TECHNICAL REPORT 017/21

# FROM SUN TO ROOF TO GRID

## *Distributed PV in Energy Sector Strategies*

ESMAP

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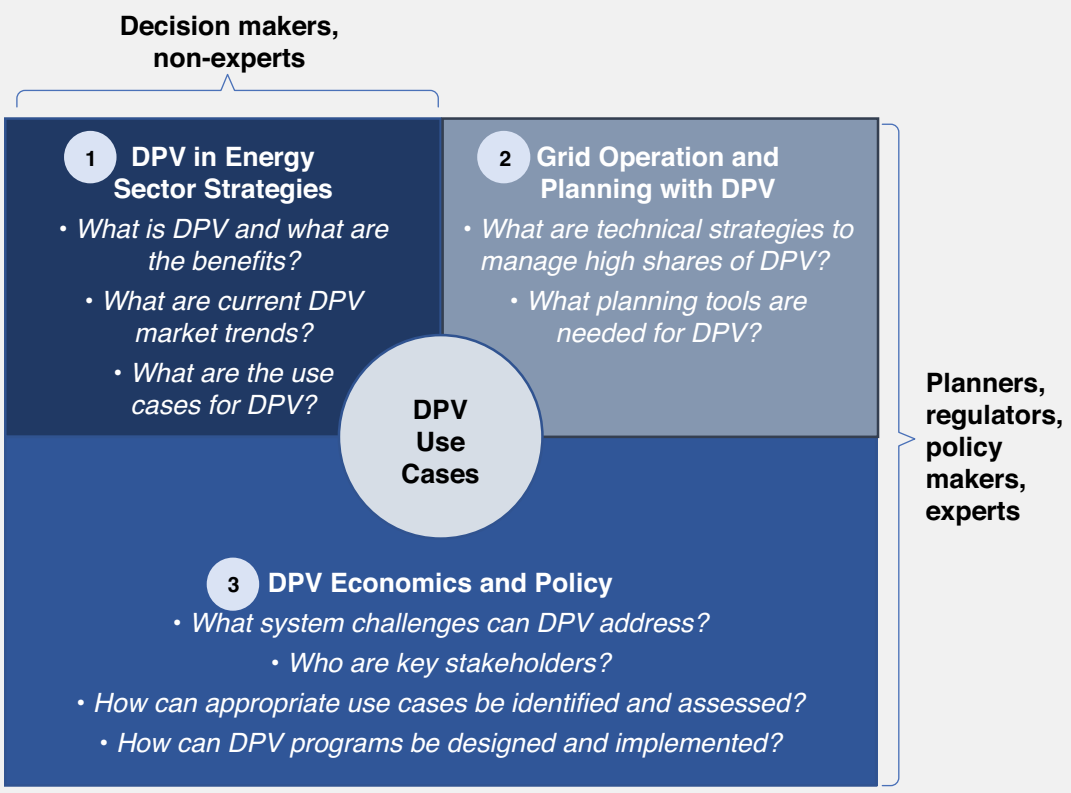
# ABBREVIATIONS

| | |
|---|---|
| DPV | distributed photovoltaics |
| ESMAP | Energy Sector Management Assistance Program |
| GW | gigawatt |
| IEA | International Energy Agency |
| kW | kilowatt |
| kWh | kilowatt-hour |
| MW | megawatt |
| O&M | operation and maintenance |
| PV | photovoltaics |
| SME | small- and medium-sized enterprise |
| STEM | science, technology, engineering, and mathematics |
| T&D | transmission and distribution |
| VPP | virtual power plant |
| W | watt |

## ABOUT THE SERIES, "FROM SUN TO ROOF TO GRID"

This report is the first in a series called "From Sun to Roof to Grid." The series deals with distributed photovoltaics (DPV), the world's fastest-growing technology for local power generation. Produced by World Bank's Energy Sector Management Assistance Program (ESMAP), the series targets various audiences—from policy makers to regulators and utilities—and provides a menu of ideas, approaches, and examples to resolve challenges to the deployment of DPV and realize the benefits it can bring. The relationship between the three reports of the series is depicted below.

**RELATIONSHIP OF REPORTS AND INTENDED AUDIENCES OF THE SERIES**




The series aims to show stakeholders how to take full advantage of this low-cost, easy-to-install modular technology, whether in a large, stable power system or in a small system, such as those found on islands or even in regions marked by fragility, conflict, and violence.

This report, "Distributed PV in Energy Sector Strategies," is an overview of DPV in different country contexts; it is aimed at energy ministries and other decision-makers. Chapter 1 introduces key concepts and the recent status of the DPV market. It also highlights key potential value propositions of DPV for different stakeholders, including consumers, utilities, governments, and society as a whole. Chapter 2 presents nine specific ways in which distributed photovoltaics (PV) is or could be used to solve problems faced in low- and middle-income country contexts. These "use cases" focus on discrete issues and are grounded in real examples from country projects. In practice, two or more use cases may be combined to generate synergies in a single project or scheme.

Reaping benefits of DPV for all stakeholders will depend on effective planning, regulation, and sustainable financing and business models—all of which are needed to mitigate the risks that poorly deployed DPV can pose to utilities, as well as for the long-term viability of distributed energy resources.

Technical considerations from a power system perspective are covered in the second report of the series, "Grid Operation and Planning with Distributed PV," while strategic objectives, cost-benefit analyses, regulatory issues, and business models are detailed in the third report, "Distributed PV Economics and Policy." Taken together, these reports (and their key messages for different stakeholders) aim to enable low- and middle-income countries to harness power from the sun to benefit all consumers connected to the grid.

For more information, visit www.worldbank.org/energy and www.esmap.org.

## ACKNOWLEDGMENTS

This report has been prepared as an activity of the World Bank's Energy Sector Management Assistance Program (ESMAP) by a task team led by Alan David Lee and Zuzana Dobrotkova, under the guidance of Rohit Khanna and Sheoli Pargal, with team members Torrey Beek, Sandra Chavez, Thomas Flochel, Tarek Keskes, Simon Müller, Claire Nicolas, and Chong Suk Song. The team gratefully acknowledges contributions and feedback from colleagues and associates including, but not limited to, Niki Angelou, Andrea Arricale, Pierre Audinet, Heymi Bahar, Nate Blair, Toby Couture, Rutu Dave, Gabriela Elizondo, Julieta Giraldez, Abhinav Goyal, Veronika Gyuricza, Tatyana Kramskaya, Wojciech Krawczyk, Jeremy Levin, Luiz Maurer, Monali Ranade, Ashok Sarkar, Inka Schomer, Yanqin Song, and Owen Zinaman. Thanks also to Steven Kennedy for editing and Veronica Gadea for graphic design. All views expressed and any shortcomings are the authors.


Credit: World Bank.

# KEY MESSAGES

**As the world's fastest-growing local energy technology, distributed photovoltaics (DPV) has upended the traditional paradigm of one-way power flow from the grid to consumers.** Solar electricity systems located close to grid consumers—known here as DPV—empower consumers to produce electricity for themselves and for the grid. Thanks mainly to falling PV costs, DPV has become a viable way to meet energy needs for a widening array of consumers. Worldwide, installed capacity of DPV exploded from just a few megawatts (MW) in 2000 to 250 gigawatts (GW) in 2019; and it is forecast to exceed 500 GW by 2025.

**Utilities may be positively or negatively impacted, depending on how they are deployed; a strategic approach to DPV's role in the power sector is thus essential.** DPV generally falls outside the purview of traditional power sector planning and grid electricity tariff design. Poorly managed, DPV scale-up can then erode utility finances and interfere with grid operation. Yet, as explained in this report, well-managed DPV can benefit not only DPV owners but also contribute to reliable grid operation and a financially sound electricity sector.

**DPV offers multiple types of benefits relevant for low- and middle-income countries,** especially when it can reduce electricity costs and widespread dependence on diesel generators. DPV can improve affordability with zero operating costs and minimal maintenance. It can improve service quality, including to power islandable microgrids, when coupled with backup power devices, such as battery storage. Since it does not rely on fossil fuels, DPV can enhance energy security and improve resilience to economic shocks caused by volatile fuel prices. Crucial especially in the context of energy transitions, DPV can also benefit broader society through job creation, inclusive economic growth, and increased consumer ownership and choice over energy supply. Displacing combustion of polluting fuels also benefits human health and the environment.

**This report catalogs nine ways that DPV can be used to meet distinct development needs, from use cases already common in countries to emerging and innovative opportunities.**

1. **Bill reduction** *(common)*: Consumers use DPV to displace purchases of grid electricity and lower electricity bills. The impact on utility revenues (negative, neutral, or positive) depends on the level and design of prices for grid electricity and for DPV electricity fed to the grid.

2. **Least-cost backup** (*common*): DPV—often combined with batteries—can provide customers with an independent power supply to help cope with an unreliable grid and reduce the use of backup generators.

3. **Least-cost generation** *(emerging*): DPV may minimize costs of new generation capacity from the perspective of the power system, especially in places with land constraints.

4. **Transmission and distribution alternative** *(emerging)*: DPV may be a lower-cost alternative to the capital expenses of power line upgrades and thus help avoid or defer costly grid expansion (also known as "non-wire alternative").

5. **Utility bootstrap** *(opportunity)*: A distribution company may use DPV, possibly in a microgrid, to improve service for a targeted set of consumers and thus build trust and increase bill collection.

6. **Ancillary services** *(opportunity)*: DPV, especially in combination with batteries, can provide a range of services, such as frequency regulation and voltage support, to the grid.

7. **Community social support** *(emerging)*: Medium-to-large DPV systems can benefit low-income communities through direct connections and/or subscriptions, allowing those specific consumers to reduce their electricity bills, even if they don't have PV on their rooftop.

8. **Financial loss reduction** *(emerging)*: DPV systems installed to serve consumers in chronic arrears to the utility may ease financial pressure on both those consumers and the utility that serves them.

9. **Box solution** *(common)*: A preassembled DPV plus battery system meets urgent power needs, such as when the grid becomes unavailable following a disaster.

**From this "menu" of DPV use cases, energy ministries and other decision- makers can assess which would make sense for the given context to inform power sector strategy and program design.** Two or more use cases may be combined to generate synergies in a single project or scheme, and be combined with other distributed energy resources such as energy efficiency and electric vehicle charging. Utility revenues can be protected through well-designed regulation and pricing that ensures project viability while fairly allocating DPV costs and benefits among stakeholders. Decisions should be based on transparent assessments comparing DPV and other energy resources. Government, utilities, consumers, or third-party providers may variously drive the use case, as illustrated by country examples from China, India, Gaza, Nigeria, Pakistan, Maldives, Vietnam, and Yemen. Unlocking the potential benefits of DPV calls for developing and implementing policies and DPV programs with streamlined processes for permitting and targeted upgrades to grid planning and operations, as elaborated in other reports of this series.

