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Grid-Connected Distributed Generation: Compensation Mechanism Basics

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This short report defines compensation mechanisms for grid-connected, behind-the-meter distributed generation (DG) systems as instruments that comprise three core elements: (1) metering & billing arrangements, (2) sell rate design, and (3) retail rate design. This report describes metering & billing arrangements, with some limited discussion of sell rate design. We detail the three possible arrangements for metering & billing of DG: net energy metering (NEM); buy all, sell all; and net billing.

Introduction

Deployment of grid-connected DG systems can be enabled through public policies and regulatory mechanisms, including well-designed *compensation mechanisms*. Compensation mechanisms are the instruments designed to reward the DG system owner for electricity that is self-consumed (if applicable) and/or exported to the utility grid.[5] Compensation mechanisms impact DG deployment because they strongly influence the value proposition of a DG investment for individual customers. A compensation mechanism is composed of three core components:

1. **Metering & billing arrangements**. This element defines how consumption- and generation-related electricity flows are measured and billed. The three options for metering & billing are net energy metering; buy all, sell all; and net billing. The selection of a metering & billing arrangement does not in itself imply an amount of compensation for the DG system owner.[6]

Why Do Compensation Mechanisms Matter?

A well-designed compensation mechanism can help minimize the negative impacts and maximize the value of DG to all stakeholder groups, including distribution utilities, the DG system owner, and other ratepayers (non-DG-system owners). Different compensation mechanisms have been tested in different country contexts, revealing useful lessons for utilities, regulators, and policymakers. Because the distinctions and design elements of different metering & billing arrangements can be easily misunderstood, this brief aims to clarify the options available to stakeholders interested in using compensation mechanisms to facilitate DG deployment around the world.

Public Policy and Regulatory Mechanisms to Address DG

Compensation mechanisms are one of several policy and regulatory options that can address challenges associated with deploying DG systems. Others include:

- Direct financial incentives (e.g., cash rebates, tax credits)
- Low-interest financing programs
- Clean electricity standards (for clean DG systems)
- Streamlined interconnection processes and standards
- Revenue decoupling.

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1. National Renewable Energy Laboratory
2. Regulatory Assistance Project
3. Lawrence Berkeley National Laboratory
4. International Energy Agency
5. We chose to classify clean energy certificates and other volumetric performance incentives as financial incentives rather than compensation mechanisms; therefore, these are outside the scope of this report.
6. NEM is an exception to this statement—the customer is by definition credited at the full volumetric retail rate for any electricity exported within a given billing period.

2. **Sell rate design.** This element defines the exact level of compensation a DG system owner receives for electricity exported from the DG system to the utility grid. The sell rate applies to distinct quantities, depending on the metering & billing arrangement selected (this will be described in more detail below). Sell rates can be static, remaining fixed over the length of an interconnection contract. They can also be more dynamic in nature, changing with time or by location with various degrees of granularity.

3. **Retail rate design.** This component defines the retail tariff structure and exact purchase rates the DG system owner must pay for electricity from the grid, and thus which costs the DG system owner can avoid if they self-consume the electricity produced by their DG system.[7]

COMPENSATION MECHANISM COMPONENTS AND OPTIONS

METERING & BILLING ARRANGEMENTS

• NEM • Buy all, sell all • Net billing

SELL RATE DESIGN

• Static rates • Dynamic rates

RETAIL RATE DESIGN

Large diversity of options

Figure 1. Primary compensation mechanism components

Who Is Affected When a Customer Installs DG?

Installing a DG system can have financial implications for utilities and ratepayers in addition to system owners. Utilities often experience lost electricity sales under metering & billing arrangements that allow DG system owners to self-consume electricity prior to export (i.e., NEM and net billing). Self-consumption allows DG system owners to reduce or eliminate the variable charge portion of their electricity bills. This may lead to an underrecovery of the utility's fixed costs because utilities often recover some of the costs incurred for maintaining the network from the volumetric energy charge component of their electricity tariff.

DG systems may also lead to an increase or decrease in required utility grid infrastructure investments. If additional investments are warranted, utilities may pass these costs on to customers through rate increases. If investments can be deferred or avoided, rates may decrease.

The net effect of DG adoption on nonadopting customers therefore depends on the entire set of costs and benefits caused by DG adoption. If the net effect of DG adoption is determined to be a net cost, then nonadopting customers may experience an increase in their bills. This outcome is sometimes called cross-subsidization or cost shifting because DG adoption sometimes shifts costs onto nonadopting customers.

A well-designed compensation mechanism mitigates negative effects, reinforces positive effects, and supports the full and fair value of DG to distribution utilities, DG system owners, and non-DG-owning ratepayers.

Other important components of any compensation mechanism include:

Contract length: The contract length specifies how long the DG system owner and utility will participate in a specific compensation arrangement.

Crediting terms: These terms define whether compensation is granted as bill credit (either in currency or kilowatt-hours) or directly as cash payments. Crediting terms determine the extent to which credit can be carried over between billing cycles and the circumstances under which credits might expire and/or cash payments are paid to the DG system owner.

