind: Opportunities for Behind-the-Meter Projects*. Retrieved from Golden, CO: https://www.nrel.gov/docs/fy17osti/67337.pdf

Larsen, J., & Jerndon, W. (2017). *What Is It Worth? The State of the Art in Valuing Distributed Energy Resources*. Retrieved from New York, NY: https://rhg.com/research/what-is-it-worth-the-state-of-the-art-in-valuing-distributed-energy-resources/

NAS. (2017). *Enhancing the Resilience of the Nation's Electricity System*. Retrieved from Washington, D.C.:

NC CETC. (2019). *The 50 States of Solar: Q2 2019 Quarterly Report*. Retrieved from https://static1.squarespace.com/static/5ac5143f9d5abb8923a86849/t/5d3787a2914fef0001f64a2d/1563920295159/Q2_19_SolarExecSummary_Final.pdf

NESP. (2020). *National Standard Practice Manual for Benefit-Cost Analysis of Distributed Energy Resources*. Retrieved from https://www.nationalenergyscreeningproject.org/wp-content/uploads/2019/06/NSPM-for-DERs.pdf

Norris, B. L., Gruenhagen, P. M., Grace, R. C., Yuen, P. Y., Perez, R., & Rábago, K. R. (2015). *Maine Distributed Solar Valuation Study*. Retrieved from https://www.maine.gov/mpuc/electricity/elect_generation/documents/MainePUCVOS-ExecutiveSummary.pdf

NRC. (2005). *Valuing Ecosystem Services*. Retrieved from Washington, D.C.:

Olatayo, K. I., Wichers, J. H., & Stoker, P. W. (2018). Energy and economic performance of small wind energy systems under different climatic conditions of South Africa. *Renewable and Sustainable Energy Reviews, 98*, 376-392. doi:https://doi.org/10.1016/j.rser.2018.09.037

OPUC. (1994). *Investigation-Conservation, Docket UM 551, Order 94-590*. Salem, OR: Oregon Public Utility Commission Retrieved from https://apps.puc.state.or.us/edockets/docket.asp?DocketID=4744

OPUC. (2015). *Investigation to Determine Resource Value of Solar.* Salem, OR: Oregon Public Utility Commission (OPUC) Retrieved from https://apps.puc.state.or.us/edockets/docket.asp?DocketID=19362

Orrell, A., Preziuso, D., Foster, N., Morris, S., & Homer, J. (2019). *2018 Distributed Wind Market Report*. Retrieved from https://www.energy.gov/sites/prod/files/2019/08/f65/2018%20Distributed%20Wind%20Market%20Report.pdf

Payne, H., & Monast, J. (2019). Valuing Distributed Energy Resources: A Comparative Analysis. *Seton Hall Public Law Research Paper Forthcoming*. doi:https://doi.org/10.2139/ssrn.3438043

Rábago, K. R., Libby, L., Harvey, T., Norris, B. L., & Hoff, T. E. (2015). *DESIGNING AUSTIN ENERGY'S SOLAR TARIFF USING A DISTRIBUTED PV VALUE CALCULATOR*. Retrieved from https://www.cleanpower.com/wp-content/uploads/090_DesigningAustinEnergysSolarTariff.pdf

Reilly, J. (2020). *1.2.2.401- DW MIRACL Quarterly Status Report – FY20 Q2* Retrieved from

Reiman, A. P., Homer, J. S., Bhattarai, B., & Orrell, A. C. (2020). *Quantifying Technical Diversity Benefits of Wind as a Distributed Energy Resource*. Paper presented at the 2020 IEEE Power & Energy Society Innovative Smart Grid Technologies Conference (ISGT), Washington, D.C.

SEIA. (2020a). Solar Cost-Benefit Studies. Retrieved from https://www.seia.org/initiatives/solar-cost-benefit-studies

SEIA. (2020b). Solar Industry Research Data 2020. Retrieved from https://www.seia.org/solar-industry-research-data

Sullivan, M. J., Schellenberg, J., & Blundell, M. (2015). *Updated Value of Service Reliability Estimates for Electric Utility Customers in the United States* (LBNL-6941E). Retrieved from Berkeley, CA: https://emp.lbl.gov/sites/all/files/lbnl-6941e.pdf

Sutter, M., Mitchell-Jackson, J., Schiller, S. R., Schwartz, L., & Hoffman, I. (2020). *Applying Non-Energy Impacts from Other Jurisdictions in Cost-Benefit Analyses of Energy Efficiency Programs: Resources for States for Utility Customer-Funded Programs*. Retrieved from Berkeley, CA: https://eta-publications.lbl.gov/sites/default/files/nei_report_20200414_final.pdf

Trabish, H. K. (2018). Locational value of DER is essential to grid planning. So why hasn't anyone found it? Retrieved from https://www.utilitydive.com/news/locational-value-of-der-is-essential-to-grid-planning-so-why-hasnt-anyone/541946/

Woolf, T., Whited, M., Malone, E., Vitolo, T., & Hornby, R. (2014). *Benefit-Cost Analysis for Distributed Energy Resources: A Framework for Accounting for All Relevant Costs and Benefits*. Retrieved from Cambridge, MA: http://www.synapse-energy.com/sites/default/files/Final%20Report.pdf

Zhou, Z., Levin, T., & Conzelmann, G. (2016). *Survey of U.S. Ancillary Services Markets.* Retrieved from https://publications.anl.gov/anlpubs/2016/01/124217.pdf

Pacific Northwest National Laboratory

902 Battelle Boulevard
P.O. Box 999
Richland, WA 99354
1-888-375-PNNL (7665)

www.pnnl.gov