# 1: WHAT IS DISTRIBUTED PV, AND WHY IS IT IMPORTANT?

Power systems around the world are being irrevocably changed by the generation technology known as "distributed photovoltaics" (DPV). Thin and modular solar photovoltaic (PV) cells can be installed in myriad ways on or near sites of electricity consumption. This distinguishes them from other power generation technologies that occupy a large amount of space and transmit energy over long distances to consumers. By contrast, DPV systems of up to several megawatts (MW) can be installed on rooftops, as canopies above irrigation canals, or in floating arrays on industrial ponds. Solar cells are even being integrated directly in construction materials such as window glass, roof tiles, and the surfaces of sidewalks and highways. For the purpose of this series of reports, DPV is defined broadly as PV systems located close to consumers of the electricity generated, with a focus on consumers connected to an electricity grid.[1] DPV is growing alongside a range of other distributed energy resources such as batteries, demand-side energy efficiency, and demand-response mechanisms.

The result is the rise of a new entity in the power sector: people or facilities that actively produce as well as consume electricity.[2] Unlike typical consumers of grid electricity, these new actors generate some or all of their own electricity instead of buying it from the grid. If they have surplus energy and are technically able and permitted to do so by regulations, they may also feed electricity into the grid for use elsewhere. At scale, this phenomenon has far-reaching implications for all stakeholders in the power sector: consumers, policy makers, utilities, regulators, planners, and grid operators. How can the benefits, costs, and risks of grid-tied DPV be managed to fairly balance different interests? How much should DPV generators be compensated for generation fed to the grid? Under what circumstances should DPV be limited or encouraged? Such questions are being asked around the world, and the answers vary by country and by sector.

If poorly managed, DPV can erode utility finances and interfere with grid operation at the expense of consumers. Yet low- and no-cost solutions—technical, financial, and institutional—can eliminate those risks. Sound planning, the right business models, effective regulation, and timely capacity building are the keys to enabling utilities and other stakeholders to exploit opportunities and manage risks. A starting point is to consider what problems DPV might solve in different contexts. That is the focus of this report.

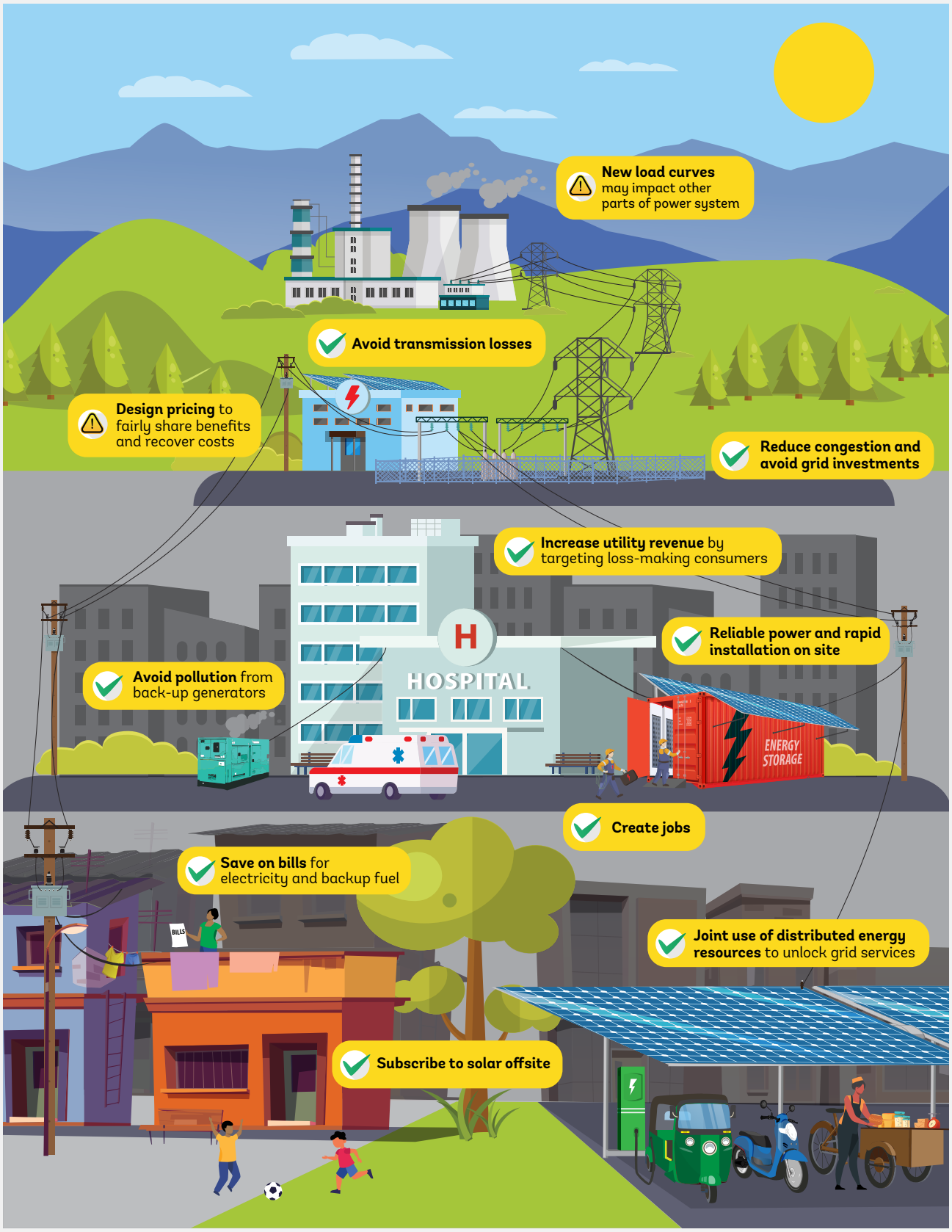
## MULTIPLE BENEFITS OF DPV

For low- and middle-income countries, DPV can contribute to the goal of reliable, affordable, and clean energy for all. It can be deployed directly by consumers, from individual households to large businesses, with zero operating costs and minimal maintenance. As figure 1.1 shows, the cumulative contribution from DPV to power systems and the society can be significant, notwithstanding challenges such as the need to design fair pricing.

1 DPV may be connected to a distribution grid or to consumers with a connection to a grid. In other words, it can be located on the grid side or the consumer side of a consumer's grid connection point. The definition of DPV used in this series of reports does not imply a minimum or maximum capacity. Off-grid installations, that is, for consumers or facilities with no grid connection, are not the focus of this report even though these are distributed installations. The report series does, however, consider grid-tied DPV installations that may be "islanded" to become temporarily independent of the main grid, as well as off-grid PV installations that may have the potential to become tied to the grid within their economic lifetimes.

2 While the term "prosumer" is used in some literature, in this report we use "DPV consumer" or "DPV producer," depending on the context.

**FIGURE 1.1: BENEFITS AND CHALLENGES OF DISTRIBUTED PV**




*Source:* Original figure prepared by the authors for this report.

*Note:* DPV = distributed photovoltaics.

Benefits of DPV include the following:

- **Direct technical and economic benefits to power systems**
  - **Access to better quality service** for consumers with unreliable grid service or insufficient power quality. Quality is particularly improved when DPV is coupled with backup power devices, for example, battery storage.
  - **Affordable electricity service and control over costs** for consumers otherwise subject to high electricity prices, or those who are vulnerable to price spikes—for example, for the fuel used in backup generators.
  - **Reduced grid congestion and reduced energy losses** for grid operators, given that DPV energy is consumed close to where it is generated.
- **Energy security and system resilience benefits**
  - **Greater domestic energy security** in cases where the use of local renewable resources replaces reliance on imported fossil fuels or electricity (box 1.1).
  - **Increased preparedness for socio-economic crises** such as the COVID-19 pandemic.
  - **Improved resilience in the face of disasters and climate events** through the decentralization of power generation, which may help create a grid architecture that is less vulnerable to major storms, wildfires, and sea-level rise.
- **Broader socio-economic benefits**
  - **Increased consumer ownership and choice** as citizens, collectives, businesses, municipalities, and other consumers make decisions about their own energy supply.
  - **Job creation and inclusive economic growth** related to a variety of skills that may be expected to lower barriers to entry, such as for women in the workforce.
  - **Local community benefits,** including for low-income and disadvantaged communities.
  - **Environmental and health benefits** from less local air pollution and lower carbon dioxide emissions in cases where DPV avoids or replaces fossil-based generation from the grid and backup generators.

BOX 1.1

### Energy Security in Island Communities

Resilience is critical in island settings with isolated power grids, given their exposure to extreme weather events and supply shocks. Distributed photovoltaic (DPV) systems can increase the resilience of islands if they are designed to supply power safely when other sources of power are unavailable. In island settings, all or most generation may be considered "distributed," since setting up transmission infrastructure to connect to large central power stations is typically either prohibitively costly or unnecessary. Small island nations are prime candidates for DPV deployment owing to their (i) dependence on expensive imported oil products for power generation, (ii) typically abundant solar resources, and (iii) scarcity of suitable land for the deployment of large-scale ground-based PV. The high costs of oil-based generation, as well as vulnerability to supply shocks, can be reduced by "hybridizing" grids with DPV and other distributed energy resources, such as energy storage, improving their resilience. DPV can also be used with grid-forming inverters to "black start" the grid after outages. Policy and regulatory support and care involving existing utilities for such deployments could improve public access to electricity during emergencies in any power system that aspires to greater resilience.

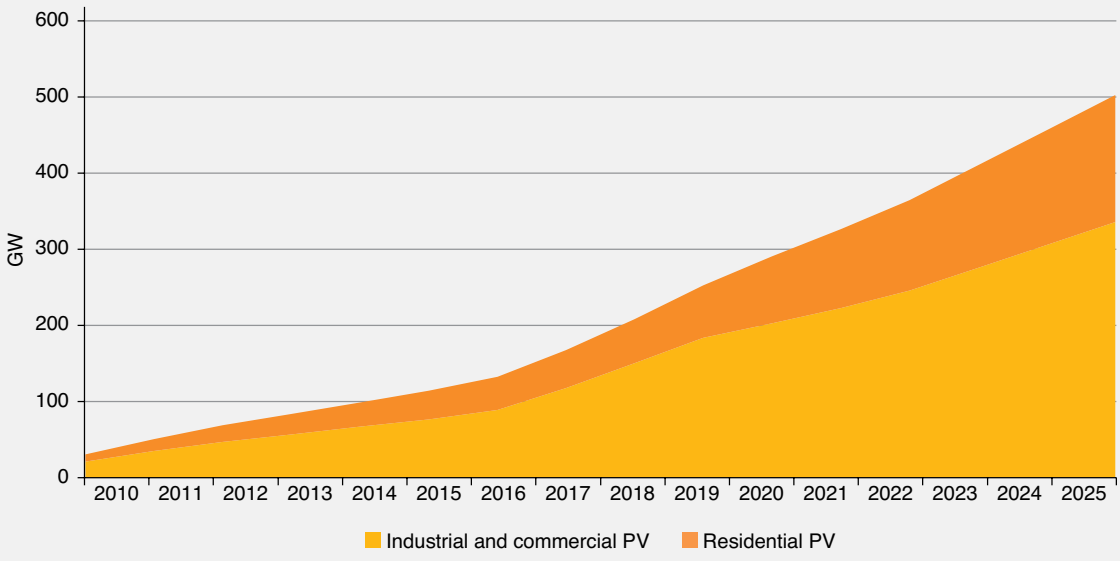
*Sources | Based on ESMAP (2019); NREL (2014).*

## DPV MARKET TRENDS

Global installed capacity of DPV has exploded from just a few megawatts in 2000 to 250 gigawatts (GW) in 2019; it is forecast to double to more than 500 GW by 2025 (figure 1.2). As of October 2020, DPV capacity additions were expected to surpass 38 GW in 2020, representing an 8 percent decline from 2019 due to the COVID-19 crisis (IEA 2020a). The share of DPV in total PV deployment was expected to decline to 37 percent in 2020, the lowest since 2017, while utility-scale PV was expected to grow by 3 percent despite the pandemic (IEA 2020a). Before the pandemic, however, not only did DPV see stable growth, but it was rivaling utility-scale solar and has overtaken coal and nuclear, combined, in net capacity added each year (IEA 2019a).