System size cap: A system size cap sets the maximum individual system size that can participate under a given compensation scheme. The cap can be capacity-based (kilowatts) or percentage-based (e.g., 120% of annual consumption).

Credit reconciliation period: A predetermined time at which a customer's banked kilowatt-hour (kWh) credits expire (if under net energy metering).

Netting frequency: If the system owner consumes DG electricity, netting frequency is the time period under which DG production and customer electricity consumption are summed and measured for billing purposes.

7. Retail rate design has been extensively documented in the literature and will not be discussed in this report. Lazar and Gonzalez (2015) and Linvill, Shenot, and Lazar (2013) provide background on this important aspect of compensation mechanism design.

Tools and models are available to help customers understand the value proposition of a DG system given a particular compensation mechanism. One such example is the System Advisor Model, or SAM (*https://sam.nrel.gov*), a techno-economic tool developed by the National Renewable Energy Laboratory (NREL). SAM can help decision makers analyze cost, performance, and financing of any grid-connected DG. SAM simulates individual systems and calculates a variety of metrics for a given DG system, including the levelized cost of energy, net present value, and simple payback period. SAM can model the impact of net energy metering; buy all, sell all; and net billing on the aforementioned metrics over a range of static and dynamic sell rates and retail rate structures.

Metering & Billing Arrangements for DG

This report describes the metering & billing arrangement schemes for DG compensation mechanisms. While there is undoubtedly a diversity of terminology and parlance around compensating DG, **we assert that there are effectively only three types of metering & billing arrangements: net energy metering; buy all, sell all; and net billing.** Public policies can specify the exact type of metering & billing arrangement a utility must offer, or provide latitude and guiding principles for regulators or utilities to decide. While an individual DG system owner can only utilize a single metering & billing arrangement, programs can provide more than one option. Specific customer types or system size specifications can be assigned distinct metering & billing arrangements, or multiple options can be offered to all or specific customer types. This document walks readers through the distinctions between metering & billing arrangements so that decision makers are empowered to make informed decisions on compensating distributed generation.

1. Net Energy Metering

Net energy metering, often referred to as net metering, allows a DG system owner who is generating more electricity than they are consuming to export that excess energy to the utility grid, receiving a credit in kilowatt-hours. The credit can be applied to offset consumption of electricity within the current billing cycle (e.g., one month) and often in future billing cycles as well. The DG system owner is billed for *net* energy consumption during a billing cycle (i.e., what the system owner consumes during the billing cycle, less what the DG system generates during the same period). In practice, the DG system owner's consumption meter is allowed to spin backward when the DG system is generating more than the system owner is using, decreasing the meter's measurement of the system owner's net kilowatt-hour consumption. NEM requires either a single bidirectional meter (with an optional export validation meter, if gross generation measurements are desired[8]) or two unidirectional meters (see Figure 2).