While policy support (such as tax incentives and feed-in tariffs) was key to early DPV growth, especially in high-income countries, market economics is now the main driver. In many countries today, DPV systems can provide electricity at a levelized cost below that of grid retail supply. Most of the growth of DPV is found in commercial and industrial rooftop systems in China and India that enjoy greater economies of scale (leading to lower per-unit investment costs) than residential installations, and better access to financing. In 2020, owing to the pandemic, DPV deployment was sluggish, particularly in China and the United States. But installations in most of Europe, Australia, and Brazil held their own (IEA 2020a). As costs for DPV systems continue to fall, the plummeting costs of batteries and growth in electric vehicles will only enhance DPV's appeal.

**FIGURE 1.2: CUMULATIVE DPV CAPACITY (HISTORIC AND FORECASTED) BY MARKET SEGMENT, 2010–25**




*Source:* Adapted from IEA (2019a), and updated from IEA (2020a).
*Note:* DPV = distributed photovoltaics; GW = gigawatt; PV = photovoltaics.

For 2021, the International Energy Agency does not expect DPV growth to return to the 2019 level, especially as Chinese developers shift their investments from distributed to utility-scale projects (IEA 2020a). As the COVID-19 crisis continues in 2021 with no end in sight (particularly in low- and middle-income countries), deviations from forecasts can be expected. This depends on how health crises evolve and whether government recovery packages push for renewables—particularly distributed renewable energy resources, which bring both environmental and job creation benefits.

## HOW DPV INTERACTS WITH THE POWER GRID—TECHNICAL AND ECONOMIC CONSIDERATIONS

DPV can interact with the main grid in a number of ways, depending on how it connects, how it is remunerated, and the types of meters, inverters, and other equipment used, including whether such equipment has "smart" functionality. Grid users can install DPV to supplement grid supply without feeding power to the grid at all. It can also be installed for the sole purpose of feeding power to the grid, with no consumption on-site. A combination of feed-in and self-supply is also possible. The choice will depend on the price difference between the two modes—and on whether meters and local regulations allow such arbitrage. DPV can also be used for various grid-support services. These different services, in certain jurisdictions, also influence whether an installation is classified as distributed or not. This publication covers all such cases.

The question of whether DPV systems are wired and regulated to feed into the grid or to self-supply the consumer on-site, or both, is important, because the end-use of the DPV output affects the value

proposition of systems, as well as the design of metering requirements and pricing schemes. Throughout this publication we distinguish three different feed-in arrangements (figure 1.3) as follows:

1. **Feed-all.** All DPV output is fed into the grid. This arrangement can be further categorized by whether the DPV is on the grid side or consumer side (if there is a consumer on-site).

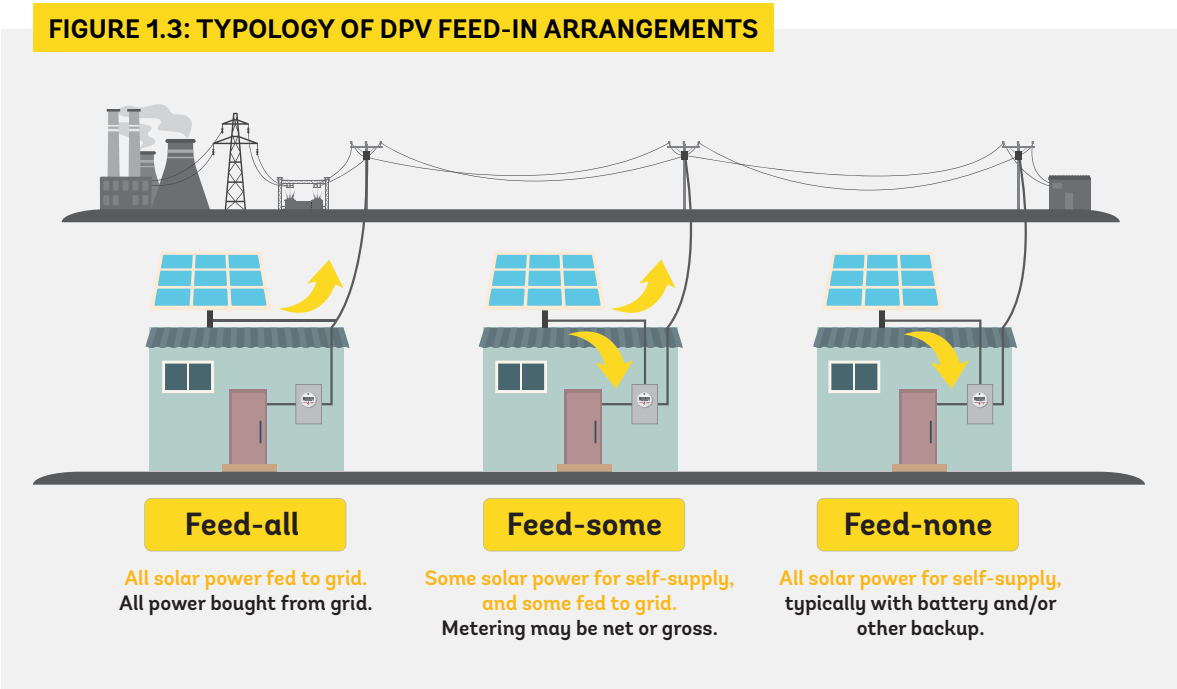
    a. Feed-all arrangements may have no grid consumer on-site (buy-none, feed-all). Such arrangements are like a standard power plant serving a distribution grid.

    b. A feed-all DPV arrangement with an on-site consumer can be called buy-all, feed-all because the consumer buys all their power from the grid. Wiring such a system to enable self-supply might be technically possible, but the feed-in arrangement implies that there is no economic incentive to do so or that it would be prohibited by regulation (notwithstanding the risk of illicit self-supply).

2. **Feed-some.** Some of the power from the distributed generation source may be consumed on-site (or stored for later use) in lieu of consuming power from the grid. The remainder of the distributed generation electricity production is fed into the grid. Feed-some models may involve a single (bidirectional) "net meter" that measures the net flow of power to or from the grid, or two (unidirectional) "gross meters," one for each direction of power flow.

3. **Feed-none.** All output self-supplies the consumer. These may not require a meter, or a meter may simply inform the user and/or the utility of the output for load forecasting purposes.

**FIGURE 1.3: TYPOLOGY OF DPV FEED-IN ARRANGEMENTS**




*Source:* Original figure produced for this report.

DPV systems may be designed for two or all three of the above arrangements, switching between modes on demand.

Another key distinction to be made between DPV systems is the extent to which they "island"—that is, operate independently of the grid. All three feed-in arrangements can be configured to continue or discontinue generating DPV output at the level of the local feeder during a general grid outage. "Islandable" feed-in systems, that continue to send output during a general grid outage, can be designed to serve as part of an alternating current mini grid. At the consumer level, feed-some and feed-none arrangements may also be connected to backup equipment, typically a diesel generator (which requires synchronization via the inverter) and/or a battery, so the user is supplied with uninterrupted power on site regardless of the state of the grid. They can also be equipped with protection devices (such as a direct transfer trip) to ensure they do not inadvertently supply the distribution network during an outage, for the safety of the repair technicians.

## STRATEGIES FOR DPV—PUBLIC POLICY PRIORITIES AND GOALS

When DPV is planned proactively and deployed strategically, as described in the "Distributed PV Economics and Policy" report, its benefits extend to utilities and consumers. Yet those benefits cannot be taken for granted—technical, financial, and institutional challenges warrant careful assessment and proportionate responses, which will vary from place to place and over time. A key purpose of this series of reports is thus to help governments, utilities, and other stakeholders think through the issues presented by the growing demand for DPV. Fortunately, low-cost and no-cost solutions already exist to meet the challenges of deploying DPV in a power grid. Much of the analysis provided in this series is also applicable, at least partially, to other distributed energy resources.

### Reliable and Affordable Clean Energy in Challenging Environments

Many low- and middle-income countries, especially those affected by fragility, conflict, and violence, are characterized by steep but uncertain growth in demand, unreliable grids, and rapidly changing circumstances. More than 50 million forcibly displaced people live in urban settings where grid capacity is commonly strained (box 1.2). Globally, some 350–500 GW of diesel generators supply temporary or backup power to consumers in such countries,[3] equivalent to 700–1,000 large coal power stations (IFC 2019). These create pollution and noise and rely on costly fuel that is vulnerable to supply disruptions. Many small islands similarly rely on expensive oil imports for power, and land may be scarce for large, ground-based power stations. Resilience to risks is a high priority for most communities, including climate change, damaging storms, and crises such as the COVID-19 pandemic, as explained later in this chapter.

In all the above contexts, DPV can provide substantial benefits when deployed on its own or in combination with other resources. Systems can be scaled to match available needs and budgets and operated with no fuel cost, no emissions, and minimal maintenance. When used in connection with batteries, DPV can power consumers independently when the grid or sunshine is unavailable, or restore power after an outage. Grid-tied DPV schemes can also inform the design of off-grid systems that may later be connected to an expanding main grid.

3 For purposes of comparison, total installed capacity across the entire African continent was around 250 GW in 2018 (IEA 2019b).

BOX 1.2

### Harnessing the Sun's Power to Improve the Lives of Forcibly Displaced People

There are more than 82 million forcibly displaced people worldwide, 85 percent of them are hosted in low- and middle-income countries with limited electricity infrastructure. An unexpected influx of large numbers of people can have major impacts on power systems, even when a grid connection is already available. Power planning therefore needs to incorporate an element of contingency, particularly in regions affected by protracted conflict or at particular risk of experiencing the effects of climate change.

Distributed photovoltaics (DPV) could help to increase access to affordable and reliable electricity for the more than 50 million forcibly displaced people, who live in urban settings where grid capacity is very often strained. In these settings, prepackaged DPV solutions (with batteries) that constitute a mini grid are a fast, cheap, and clean complement to the expansion of grid capacity, one that substitutes for reliance on costly diesel generation.

DPV's modularity also confers significant advantages in settings where refugee camps are located or where a large influx of people may be expected. In Jordan, for instance, the Zaatari camp has a 12.9 megawatt (MW) plant that is providing not only energy for refugees but also jobs for the camp's residents. The excess energy produced by the plant helps to power nearby host communities. While the system is ground mounted, typical of a central power station, it is integrated into the distribution grid and thus provides a model for similar settings.

In Lebanon, a country with extensive grid connections but many outages, there are no formal, centralized refugee camps; rather, thousands of informal settlements are scattered throughout the country. A survey of refugees in Lebanon conducted by the World Bank's Lighting Global program found that many refugee households were interested in—and willing to pay for—solar energy systems to replace or supplement their reliance on generators.

These examples illustrate how DPV can help fill gaps, in coordination with traditional grid extensions and off-grid solutions, and so help ensure energy access for all.

*Sources | Based on UNHCR (2017, 2018, 2020); Lighting Global (2019); Maier, Constant, and Ahmad (2020).*

## Economic Development in Low-Income Communities

Low-income households can be helped to realize the benefits of DPV. Integrating elements of community-driven energy plans can help define how DPV will serve low-income consumers and, in turn, be supported by them. The planning process should engage community members and determine how and where to build the DPV system. Other how-to's are important as well: ex-financing and capturing revenue, setting up the grid connection and metering, and managing certifications and technical requirements. The most effective low-income programs offer long-term, dedicated funding; cover up-front costs; integrate with energy efficiency offerings; mesh with existing energy assistance programs; include direction and funding for community education and engagement; and provide job training and placement opportunities (Figel and others 2016). Policies or programs that do not include such elements are less likely to succeed. For example, community programs that include a carve-out for low-income customers but offer no additional incentives may not produce the desired participation. Programs that offer meager savings to consumers are also unlikely to succeed. Policies and programs can be designed to overcome the obstacles to DPV adoption that low-income families face. While solutions and their details will vary by market, the basic principles are detailed in box 1.3.

## DPV Jobs and Gender

Among the renewable energy industries, solar is the largest employer in absolute terms. An estimated 3.8 million people worldwide were employed by the solar PV industry in 2019 (IRENA 2020), and this figure could grow to exceed 11.7 million in 2030 and 18.7 million in 2050 (IRENA 2019b). Rooftop solar PV is the power generation technology with the highest job creation per million dollars of capital investment (IEA 2020b), more than triple any other generation technology, except for utility-scale PV, which creates about two-thirds as many jobs as rooftop solar PV. DPV is also the fastest way, together with repowering existing wind farms, to invest capital into sustainable power generation technologies. Energy efficient buildings, both new and retrofits, are the only other technologies that offer a comparable job benefit.

The growing solar industry requires a wide range of skills, including not only those of factory workers, installers, and engineers, but also in supporting fields such as law, finance, economics, logistics, marketing, sales, and permitting. DPV involves more jobs per unit of installed capacity than centralized solar plants and a different mix of skills. For example, it involves less advanced engineering and construction skills than centralized PV, but relatively more person-hours for permitting, finance, legal knowledge, marketing, and sales. Because some of these jobs can be performed by members of the local community, DPV projects offer opportunities to increase local employment. Some nonprofit organizations focused on community solar initiatives offer training in the installation of solar systems, enabling local residents (particularly women in some cases) to become solar installers (box 1.4).

DPV project design could have a transformative role in pushing the gender equality agenda. DPV employment is an opportunity to improve gender balance in the energy sector and to create a more inclusive and diverse sector. Training and recruiting women in the industry can help minimize potential skills shortages. Given that most engineering and construction firms are male-dominated, the diversity of skills involved in DPV deployment could lower the barriers to entry for women.

Sex-disaggregated data in the solar industry are scarce but point to underrepresentation of women, especially in technical positions, similar to structural gender inequalities in the energy sector more broadly. A survey by the International Renewable Energy Agency (IRENA 2019a) found that women represent 32 percent of full-time employees in renewable energy industries, substantially more than the 22 percent

BOX 1.3

### Principles for Low-income DPV Programs

**Accessibility and affordability.** An effective, low-income distributed photovoltaics (DPV) program combines opportunities to participate with meaningful financial benefits by combining energy cost savings with direct support to overcome some of the financial and other obstacles to access.

**Community engagement.** A successful program requires a partnership with communities through local organizations, such as community development corporations, housing organizations, and other service providers to ensure that community needs and challenges are addressed and assets utilized. These partners can provide critical outreach, planning support, and engagement with low-income communities. Moreover, many communities desire even more engagement, including an ownership interest in DPV projects serving them.

**Consumer protection.** Programs should not create incentives for predatory lending or exploitation of communities for financial gain. They should include adequate consumer protection measures, disclosures, and accountability measures so that financially vulnerable consumers are not exploited or compromised.

**Sustainability and flexibility.** A successful low-income program must encourage long-term market development and be flexible in order to best serve the low-income market segment over time and as conditions and circumstances change.

**Compatibility and integration.** Low-income DPV programs and policies should complement existing renewable energy and energy efficiency programs, not undermine them. They should also integrate well with synergistic programs, such as energy efficiency, workforce development, healthy home programs, and others that address the intersection of equity, energy, and infrastructure.

*Source | Figel and others 2016.*

average in global oil and gas, but still symptomatic of structural gender inequalities. Women's participation in science, technology, engineering, and mathematics (STEM) jobs in the renewable energy sector is lower, at 28 percent. Renewables-related administrative jobs and non-STEM technical jobs are filled by relatively large shares of women—45 and 35 percent, respectively (IRENA 2019a).

A recent study (IEA and CEEW 2019) found that women represent 11 percent of the workforce among eight rooftop solar companies in India. Among these companies, the highest share of women are in corporate functions (34 percent) and in the design and preconstruction phase (18 percent). Few women work in construction and commissioning (3 percent), or in operations and maintenance (1 percent). Women

represent 12 percent of senior management and 17 percent of mid-level management. Only three of the eight companies surveyed have women serving as a board member, and no board has more than one woman. Reported barriers include women's perception that safety and security are insufficient at project sites; misperception of women's engineering capabilities; deficient human resources policies; social norms and practices at workplaces that fail to recognize and address the needs of female employees; and a lack of positive gender awareness among employees.

Barriers inhibiting women's participation in DPV can be mitigated through interventions at the sector and company levels. Women can be trained as DPV installers (box 1.4). Encouraging companies to invest in facilities suitable for women at project sites and setting guidelines for flexible working arrangements—while addressing the persistent gender pay gap—are examples of measures that could improve women's participation in the sector. Costs related to parental leave can be covered by public social security, instead of being borne entirely by employers. Campaigns can promote women's leadership (including mentorship efforts), while training can sensitize employees to gender issues and strengthen a supportive work culture.

**BOX 1.4**

### DPV Job Training and Placement Opportunities for Women

Increasing the participation of women in distributed photovoltaics (DPV) construction, operation, and maintenance can help fill skill gaps in the workforce, thus accelerating DPV growth. For example, GRID Alternatives (a nonprofit US solar installer) works to provide pathways to technical careers for women with hands-on installation training to hone their technical skills and increase opportunities for paid employment. In Nicaragua and Nepal, the GRID Alternatives' Women in Solar program employs local women to install solar systems alongside international volunteers and GRID staff. In this way local women gain more hands-on solar installation experience to enter the solar industry and become solar installers.

*Source | Adapted from Grid Alternatives (2019).*

Financial institutions can encourage companies to hire more women by integrating gender equality as a social aspect of lending requirements. Some DPV companies surveyed for the study in India reported that recent capital injections from private equity firms were accompanied by a mandate to improve gender quality. This led to internal goals for hiring women. Even if the adoption of such measures is primarily driven by the need to comply with funders' requirements, greater gender equality is likely to be achieved. As the workforce diversifies, company values may also shift. Finally, investors and donors can also require gender-balanced teams, setting an example.

## DPV in the Context of Crisis

DPV can provide distinct benefits during periods of acute crises, as seen during the COVID-19 pandemic. These benefits have two general aspects: first, the response strategy to the acute crisis itself and, second, DPV's role in economic resilience and recovery strategies.

In responding to an acute crisis, DPV has provided reliable power for critical medical applications—notably to operate ventilators, refrigerate medical supplies, and boost energy system resilience. For example, Afghanistan's national power utility, Da Afghanistan Breshna Sherkat, installed DPV in 10 hospitals across Herat Province to provide reliable power for COVID-19 intensive care units (World Bank 2020). DPV deployment allowed Al-Salam Hospital in Yemen to remain open 24 hours a day during the pandemic thanks to reduced electricity costs (World Bank 2021). In Nigeria, thanks to the stock of solar and battery systems in warehouses, local companies designed and installed mini grid systems for COVID-19 isolation centers in as little as two weeks (REA 2020). Box 1.5 describes a tool recently developed to design DPV systems for health facilities responding to COVID-19, including microgrids connected to unreliable grid power.

**BOX 1.5**

### Designing DPV as Part of Emergency Power for Health Facilities Responding to COVID-19

Tools are available to help project managers, engineers, and financiers working with hospitals and clinics in low- and middle-income countries where grid electricity is unavailable or unreliable. One example is the HOMER Powering Health Tool. (HOMER stands for hybrid optimization model for multiple energy resources.) The tool simplifies the process of sizing distributed generation systems to meet a facility's needs. Users customize selections from a prepopulated list of typical medical equipment needed to screen, test, and treat COVID-19 patients alongside other health care services. Based on the given power needs and supply options, the tool calculates least-cost combinations of batteries, distributed solar photovoltaic (PV), and diesel generator sets, including as a backup to grid electricity (if the latter is available for a certain number of hours each day). A key feature of the HOMER Powering Health Tool is that it runs entirely online and can be used repeatedly with no need to sign in or download software. The tool is deliberately kept simple enough for nonspecialists to use without special training. This comes with limitations, of course. For certain advanced needs, other tools are available, such as the full, licensed software of HOMER Energy by UL or the free System Advisor Model (SAM) of the US National Renewable Energy Laboratory (NREL). The latter is especially useful for systems that may feed DPV power back to the grid when it is not needed on-site.

The tool is freely available at https://tools.poweringhealth.org.

Regarding economic resilience, DPV deployment has proven robust in the face of economic challenges during lockdowns and supply chain disruptions. For example, India added 883 MW of rooftop solar in the first nine months of 2020—despite the COVID-19 crisis (Lempriere 2020). This is particularly noteworthy since DPV relies on a mobile workforce and is organized largely around small- and medium-sized enterprises (SMEs). Governments can boost the sector's resilience and contribution by designating it as an essential service, especially where it supports emergency power supply. DPV can also contribute to economic recovery as part of "green stimulus" packages. Of the nine DPV use cases, four are particularly useful here: least-cost generation, utility bootstrap, ancillary services, and financial loss reduction. Recovery efforts provide an opportunity for rapid job creation, as noted above.

## SUMMARY

This chapter has provided a definition of DPV, reviewed recent market trends and discussed fundamental economic and technical aspects of DPV deployment. DPV can help reach societal goals in challenging deployment environments, such as fostering inclusive economic growth, creating jobs and enhancing resilience in the face of crises. But to reap the full benefits of DPV, an integrated deployment strategy is indispensable.

DPV's different use cases are the building blocks of such a strategy. The next chapter of this report describes these nine use cases, which vary from well-established value propositions to emerging value additions. Each case responds to a specific problem or set of problems found in low- and middle-income countries. In practice, two or more use cases may be combined to generate synergies in a single project or scheme, or be combined with distributed energy resources and schemes such as energy efficiency and microgrids.

Growing evidence shows how DPV, appropriately deployed, can offer net benefits to stakeholders. Newer DPV use cases and business models are the subject of ongoing pilot projects to demonstrate feasibility in different contexts. Transparent assessments should inform decisions on program design for DPV and other energy resources, including decisions on trade-offs among investments.

The two companion reports in this series—"Grid Operation and Planning with Distributed PV" and "Distributed PV Economics and Policy"—offer further details from the technical and policy perspectives.