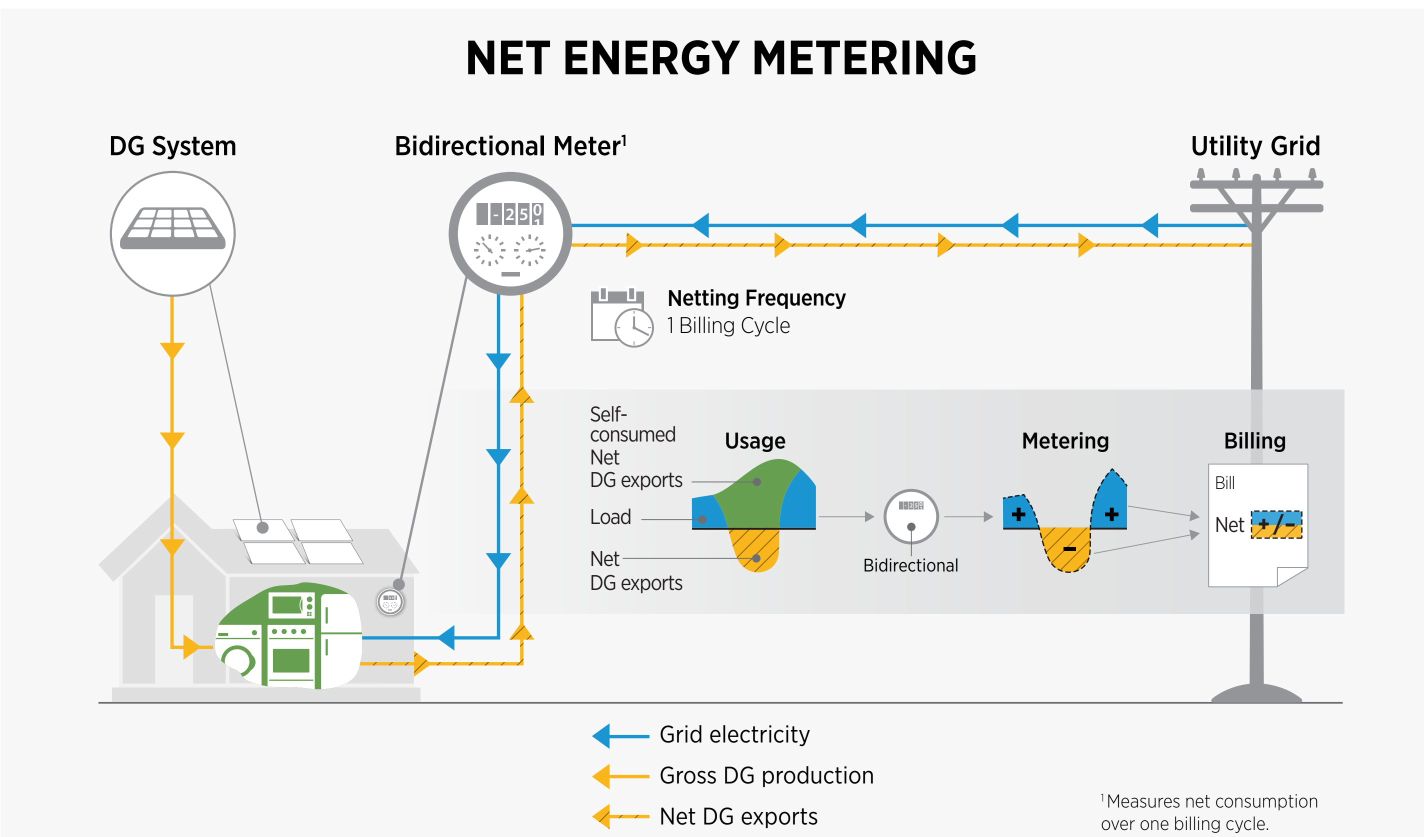

Figure 2. NEM schematic

8. Gross generation measurements for DG systems are often desired to inform: distribution network planning and investment strategies for utilities, goal tracking (i.e., progress toward clean energy generation targets), and/or validation of claimed levels of production to provide financial incentives (i.e., clean energy certificates).

Table 1. NEM Summary

Net Energy Metering	
Is self-consumption allowed in this scheme?	*Yes*
Netting frequency	*Billing cycle*[a]
Are kilowatt-hour banked *within* billing periods?	*Yes. Kilowatt-hours exported to the grid can be applied to consumption at other times within the billing cycle. Under NEM, the grid is effectively used as a bank for kilowatt-hours within the billing cycle.*
Can kWh credits and monetary credits be carried over *between* billing periods?	*Allowing for the inter-month banking of kilowatt-hours is quite common for NEM programs. However, it is not an absolute requirement to implement NEM. Kilowatt-hour credits could hypothetically expire at the end of each billing cycle. This would still constitute NEM as long as banking within each billing cycle is allowed.*
What quantities are being measured and billed/credited?	*Net consumption over the billing cycle is measured. Excess kWh credits are commonly allowed to be carried over and applied to future billing cycles (this quantity must be tracked by the utility billing department).*
Do credits expire?	*This depends on the exact NEM design specifications. In some cases, the kWh credits never expire, though it is more common for them to expire after a finite number of billing cycles (e.g., 12 months) or at the end of a calendar year, after which they are either forfeited or credited at a predetermined net excess generation rate, usually between zero and the full retail electricity rate.*
How much is DG production worth to the customer?	*If a kWh is self-consumed, it is implicitly worth the customer's full retail rate. If a kWh is banked and applied as credit at a later time, it is also implicitly worth the full retail rate. If a banked kWh expires (e.g., after 12 months), it may be credited at the predetermined net excess generation rate. If a DG system owner is on a time-of-use rate,*[b] *DG is implicitly compensated at the applicable rate at the time the generation occurs, and could be worth more during times of high electricity demand.*

a. To our knowledge, there is one exception to this design aspect. Denmark offers what they term a "net-energy-metering" arrangement; however, netting is performed on an hourly basis, after which any net excess generation is converted into credit at a predefined sell rate. While the Danish refer to this arrangement as net energy metering, under the definitions set forth in this report, we would refer to this as net billing with an hourly netting frequency. Regardless of the exact nomenclature, the Danish approach appears to be a metering & billing arrangement that combines elements of both net energy metering and net billing.

b. Under time-of-use (TOU) rates, kWh credits generated in a given TOU period are netted to consumption in the corresponding period.

Table 2. Benefits and Challenges of NEM

Benefits	Challenges
• NEM is a relatively simple mechanism for both DG system owners and utilities to understand and implement. • NEM does not require significant regulatory changes; it can easily be incorporated on top of existing retail electricity rates. • NEM can often use existing metering infrastructure, so it does not typically require the purchase of an additional meter.	• NEM is often considered an imprecise instrument for compensating excess generation because the retail rate may not reflect the value of the DG electricity to the utility. • Because it requires self-consumption of electricity prior to export, NEM leads to reduced utility sales. • Utilities *may* suffer revenue sufficiency issues if the retail rate paid to customers for excess generation is higher than the actual DG value. This challenge is negligible at low levels of DG adoption but may materialize as adoption levels increase (Bird et al. 2013). • Non-DG-system owners may experience retail rate increases if DG deployment increases utility costs and/or reduces utility electricity sales. Again, this may be negligible at low levels of DG adoption.

What About Feed-in Tariffs?

In the context of DG, we define a feed-in tariff (FiT) as a predetermined sell rate for electricity that is fed back into the grid. In practice, it is often (but not always) associated with a buy-all, sell-all scheme. *It is not a metering & billing arrangement in itself.* The term FiT has been used to describe both buy-all, sell-all and net-billing arrangements. In some settings, FiT policies have remained the same in name, but over time have shifted from buy-all, sell-all to net-billing schemes (often in concert with lowering the FiT sell rate below the retail rate of electricity). Germany is an example of this dynamic: the country's original solar feed-in-tariff policy provided customers with sell rates above the retail rate under a buy-all, sell-all scheme but has evolved to allow for self-consumption (and offer lower rates for exported energy). Australia refers to its DG policy as a FiT, offering both a "net-FiT" (i.e., net-billing) and a "gross FiT" (i.e., buy-all, sell-all) option. In an effort to create clear and unambiguous distinctions between the three metering & billing arrangements, we have chosen to omit use of the term "feed-in tariff" throughout this report.

A DG system owner under NEM is able to "bank" kilowatt-hours *within* a billing cycle, as the meter only reports net consumption at the end of the billing cycle. During a billing cycle (e.g., a month), a DG system owner's produced electricity may exceed electricity consumed from the grid; in this case, DG system owners can typically bank those credits *between* billing cycles (i.e., carry the balance forward to the next billing cycle). These credits can be banked indefinitely, or may expire at a predetermined time (often referred to as the "credit reconciliation period," defined above) and be credited at a predetermined sell rate (oftentimes lower than the retail rate), depending on the specific NEM program.

NEM provides benefits to various stakeholders but also poses challenges, as outlined in Table 2.

2. Buy All, Sell All

A buy-all, sell-all arrangement offers a standard sell rate to a DG system owner for *all* of the DG electricity they generate. Buy-all, sell-all schemes commonly offer a fixed long-term