*Credit: World Bank.*

# 2: USE CASES FOR DPV IN LOW- AND MIDDLE-INCOME COUNTRIES

In developed countries, the deployment of distributed photovoltaics (DPV) has been driven chiefly by a combination of consumers' financial considerations and governments' clean energy policies. Consumers deploy DPV to lower their electricity bill and, in some cases, to generate income. Some governments compensate users for DPV fed to the grid, and a few do so at generous rates. This is done to boost the share of renewables in the power system and advance toward clean energy or other climate-related targets. Beyond cost savings, a niche of grid-connected consumers, such as health care and industrial research facilities, combine DPV with storage in microgrids to meet stringent power quality requirements. In the wake of several major natural disasters in recent years, there is an emerging trend of so-called islandable microgrids and backup systems for individual buildings using photovoltaics (PV) and storage. Such setups have been deployed by a variety of consumers in developed countries seeking to build resilience against rare but disruptive grid outages.

The situation is much different in those parts of the world where grid interruptions are common. Underlying problems include insufficient power generation to meet peak demand, weak grids with inadequate transmission and distribution (T&D) capacity, and inadequate power frequency and voltage. Most incumbent utilities in low- and middle-income countries have financial weaknesses resulting from operational inefficiencies, tariffs below cost-recovery levels, and undercollection of charges for power supplied. Under those conditions, DPV can help solve the problems faced not only by the consumer but also by the government, incumbent utility, or other responsible entity.

This report identifies nine types of deployment of DPV in parallel with or connected to a grid, as shown in figure 2.1. The name for each "use case" refers to a distinct solution offered by the DPV system, sometimes in association with other distributed energy resources such as batteries, advanced inverters, and microgrids. Use cases represent value propositions for DPV projects or programs that may stand alone or be combined with other use cases and with other distributed energy resources.[4]

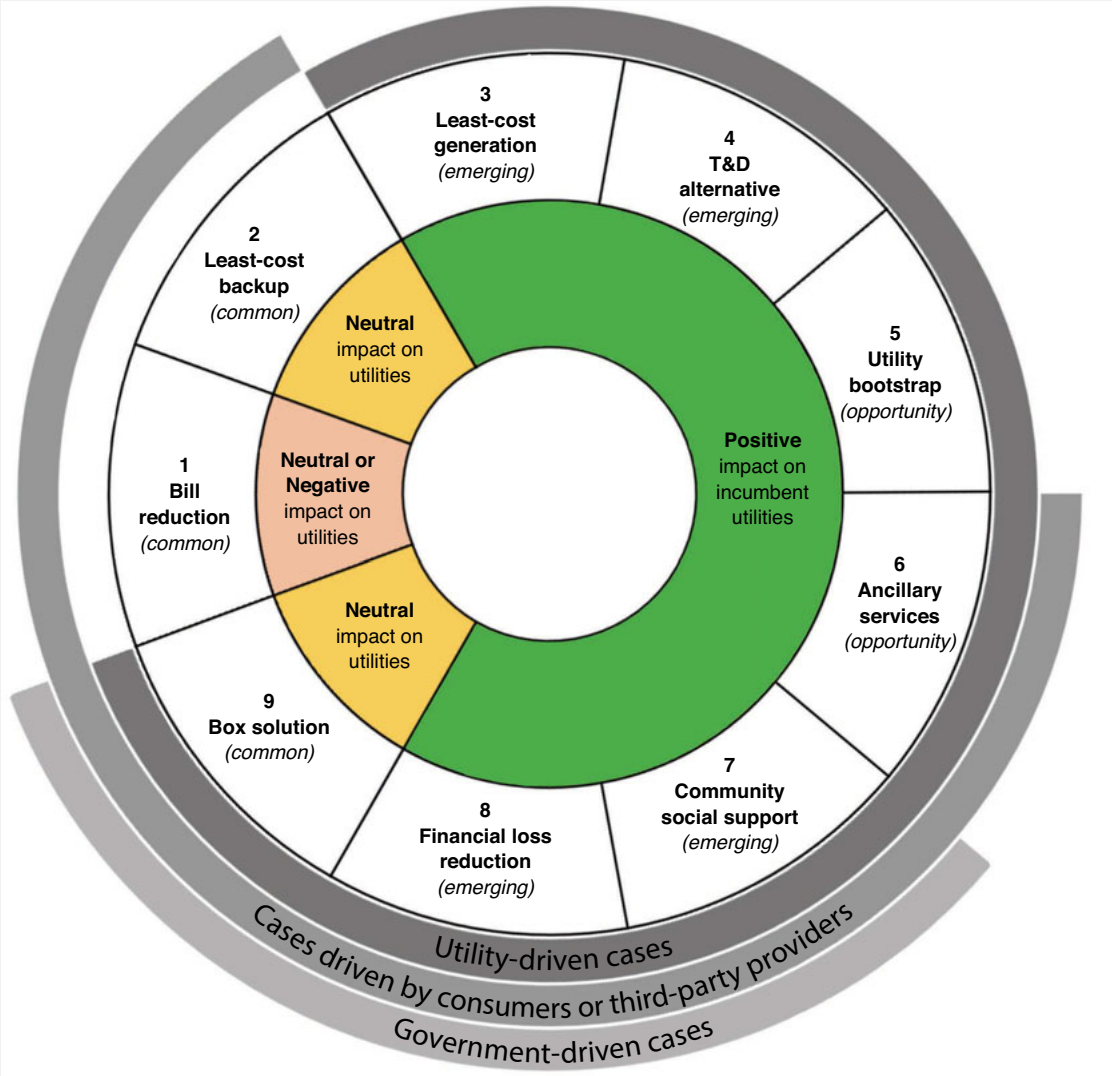
Several use cases are well established and their deployment is *common*. Other use cases have been deployed in a few circumstances (*emerging* use cases), and some are yet to be deployed (*opportunity* use cases). The nine uses covered in this chapter are:

- **Bill reduction, least-cost backup,** and **least-cost generation** to help reduce the cost of grid electricity or backup fuels, and to bolster resilience against fluctuations in fuel prices and availability.
- **T&D alternative,** where DPV addresses constraints in grid infrastructure.
- **Utility bootstrap,** where DPV, as part of a microgrid, helps address the vicious cycle of poor utility performance and customer defections.
- **Ancillary services,** where DPV supports power system operations and flexibility as a potential added layer of value.

4 Use case 6, ancillary services, is a potential value addition rather than an isolated value proposition.

- **Community social support,** where DPV supports low-income consumers.
- **Financial loss reduction,** where DPV addresses the chronic arrears of consumers that are public institutions.
- **Box solutions,** where complete DPV systems are preassembled with batteries or other backup sources and deployed to address urgent power needs, such as when the grid becomes unavailable following a disaster.

**FIGURE 2.1: DPV USE CASES, THEIR PREVALENCE,* DRIVING AGENTS, AND ASSOCIATED IMPACTS ON UTILITIES****




*Source:* Original figure prepared by the authors for this report.

*Note:* *Use cases that are well established in their deployment are called common. Use cases that have been deployed in a few circumstances are called emerging use cases, and those that are yet to be deployed are called opportunity use cases.

**Utility here refers to a distribution company or vertically integrated utility.

As presented here, the use cases focus on discrete issues. However, in practice, two or more may be combined to generate synergies in a single project or scheme. One important objective of DPV deployment that cuts across use cases is to displace emission-intensive forms of power production. Each use case features one or more stakeholders with a leading financial or technical interest in its realization. These are most often consumers, a distribution company, or a government agency, with or without a private sector partner.

An important consideration is how each use case may affect the incumbent utility. All nine cases can be designed to support the interests of utilities (be they distribution companies or vertically integrated utilities), though a few may involve trade-offs that require special supporting measures. While our focus is on low- and middle-income countries, the use cases also reflect DPV deployment arrangements in high-income settings. All cases may be designed to foster social inclusion through appropriate pricing or business models that aggregate demand and include disadvantaged consumers.

The remainder of this chapter is devoted to presenting the nine use cases in a standardized format. Relevant details are provided for each case, including optional financing structures, alternative technologies that can be used to address similar problems, and a real-life example of a project in implementation or design that illustrates key features of the use case. For newer DPV use cases and business models, further pilot projects are needed to demonstrate feasibility in various contexts. Transparent assessments should inform decisions on program design for DPV and other energy resources, including deciding trade-offs between investments.

## USE CASE 1: BILL REDUCTION

**Driver.** Consumers want to save money on the bills they pay for grid electricity.

**Description and benefits.** DPV reduces consumers' electricity bills by displacing some or all of the electricity they would otherwise purchase from the grid. Besides financial savings, many consumers also like the idea that DPV contributes to reducing pollution. Bill reduction is the most common reason for DPV deployment around the world. Several business models are possible, as discussed below. In some markets, remuneration for DPV fed to the grid provides consumers with a source of income to offset some or all of their grid electricity bills. Consumer-side installations are typical, but consumers may also get equivalent benefits from subscribing to a community-level grid-side installation. For consumer-side systems, DPV may be coupled with batteries to help reduce electricity charges in response to time-of-use tariffs or demand charges.

**Agent driving deployment.** Consumers drive the deployment of DPV at either the individual or community level. Third-party providers can act as aggregators and provide full-service solutions.

**DPV feed-in arrangement.** Systems may be arranged to feed all, some, or none of their DPV output to the grid. If feed-in remuneration is lower than the retail volumetric rate, consumers have an incentive to self-supply as much as possible. In the rare case that feed-in remuneration is higher than the retail price, the incentive is to feed all DPV into the grid.

**Retail electricity tariffs.** The retail tariff is the primary factor driving the viability of this use case. Volumetric charges determine the costs that consumers avoid by using DPV: the higher the tariff, the greater the savings. Feed-in remuneration, if any, will also factor into the equation. Consumers who face certain demand charges or time-of-use tariffs may also use DPV to lower this part of their bill, especially if the DPV is coupled with batteries.

**Impact on the utility.** The impact on the utility may be neutral or negative depending on whether energy tariffs recover the utility's costs in the presence of DPV, or if subsidies cover any revenue shortfall. For each unit of DPV power generated, the utility avoids the need to purchase wholesale energy, including to make up for distribution losses. The utility derives revenue from the on-sale of DPV fed to the grid, but each unit of DPV that is self-consumed represents a foregone sale. The utility may benefit from the T&D alternative (see use case 4), if bill reductions involve time-of-use or demand charges.

**Financing.** Consumers may self-finance or obtain a loan to install a DPV system on their own property (most often the roof of a building). The loan may be paid off with cash derived from subsequent electricity bill reductions. In some countries, DPV can be built into a home mortgage or leasing option. Private energy service providers may provide packages of equipment and services in various combinations. A common option is to provide DPV equipment along with installation and maintenance through a power purchase agreement with large consumers, or through a lease agreement with small consumers. The consumers will reap the benefits of advantageous feed-in remuneration and save on electricity bills.

**Technical prerequisites.** Depending on the remuneration, two separate meters may be needed (one measuring grid consumption and the other measuring DPV grid exports) or only a bidirectional meter (with or without a gross PV production meter).

**Suitable technology alternatives.** Options include distributed renewable energy (with or without batteries) and energy efficiency (especially where increasing block tariffs are applied, and energy savings easily translates into cost savings).