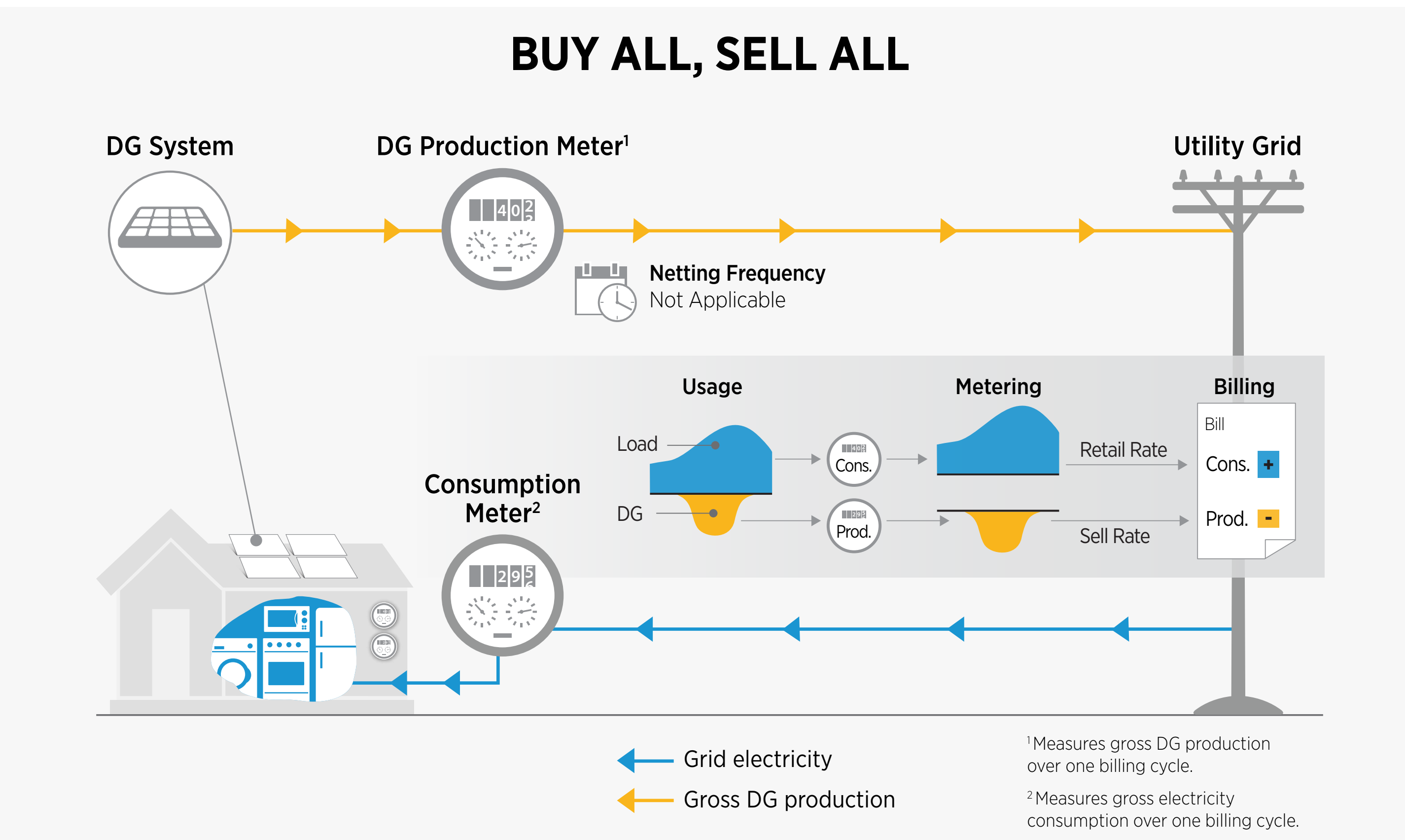

Figure 3. Buy-all, sell-all schematic

Table 3. Buy-All, Sell-All Summary

Buy All, Sell All	
Is self-consumption allowed in this scheme?	*No*
Netting frequency	*Consumption and production are not physically netted, so netting frequency is not an applicable design element to consider. However, these quantities are financially netted (typically at distinct values) on customer bills.*
Are kilowatt-hours banked *within* billing periods?	*No*
Can kWh credits or monetary credits be carried over *between* billing periods?	*Kilowatt-hour credits are not granted under a buy-all, sell-all scheme. If a utility bill credit is granted, it can likely be carried over, depending on the specific crediting terms.*
What quantities are being measured and billed/ credited?	*1) Gross consumption over the billing cycle is measured. There is no difference in consumption measured and billed between pre-and post-DG system ownership.* *2) Gross DG production over the billing cycle is measured.*
Do credits expire?	*If a utility credit for exported DG is granted rather than a direct cash payment, it may or may not expire based on the specific crediting terms.*
How much is DG production worth to the customer?	*The kilowatt-hours generated by the DG system are compensated at a predetermined sell rate (either fixed or dynamic).*

Table 4. Benefits and Challenges of Buy-All, Sell-All Mechanisms

Benefits	Challenges
• Buy-all, sell-all mechanisms provide simple and predictable value propositions to both DG system owners and utilities over an agreed-upon contract length. • Because buy-all, sell-all mechanisms do not change customer electricity consumption patterns, there is less of an incentive for utilities to attempt to recover costs through additional fixed charges. Cross-subsidization issues are also minimized for this reason. • Buy-all, sell-all mechanisms do not require retail rate redesign. • Buy-all, sell-all prices can be adjusted throughout the lifetime of a program for new customers to steer the market toward the desired level of DG deployment.	• If the value of DG is not well understood, buy-all, sell-all mechanisms can potentially over- or undercompensate DG system owners, potentially leading to cost-shifting if buy-all, sell-all program costs are fully passed through to the consumer. • If a buy-all, sell-all mechanisms rate is lower than the retail rate (a very common practice), customers may be incentivized to illegally wire their DG system to self-consume electricity instead of exporting it all to the utility grid, potentially leading to traditional revenue sufficiency and cross-subsidization issues.[a]

a. This scenario would effectively result in a metering & billing arrangement of net billing with net exports rewarded at the sell rate. Illegal wiring is perhaps more likely in settings where utility enforcement is unlikely. There are a range of processes and technologies available to decrease the likelihood of this outcome.

contract price for energy exports. Unlike NEM, buy-all, sell-all customers do not physically consume the electricity their DG systems produce.[9] A buy-all, sell-all customer continues to be billed for all the electricity they consume at the applicable retail rate, independent of electricity generated by their DG system. The DG system exports all electricity directly to the utility grid, and the system owner is compensated at a predetermined and typically fixed sell rate either through utility bill credits or in cash. In other words, in a buy-all, sell-all scheme, the DG system owner continues to buy all electricity from the utility and sell all electricity produced by the DG system to the utility.

While buy-all, sell-all sell rates are typically set at a fixed volumetric rate, a dynamic (nonfixed) sell rate can also be applied. These more dynamic sell rates may include TOU pricing or even more granular energy market pricing schemes. There are many approaches to setting a fixed or dynamic sell rate for exported generation.[10] The level at which the sell rate is set will influence the value proposition for the customer, which will impact DG deployment levels.

A buy-all, sell-all scheme requires a DG production meter in addition to the pre-existing consumption meter (see Figure 3).

Buy-all, sell-all arrangements provide benefits to various stakeholders but also pose challenges, as outlined in Table 4.

3. Net Billing

In net billing, a DG system owner can consume electricity generated by their DG system in real time and export any generation in excess of on-site consumption to the utility grid. In this way, net billing is akin to NEM. However, under net billing, banking of kilowatt-hours within a billing cycle to offset future consumption is not allowed—in fact, credits are not granted in kilowatt-hour terms at all. Rather, all net energy exports are metered and credited at a predetermined sell rate the moment they are injected into the grid.

If, at any point the customer is generating more electricity than they are using on-site, then the customer is *net exporting*—injecting electricity into the grid. A net electricity export meter

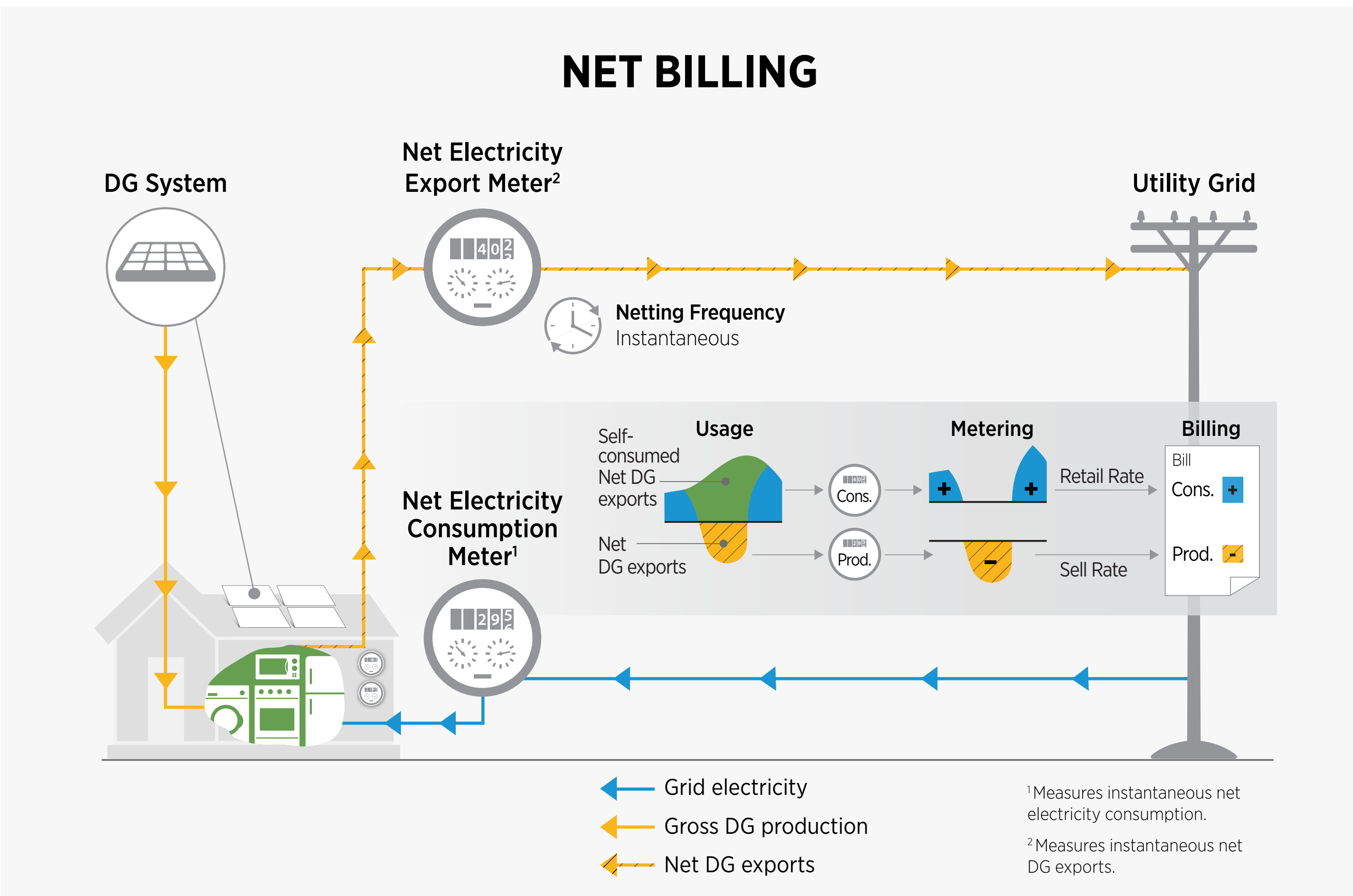

Figure 4. Net billing schematic

9. In the event that a shift in policy begins to allow self-consumption with a buy-all, sell-all scheme (this is often done in concert with lowering the sell rate below the retail rate to encourage self-consumption), under the definitions set forth in this paper, we would refer to such an arrangement as net billing.