**Example: A distributed solar photovoltaic scale-up project in Beijing.** A World Bank–supported solar project in Beijing yielded bill savings for a variety of public, commercial, and industrial consumers with DPV installations ranging from hundreds of kilowatts (kW) to several megawatts (MW). All cases applied a similar model—an energy service company entered into an energy management contract with each consumer to share in savings on the grid electricity bill. Savings were achieved by DPV installations on the consumer side, which fed some output to the grid, and which were sized to cover a certain share of site demand while also staying within the limits set by the grid company, based on the capacity of the local transformer. Consumers gave site access to the energy company, which provided all engineering, procurement, and construction services, and retained ownership of the systems, with financing from a government loan that the company was to pay back with earnings from the energy management contracts (World Bank 2013).

## USE CASE 2: LEAST-COST BACKUP

**Driver.** Power is unreliable or its quality insufficient for the consumer (whether commercial, industrial, or residential). Meanwhile, the operating costs of backup diesel generators are high or fuel supply is unreliable—sometimes both.

**Description and benefits.** Consumers or third-party providers install DPV typically to save costs on the fuel being used by an existing generator, or they do so as part of a more sophisticated microgrid solution designed to guarantee reliable power—for example, during hours of industrial production that cannot be interrupted or for the operation of medical facilities. DPV can reduce backup costs on the consumer side (thanks to fuel savings), with the added benefit of decreasing local air pollution and noise. At the end of the existing generator's lifetime, it can be replaced by batteries for a completely fuel-free backup.

**Agent driving deployment.** In this use case, consumers or third-party providers drive the deployment of DPV to improve the reliability and quality of the power supply. Meanwhile, the government can incentivize

the use of DPV as part of a strategy to reform energy subsidies or to reduce reliance on fossil fuels. If the consumer is a public institution, the use case may be driven by the government on behalf of the consumers.

**DPV feed-in arrangement.** The energy generated is mostly or entirely used on-site in a feed-none arrangement, since the primary characteristic of this use case is to increase self-supply. A feed-some arrangement may be possible, but exports to the grid may not be compensated.

**Retail electricity tariffs.** The starting tariff is irrelevant, as the utility has problems ensuring reliable service delivery. The goal is to replace the consumer's consumption of diesel fuel.

**Impact on the utility.** The immediate effects on the utility will be neutral or negative, depending on whether DPV is replacing diesel generation or utility-supplied power. In some cases, a well-functioning and cost-competitive backup option, particularly when led by a third-party provider, can lead to significant grid defection. If local demand decreases and some customers defect from the grid, the utility will be negatively affected by the subsequent loss of revenue. Yet again, if some of these customers were not paying their bills owing to the poor service they received, the utility may in fact benefit financially from not having to supply power that was not being paid for.

**Financing.** Consumers may self-finance a DPV system or get a loan against expected fuel-cost savings (similar to energy efficiency loans). A third-party provider may finance a DPV system with a loan, which it can repay from fixed monthly payments received by consumers of the service. The consumers still pay for the service with fuel-cost savings. The government may provide financial incentives to consumers or third-party providers to deploy DPV systems. It finances such schemes with projected savings on fossil fuel subsidies, or through a loan, if needed. Financial incentives could also be implemented to promote the use of high-quality products that will last longer and require less maintenance.

**Technical prerequisites.** If the DPV installation is grid tied, the utility will need equipment to ensure safe and controlled disconnection and reconnection to the grid. If it is operated as a microgrid, dynamic balancing of supply and demand from sources within the microgrid is needed to ensure adequate power quality. This typically requires investment in energy storage technologies or other means to improve the dispatchability of the energy generated.

**Suitable technology alternatives.** Other distributed renewable energy with batteries or a full microgrid solution.

**Example: DPV to improve electricity sector performance in Gaza.** Nearly 2 million people living in Gaza suffer from severe electricity shortages owing to a lack of sustainable power supply options. Available power supply in Gaza meets only half of the demand, resulting in rolling blackouts of eight hours of power supply followed by eight hours of power cuts. During winter and summer peak loads, the situation deteriorates, and power is available for only three to four hours per day. Bilateral aid from several countries is available, currently funding emergency diesel fuel for the highly inefficient and expensive Gaza power plant. To improve energy security in Gaza, the World Bank is supporting efforts to install some 1.5 MW of DPV on the rooftops of residential buildings, small- and medium-sized enterprises, and hospitals. Qualified residential and business consumers that receive DPV are expected to pay back the cost in monthly installments; for hospitals, DPV is a donation. There are plans to use a revolving fund to install more DPV. The benefits of scaling up DPV include not only increased energy security in case of conflict, but also longer hours of available power supply that is a cleaner and cheaper alternative to backup diesel generators (World Bank 2017a).

## USE CASE 3: LEAST-COST GENERATION

**Driver.** DPV is among the cheapest and lowest risk source of new power for grid supply where large, centralized PV plants or cost-effective transmission are not viable options. The benefits are particularly great where grid power relies on expensive liquid fuels.

**Description and benefits.** In some countries, such as small island states, DPV may be consistent with least-cost generation planning. A utility or a third-party provider selects available sites to host DPV (and may need to pay rent for some or all of these sites); obtains the equipment; and installs, operates, and maintains the systems as a cheaper alternative to other technologies capable of serving the grid. The utility benefits from avoiding the costs of a more expensive means of power generation, or from the purchase of electricity from a third-party provider, while selling DPV output fed to the grid onto its customers. If DPV displaces the use of fuels to power the grid, especially imported fuels, it mitigates price volatility and fuel-supply shocks, and thus increases energy security and resilience while reducing emissions. Where generation fuels are subsidized, subsidy burdens are reduced.

**Agent driving deployment.** The utility seeks to deliver cost-efficient power to consumers.

**DPV feed-in arrangement.** DPV systems (on the grid or consumer side) feed the electricity they generate to the grid for the utility to sell to consumers. A consumer-side installation may also feed some or none of its output to the grid. In this case, the utility considers the self-consumed DPV generation as avoided generation. If the consumer-side system is managed by the utility, the consumers may pay the utility the standard retail rates for all the power they consume, including from the DPV system, or they may receive a discount or rebate for allowing the utility access to the site of the DPV installation (usually a roof).

**Retail electricity tariffs.** Irrelevant for this use case.

**Impact on the utility.** Positively, utilities may forego more expensive supply options and can pass that benefit to all consumers. Large generators and transmission systems may see reduced sales and a new net load curve. Under the utility-led model, the utility pays for the DPV systems and invests in metering and monitoring infrastructure. If the third-party service provider is selling to distribution companies or directly to consumers, then it might undercut the utility, which can start losing consumers.

**Financing.** Financing is the same as for any power generation asset. The utility or a third party may finance up-front costs from its own capital or borrow from a financial institution and then recover costs through power sales, after accounting for rental fees to the host sites.

**Technical prerequisites.** The utility or a third-party provider requires metering and monitoring services across installations to confirm system output and determine potential operation and maintenance needs. It also aggregates outputs and coordinates service delivery with the system operator.

**Suitable technology alternatives.** Other relatively low-cost sources of distributed renewable energy (plus batteries, if firm power is required).

**Example: Accelerating sustainable private investment in renewable energy in Maldives.** Maldives is accelerating sustainable private investments in grid-tied rooftop PV, with and without batteries. Few other technologies are as cost-effective, since limited space is available for large-scale central power stations. DPV replaces part of the diesel-based generation that is dominant in the country, and has significantly reduced government subsidies to the sector while bolstering price stability. Local utilities offtake DPV generation from private sector entities, and a sovereign guarantee backstops their obligations. The project is accompanied by energy efficiency efforts to optimize the sizing and use of DPV (World Bank 2014).

## USE CASE 4: TRANSMISSION AND DISTRIBUTION ALTERNATIVE

**Driver.** The capacity of the local transmission or distribution grid is insufficient to bring bulk power to consumers, or grid congestion is a problem.

**Description and benefits.** A utility or third-party provider may install DPV (and possibly also storage) on the grid or consumer side as a quicker or lower-cost alternative to T&D infrastructure upgrades in the near term. Such a measure is also known as a "non-wire alternative" (Navigant 2017), i.e., an alternative to investments in more T&D lines and associated infrastructure. DPV may be particularly beneficial where the permitting for T&D infrastructure (for example, right-of-way for lines) takes much longer than permitting for distributed generation resources.

**Agent driving deployment.** The utility or third-party provider drives DPV deployment as a faster and possibly cheaper solution than investment in wires, transformers, and other T&D equipment.

**DPV feed-in arrangement.** All or some of the electricity generated is fed to the grid to create a new source of power generation in the network that is located closer to the final consumer. This avoids grid bottlenecks to bulk-power delivery. A feed-all arrangement may be sited on the grid side or the consumer side. DPV also serves to reduce load. A feed-none arrangement is also possible, but the system should be sized so as not to exceed the minimum site demand (to avoid curtailment) or be equipped with storage. In the latter case, the associated costs of storage need to be carefully considered.

**Retail electricity tariffs.** The energy component of the retail tariff is not relevant to this use case. Time-of-use and demand charges may create an incentive to design and size systems to shape the load curve to reduce net peak demand.

**Impact on the utility.** Positive: The utility may benefit when DPV is a lower-cost alternative to the capital expenses of T&D upgrades. Avoided T&D constraints allow utilities to maintain or improve the service they provide to consumers. If the utility is exposed to congestion charges, these may be avoided through the deployment of DPV.

**Financing.** The utility has the mandate to provide service to customers and would therefore incur T&D investment costs; DPV can be financed the same way as T&D would be. DPV investment costs can be recovered from tariffs through performance improvement regulations. A third-party provider may also be involved, in which case the utility could invest in technical measures such as batteries to increase the local grid-hosting capacity.

**Technical prerequisites.** The utility or third-party provider needs to ensure that the timing of DPV generation aligns with the timing of system infrastructure needs—for example, periods of peak demand or voltage issues. DPV-as-infrastructure needs to be monitored closely to measure performance over time, and the utility must consider its feasibility as an ongoing strategy to address system constraints.

**Suitable technology alternatives.** Nodal energy pricing can solicit demand response to avoid congestion. Other sources of distributed renewable energy, batteries (even without generation powered by renewable energy, if congestion occurs only at certain hours of the day), and diesel generators are other options.

**Example: DPV in Ho Chi Minh City and Da Nang, Vietnam.** A geospatial analysis of rooftops in Ho Chi Minh City and Da Nang estimated up to 6.4 gigawatts (GW) and 1.1 GW of rooftop solar capacity for these two cities, respectively. As part of its solar strategy, the government of Vietnam has sought to exploit this potential since DPV generation, and distributed resources in general could reduce the need for costly large-scale grid infrastructure such as high-voltage transmission lines and substations. DPV can also

reduce line losses due to transmission across large distances, as well as the need for additional centralized capacity investment. These benefits are best realized when the utility is planning and coordinating the deployment of distributed energy resources, while developing its own transmission and generation least-cost plan (PwC 2019). To this end, Vietnam is learning from the United States' experiences with DPV as a non-wire alternative (Chew and others 2018).

## USE CASE 5: UTILITY BOOTSTRAP

**Driver.** The search for cost-effective utility service delivery is driven by the vicious cycle of an unreliable grid, high commercial losses, low collection rates, grid defection, and lack of cost recovery.