10. See, e.g., Couture et al. (2010).

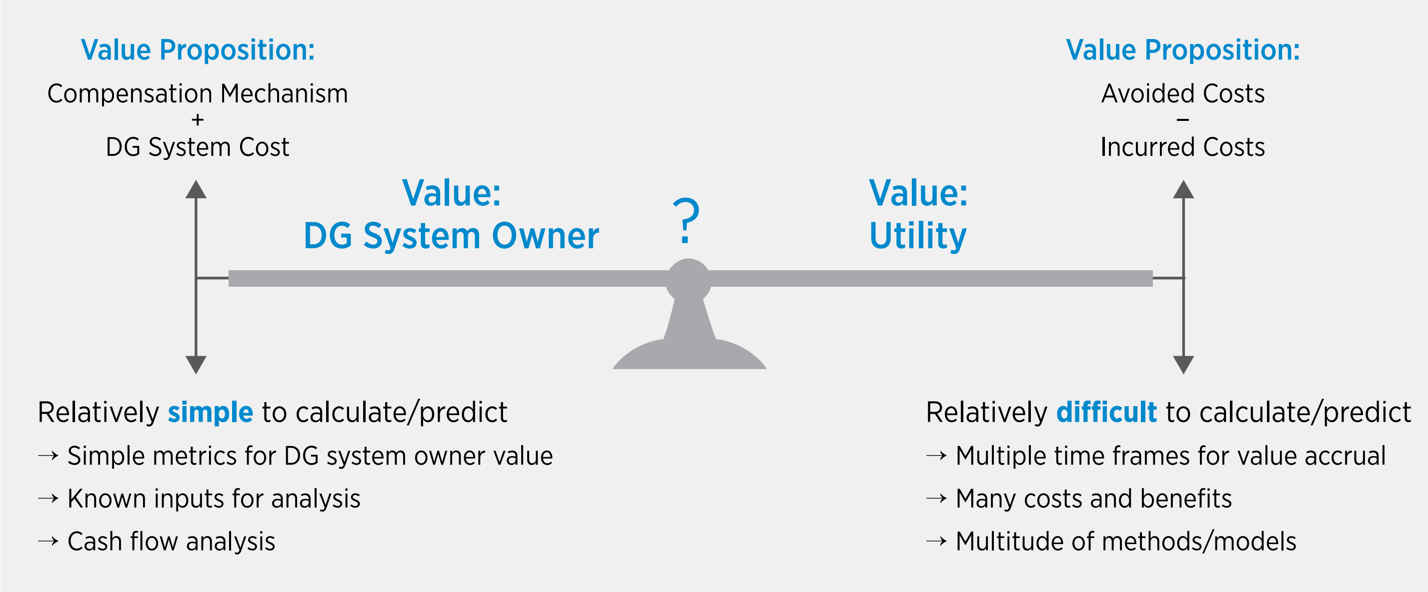

Figure 5. Determining the relative value of a DG system

Note: Noneconomic drivers to deploy DG also exist, including desire for self-supply or backup power, environmental stewardship, support for local small- and medium-sized enterprises, and others.

would then spin forward, measuring the injected kilowatt-hours, and the customer would receive a predetermined sell rate for this exported electricity. Similarly, if at any point the customer is using more electricity than they are producing, then the customer is *net consuming* and drawing electricity from the grid. A net electricity consumption meter would then spin forward, measuring the electricity being drawn from the grid, and the customer would pay the applicable retail rate for this energy. Neither the net electricity export meter nor the net electricity consumption meter have the ability to "spin backward" during a billing cycle under net billing—the meters can only spin forward when measuring net consumption and net exports in real time. These quantities are measured in real time and billed/credited separately at the end of the billing cycle.

A DG system owner's meter(s) must at least record (1) real-time *net* electricity consumption, and (2) real-time *net* electricity exports. This can be done with either a single smart meter or with two separate meters. Figure 4 portrays net billing with two meters for illustrative purposes.

Net billing provides benefits to various stakeholders but also poses challenges, as outlined in Table 6.

Determining DG Value

At the heart of designing a compensation mechanism lies two questions: What is the value proposition of DG to the utility and ratepayers, and how does it change over time? Is the average level of DG compensation greater than, equal to, or less than

What Is a "Value of Solar" Rate?

A Value of Solar (VoS) rate is a sell rate that a solar DG system owner receives for exported DG electricity that is designed to reflect the value of the electricity to the utility or to society. *VoS is not in itself a metering & billing arrangement or compensation mechanism*. Rather, it is a *sell rate* that can be applied to either:

- Net excess generation credit for NEM scheme
- Sell rate for buy all, sell all
- Sell rate for net billing.

A VoS rate is determined through a bottom-up calculation that accounts for the benefits and costs of the solar DG system to the grid. VoS sell rates may be locked in for a fixed contract length or can be revisited periodically to reflect changes in solar DG value over time. More granular value-based sell rates can also be implemented to reflect market conditions at specific times and locations. However, this granularity may add complexity to billing procedures and increase the perceived risk of a solar DG investment.

Table 5. Net-Billing Summary

Net Billing	
Is self-consumption allowed in this scheme?	*Yes*
Netting frequency	*Instantaneous*[a]
Are kilowatt-hours banked *within* billing periods?	*No*
Can kWh credits or monetary credits be carried over *between* billing periods?	*Kilowatt-hour credits are not granted under a net-billing scheme. If utility credit for net exported DG is granted rather than a direct cash payment, that credit can likely be carried over between billing cycles (depending on the specific crediting terms).*
What quantities are being measured and billed?	*1) Instantaneous net consumption throughout the billing cycle is measured. The DG system owner pays the applicable retail rate.* *2) Instantaneous net exports throughout the billing cycle are measured. The DG system owner receives the applicable sell rate, which is often but not always a static rate.*
Do credits expire?	*If a utility credit for net exported DG is granted, rather than a direct cash payment, it may or may not expire depending on the specific crediting terms.*
How much is DG production worth to the customer?	*If a kWh is self-consumed in real time, it is implicitly worth the full retail rate. Any net exported kilowatt-hours are compensated at the applicable sell rate, which is typically less than the retail rate.*

a. A more precise—but also more esoteric—definition of net billing would be a self-consumption metering & billing arrangement *where the netting frequency is less than the billing cycle*. In practice, net-billing arrangements nearly always have an instantaneous netting frequency.

Table 6. Benefits and Challenges of Net Billing

Benefits	Challenges
• Net billing allows for a more precise approach to compensating electricity being injected into the grid relative to NEM because the sell rate for exported electricity can be set to match the value to the utility. • Net billing can encourage self-consumption (particularly by setting sell rates as less than retail rates), if desired by regulators and policymakers.	• Because net billing requires self-consumption of electricity prior to export, it can lead to lost utility sales. • Utilities *may* suffer revenue sufficiency issues if the net export rate paid to customers for excess generation is higher than the actual DG value. This challenge is negligible at low levels of distributed generation penetration but may materialize as penetration levels increase (Bird et al. 2013).

Table 7. Summary of Metering & Billing Arrangements

	Net Energy Metering	Buy All, Sell All	Net Billing
Self-Consumption Allowed	Yes	No	Yes
Netting Frequency	Billing Cycle	Billing Cycle	Instantaneous
Quantities Measured and Billed	*1) Net consumption over the billing cycle* *2) Net excess kWh credits to be compensated or banked*	*1) Gross consumption over the billing cycle* *2) Gross DG production over the billing cycle*	*1) Instantaneous net consumption throughout the billing cycle* *2) Instantaneous net exports throughout the billing cycle*
Sell Rate Applicability	Accrued net excess generation credits that have expired after credit reconciliation period	Gross DG production	Instantaneous DG exports
Value of DG to Customer	• Retail rate for self-consumption and exported generation • Sell rate for expired net excess generation credits	• Sell rate for gross DG production	• Retail rate for instantaneous self-consumption • Sell rate for instantaneous net DG exports
Intra-Billing Cycle Banking of Kilowatt-Hours	Yes	No	No
Key Benefits	Simplicity	No reduced sales for utility Potential for more precise compensation for DG production	Potential for more precise compensation for net injections Can encourage self-consumption (if desired)
Challenges	Reduced utility sales Retail rate compensation may not be aligned with DG value	Customers may illegally wire for self-consumption if more economically desirable and utility enforcement unlikely	Reduced utility sales

the value of DG to the utility? These questions can be quite challenging to answer. On the one hand, the metering & billing arrangements, the sell rate, the retail rate of electricity, and the DG system costs are known, and hence an average compensation level for DG can be estimated based on generation from the DG system and customer load profiles. However, from the utility perspective, the avoided costs less the incurred costs of a DG system are more difficult to quantify (Figure 5) and may be realized over different time frames.

When assessing utility impacts and cost shifting, it is essential to do so from both short-term and long-term perspectives because the benefits of DG are not always realized immediately. In many circumstances, short-term rate increases resulting from reduced electricity sales can be followed by longer-term decreases resulting from deferred or avoided investments and other DG benefits. The true long-term system value of DG systems may outweigh immediate-term cost shifting impacts (Woolf et al. 2016).

The sell rate for DG electricity exported to the grid can be higher or lower than the value of that electricity to the utility. The value of exported DG electricity to the utility is frequently not well understood, and utilities may overcompensate or undercompensate DG system owners. Overcompensation can exacerbate cost shifting to non-DG-system owners and can, in some cases, accelerate deployment; conversely, undercompensation can shift additional costs to DG system owners and potentially stymie DG deployment.

Given this complexity, it is critical that DG analyses that examine DG programs distinguish between short- and long-term impacts, and also consider different stakeholder perspectives to achieve a balanced and holistic understanding of DG impacts at large. There are numerous methodologies for quantifying DG costs and benefits (Denholm et al. 2014). As these methodologies evolve and technologies (e.g., communications, smart grid) advance, policymakers and regulators will glean more insight into DG's value to customers, utilities, and society.

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