**Description and benefits.** A utility facing financial and operational difficulties may want to install DPV to improve the reliability of service as part of a strategy to build consumer trust and increase bill collection. DPV systems can provide clean and low-cost electricity, while also being modular (allowing for small investments) and easy to install (bringing rapid results after initial investment). Coupled with batteries, DPV systems can provide reliable electricity day and night, giving consumers a motivation to pay for the power they receive in exchange for the utility guaranteeing a quality of service it cannot provide on the rest of the grid. The improved service leads to higher sales of power for the utility and should also avoid grid defection. In certain cases, DPV can also improve local power quality.

**Agent driving deployment.** The utility drives DPV deployment as a solution to improve service, collections, and revenue recovery.

**DPV feed-in arrangement.** The arrangement depends on where the DPV is connected. DPV can feed all of the electricity generated to the grid when the system is connected at the level of the substation. In this case the DPV acts as a generator in a mini grid. When DPV is installed at the consumer end, it may feed all, some, or none of its electricity to the main grid.

**Retail electricity tariffs.** The starting tariff is irrelevant; the utility has problems ensuring service delivery and recovering revenues. Once consumers receive reliable power, are adequately metered and billed, and are paying, the tariff must allow the utility to recover its costs, at least on a cash-needs basis.

**Impact on the utility.** This use case is designed to have a positive impact. The utility pays for the DPV system or franchises it. Viability rests on the costs being balanced by increased revenue recovery, improved commercial relationships with consumers, and avoided grid defection.

**Financing.** Public financing for capital investment comes from the utility, which typically takes a loan, with repayments from its increased revenue from paying customers who had been unmetered or refused to pay for unreliable service. The utility can franchise its business model to a partner able to finance the DPV and manage payment collection. Customers may agree to finance part of the DPV system in exchange for lower payments for electricity.

**Technical prerequisites.** The utility may be required to retrofit network equipment to ensure reliable and safe service to consumers both before and after DPV is added. The utility may also require systems to monitor consumer data on service quality to ensure a sound commercial relationship with consumers. For consumer-side DPV, the utility will need meters to account for the destination of every unit of power produced.

**Suitable technology alternatives.** These alternative sources include distributed renewable energy, batteries, or diesel generators for remote locations (for example, islands), although fuel supply is an issue in the latter case.

**Examples: "Renewable Energy for All" in Haiti.** As part of the "Renewable Energy for All" project in Haiti, plans for 5–12 MW of DPV capacity, plus battery storage, are being pursued for two to three isolated grids run by the local utility, Electricité d'Haïti. The grids have historically been powered by diesel fuel, which is expensive and not always available. Besides reducing the utility's generation costs, DPV will improve service quality and expand access to at least 100,000 people, 1,000 enterprises, and community users. As the first grid-tied PV investment in Haiti, this installation engages the private sector in DPV construction and operation, and charts a path toward attracting commercial investments in the technology in Haiti. The initial focus of the project is the south of Haiti—the area most affected by Hurricane Matthew. A later phase will explore options to promote the development of DPV with battery storage plants financed by private investors. In such a case, the project's funding will be used as a guarantee (World Bank 2017b).

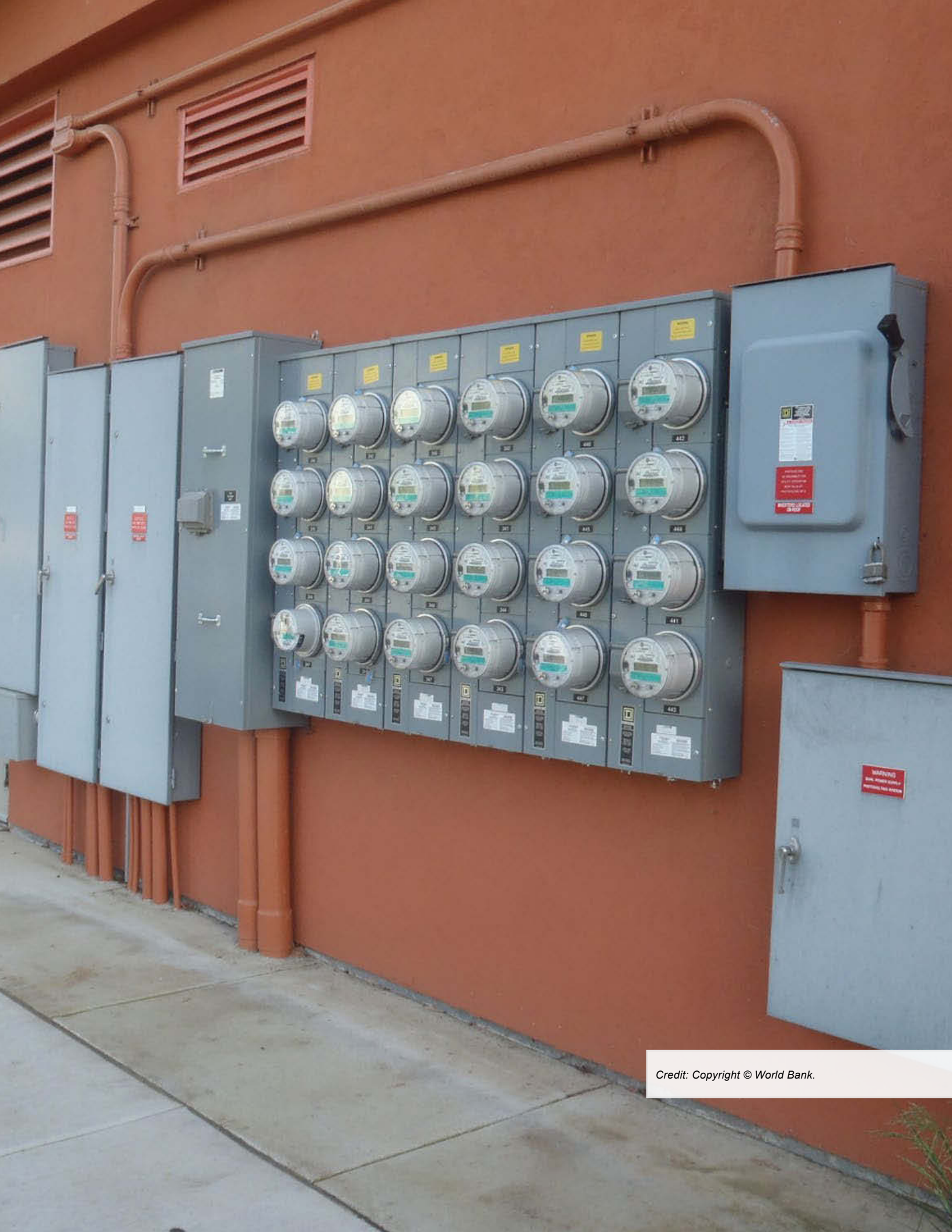
**Undergrid communities in Nigeria.** Nigeria is exploring the viability of achieving bill reductions by using microgrids or mini grids for communities underserved by distribution companies in rural and peri-urban areas (so-called undergrid communities), akin to the utility bootstrap use case. Defined as being up to 1 MW in size, microgrids (small grid systems that serve targeted consumers and can also connect to the main grid) can improve service reliability over existing grid service, while leveraging existing distribution infrastructure to achieve lower system costs than isolated mini grids (which are typically small grid systems built for off-grid consumers). Four business models have been identified, each led by a different actor: a private operator, a special purpose vehicle, a cooperative, or a collaborative special purpose vehicle. Cost savings benefit both consumers and the utility. In a typical case, the distribution company can avoid 50 percent of current financial losses by cooperating with a mini grid developer to serve a community, thereby eliminating the costs of bulk power purchase, distribution, and variable operating expenses. While the distribution company retains some sunk costs (for example, overhead, debt, and asset depreciation), the distribution company will nevertheless save a minimum of US$12 per connection on average. Finances are further improved with savings realized through a usage fee. On the one hand, distribution companies are not covering their costs and struggle to invest the capital required to meter all customers; on the other hand, the independent operator can charge a cost-reflective tariff and install metering solutions that minimize collection losses (Graber and others 2018, 2019).

## USE CASE 6: ANCILLARY SERVICES

**Driver.** Many grids are facing increased variability and uncertainty in both supply and demand. To maintain the quality of power system operations, more ancillary services—understood as grid support—are needed.

**Description and benefits.** The utility is the main beneficiary of ancillary services. Beyond the energy generated, DPV, especially in combination with inverters and batteries, can provide a range of services to the grid, such as frequency regulation, voltage support (including reactive power),[5] and demand response (including ramping). The response time of DPV systems ranges from milliseconds to seconds. Some services are "passive," for example, inverters may be preprogrammed to automatically respond to specified conditions and contingencies. Other services are "active," responding to live instructions from a grid operator. At sufficient scale and with headroom based on high-quality forecasting, DPV can even provide upward as well as downward dispatch to balance unexpected drops or rises in demand and supply—for example, as a virtual power plant (VPP) participating in a power market. Adding battery storage improves the provision of these services. The result is improved grid flexibility to better integrate variable renewable energy at all levels. Active services require not only an underlying infrastructure of information and communications technology, but also enabling policy, regulatory, and market conditions.

5 Voltage regulation typically occurs only at medium- and low-voltage substations, leaving utilities unable to regulate fluctuations in low-voltage networks.



**Agent driving deployment.** The utility drives the deployment of DPV—one of its goals being the procurement of ancillary services. These services may be provided by individual DPV installations (when sufficiently large) or DPV installations aggregated into VPPs. The need for ancillary services increases with the penetration of variable renewables into the power grid.

**DPV feed-in arrangement.** The DPV system feeds some or all of its output to the grid. Feed-all arrangements may be on the consumer or grid side.

**Retail electricity tariffs.** Volumetric tariffs are irrelevant. Incentives for the provision of ancillary services may come in the form of preestablished compensation at flat rates or based on the market.

**Impact on the utility.** Ancillary services benefit utilities. The utility uses its own DPV, if it owns any, or procures ancillary services from consumers or third parties. The magnitude of the benefit depends on how related costs stack up relative to other available options, and on how ancillary services are priced and reflected in tariffs. Ancillary services derived from DPV have been recognized as a benefit in a variety of studies, most of them focused on the United States (RMI 2013; ICF 2018). In 2013, Arizona found benefits close to 1.5 cents/kilowatt-hour (kWh), based on load reduction and reduced operating reserve requirements, as well as peak demand reduction and utility capacity requirements (ICF 2018).

**Financing.** Ancillary services may be remunerated through participation in a market, if one exists. Without markets, the utility may pay a flat rate to private providers, if they are involved. Payment for ancillary services will not be sufficient to finance the DPV systems, but it adds an additional value stream on top of the value of the power generated. To foster the wider provision of ancillary services, utilities and regulators can offer additional financing options (including subsidies) to finance the information and communications infrastructure needed to control the DPV.

**Technical prerequisites.** Passive service requires only that inverters be appropriately programmed. For active services, investments in information and communications technology (including smart meters, line sensors, and communications networks) are needed to enable interactions, along with related protocols. At the level of the individual consumer, smart inverters are needed as well.

**Suitable technology alternatives.** Alternatives include other distributed energy resources with inverters, such as battery storage, and electric vehicles using smart charging stations.

**Example: Service markets in New York State.** New York State has permitted DPV providers to participate in ancillary service markets since 2016 in a manner similar to traditional generators. Large facilities that generate power to serve loads on-site and have excess capacity can feed some power to the grid. Examples include industrial complexes, large residential facilities, and college campuses. Coordination entities for distributed energy resources can participate individually or in aggregate, as long as the entity has at least 2 MW of installed capacity (aggregating systems of at least 100 kW each), a minimum 1 MW in site load, and the ability to feed in at least 1 MW to the grid under a given transmission node (NYISO 2017).

## USE CASE 7: COMMUNITY SOCIAL SUPPORT

**Driver.** Retailers are suffering chronic financial losses from relying on subsidies to supply energy to consumers whose volumetric tariff rate ("social tariff") is below operating costs. Such consumers are generally low income, lack the financing for the up-front costs of DPV systems, and often live in housing with no access to a rooftop appropriate for DPV.

**Description and benefits.** Medium to large DPV systems are installed at suitable sites for the benefit of a community (for example, the rooftop of an apartment complex or the solar canopy installed over a public space). These community DPV systems are used to reduce the billed load of low-income consumers eligible to subscribe to the scheme. Participating consumers may be located at the DPV site or elsewhere on the grid. The reduced sales to loss-making consumers minimizes the utility's exposure to financial losses and its dependence on subsidies. If it is the government (i.e., Ministry of Finance) that subsidizes the sector, then the government will benefit from reduced spending on subsidies. And if low-income consumers are cross-subsidized by other consumers, DPV benefits those other consumers. DPV may be integrated with energy efficiency measures in a comprehensive package to save costs during a low-income housing renovation. As a bonus, the government can use these DPV installations as a showcase to encourage the uptake of DPV in other segments of the energy market.

**Agent driving deployment.** The government drives deployment as a way to make electricity more affordable for participating low-income consumers and to lessen the financial burden of social tariffs.

**DPV feed-in arrangement.** Community installations may feed all DPV output to the grid as a grid-side system. The DPV may feed all or some output to the grid if installed on a site with a master meter for a set of consumers, such as residents in an apartment complex.

**Retail electricity tariffs.** The tariff for participating consumers is below the utility's operating costs for serving those consumers.

**Impact on the utility.** The utility benefits from reduced sales to loss-making consumers.

**Financing.** DPV systems may be financed by the government or the utility with a revolving fund to cover up-front costs, while funds formerly dedicated to subsidies and/or bill savings are used to repay the loan on concessional terms ("on-bill financing") and cover operations and maintenance (O&M) so that consumers have no out-of-pocket expenses.

**Technical prerequisites.** A community installation requires just one meter, making it cheaper than individual installations.

**Suitable technology alternatives.** These include other distributed renewable energy solutions promoted by the government (accompanied by battery storage, if needed).

**Example: Community solar project in New Delhi.** SES Radjhani, the largest distribution company in New Delhi, with 2.3 million customers, has aggregated DPV capacity among its customers to attract investment. In 2018 it demonstrated the viability of a utility-led community solar model by installing PV systems across multiple rooftops and connecting them to the grid through a single metering point. Because power flows in both directions are aggregated, consumption costs and production benefits (that is, lower electricity bills) can be shared among all households in the community. The involvement of distribution companies and community-level intermediaries provided assurances to both consumers and investors. For households, the involvement of these intermediaries helped ease the complicated application processes and contracting of DPV vendors. Once the installation costs are paid off in full, ownership will be transferred to the households (Gillard and others 2018).

## USE CASE 8: FINANCIAL LOSS REDUCTION

**Driver.** The distribution utility is suffering financial losses from supplying energy to public institutions (such as government agencies, hospitals, and so on) that are in long-term arrears on bills and cannot be disconnected.

**Description and benefits.** In some cases, funds allocated to public institutions are not used to cover the institutions' utility bills. Meanwhile, given the strategic or political importance of these institutions, the utility cannot disconnect them for nonpayment. DPV can be used to reduce the load of the delinquent entities and therefore decrease the size of their unpaid utility bills. DPV is expected to be a good match for the demand of public institutions. These typically use electricity for daytime loads, including air conditioning in hot climates, that correspond quite well to a typical solar production curve. As an added bonus, the government can showcase these DPV installations to encourage the uptake of DPV in other segments of the energy market.

**Agent driving deployment.** The government drives the deployment as a solution to public institutions not paying their utility bills. The systems may be customer owned with government support or even be driven by the utility.

**DPV feed-in arrangement.** DPV is reducing the effective load of public entities. For DPV consumed on-site in a feed-none arrangement, systems may be designed to serve the minimum site load—or up to the maximum site load with some degree of curtailment. If designed as a feed-some or feed-all output to the local distribution grid to offset the consumption of several public entities, the compensation rate for such a feed needs to be low or at zero to be financially viable, since the utility would still be suffering losses from grid sales to these consumers.

**Retail electricity tariffs.** The starting tariff is irrelevant for public entities; they do not pay because they cannot be disconnected.

**Impact on the utility.** The utility either gets rid of nonpaying customers or decreases their consumption significantly, lowering its losses.

**Financing.** The government utilizes the rooftops of public buildings for the installations and uses money assigned by the Ministry of Finance to pay utility bills, thereby reimbursing the capital investment; the sum that was previously the source of arrears to the utility effectively becomes a public investment on the government's balance sheet. If the government's budget is insufficient, it can borrow the capital expenditure instead of requesting general budget support. DPV can be integrated into a building renovation as part of a comprehensive package of energy efficiency measures. For the project to be successful, a sustainable O&M financing strategy must be designed. Up-front costs are not the only costs that must be borne during the project's lifetime.

**Technical prerequisites.** For a feed-none arrangement, the timing of DPV generation should align with the shape of the building-level demand. If it does not, the system orientation (and therefore the output profile) can be altered or loads can be shifted in time to coincide with hours of DPV generation. The output should be sized below or close to the minimum site load.

**Suitable technology alternatives.** Other distributed renewable energy promoted by the government, which can be accompanied by battery storage, if needed.

**Example: Solar energy project in Sindh Province, Pakistan.** Distribution companies' technical and nontechnical losses in Sindh Province are high, at around 18 percent, and collection rates are relatively low, at around 94 percent, leaving these companies with a chronic liquidity crisis. A World Bank–supported solar project aims to identify suitable roofs, aggregate them, and auction them out to private developers for construction and long-term O&M. This produces 20 MW of DPV on and around public buildings in Karachi and Hyderabad, helping to reduce public sector electricity bills. The contracts put in place are performance-based O&M contracts; a revenue-generating model covers long-term O&M. Distribution companies in Sindh are expected to benefit from reducing their sales to nonpaying, public sector entities,

thereby helping to reduce circular debt. The arrears of payments from distribution companies to their suppliers amounted to around 1.2 percent of gross domestic product at the time of the project's start (World Bank 2018a).

## USE CASE 9: BOX SOLUTION

**Driver.** Drivers include emergency power needs following a disaster when grid services are temporarily disrupted, or needs for temporary new services, such as for pandemic isolation wards or settlements of forcibly displaced persons.

**Description and benefits.** A utility or private service provider installs an "out-of-the-box solution" to provide electricity service. This is a preassembled DPV system that is easy and quick to install, typically integrating a battery, diesel generator, or even hydrogen fuel cells for energy storage. Technologies include shipping containers that can serve as a stand-alone mini grid for a site, or that convert to become a multiuse facility such as a temporary self-powered building. Some box solutions smaller than shipping containers may be used by individual consumers or connected as a network for community use. Depending on their design, these DPV systems can provide electricity during the day or night, and some solutions can include appliances such as lights and fans. The modularity of box solutions enables them to be easily deployed in new locations with temporary service constraints or new temporary service needs, including in the event of a natural disaster (for example, a typhoon or hurricane). This feature is similar to the diesel systems widely available for lease in low- and middle-income countries. The box solution provides a quick improvement in service in case of a temporary disruption and can also strengthen a community's power delivery resilience.

**Agent driving deployment.** Users can buy the DPV system as a lower-cost alternative to diesel generators. DPV promotes resilience as it lowers consumers' risk to fuel price shocks or disruptions in the fuel supply chain. Utilities may choose or be mandated to deploy box solutions while grid infrastructure is being repaired. Humanitarian organizations or governments, on their own or with a private sector, can deploy box solutions to improve the socioeconomic well-being of vulnerable communities, such as for forcibly displaced people in temporary settlements.

**DPV feed-in arrangement.** The DPV arrangement depends on the functionality of the grid and whether it is directly connected to a load. When the DPV system is not linked to one consumer, it can feed *all* the electricity it generates, acting as a mini grid. Once the main grid is restored, it can continue to function or be moved to a different location. When it behaves as a stand-alone PV system, the box solution can feed *none* of the electricity generated to the grid. When connected to a load, it can be in a feed-*some* mode, by which it consumes some of its production and feeds the rest to the mini grid or islanded section of the power system it supports.

**Retail electricity tariffs.** In this case, DPV is providing electricity service in a place where electricity is not being supplied (that is, where there is no other generation option). Thus, tariffs for the main grid are irrelevant.

**Impact on the utility.** Governments or humanitarian organizations typically provide box solutions on a grant basis in places where costs are not expected to be recuperated. In the short term, this is typically beneficial to a utility that would otherwise need to provide power to nonpaying customers. The utility or private sector provider may be interested in providing a box solution on an "energy as a service" basis. If the utility is the driving agent, the box solution can increase the utility's revenues. If third-party providers seize the opportunity, they may acquire the incumbent's customers beyond the crisis situation, causing financial damage to the utility.

**Financing.** Typically, a grant, a loan, or a line of credit for "energy as a service" is extended to consumers, who pay it back in small monthly installments for the life of the service contract (pay-as-you-go). Such a business model can be scaled up through franchising.

**Technical prerequisites.** Making the box solution compatible with the main grid requires an inverter capable of operating as a stand-alone generator when islanded. If the box solution is tied to the grid, the utility must have equipment to ensure its safe disconnection and controlled reconnection to the grid.

**Suitable technology alternatives.** Alternatives include other sources of distributed renewable energy, with battery storage or diesel generators for remote locations, although fuel supply is an issue in the latter case.

**Example: Emergency electricity access in Yemen.** Recent conflicts have decreased the effective electricity access rate to less than 10 percent in Yemen, and solar power is the most immediate opportunity to alleviate the impact of the crisis. An ongoing World Bank–supported project targets the use of DPV to improve access to electricity in rural and peri-urban areas of Yemen and to restore electricity supply to critical service facilities, such as hospitals. For hospitals, predefined solutions, including standardized technical specifications and standards, are being offered under the project. Some customization of systems is required, particularly for grid-tied facilities, to ensure the value of these systems even after grid power is restored. It is also critical to invest in high-quality products, as it has been shown that they will generate higher benefits owing to their longer lifetime, despite their higher up-front costs. The supply of systems, their installation and maintenance, and local training and user manuals for solar energy systems are being bundled to ensure adequate operation (World Bank 2018b).

## UTILITIES AS PARTNERS IN DPV DEPLOYMENT

Utilities, contrary to popular belief, are not only critical to implementing DPV, they can also benefit greatly from it. As shown in figure 3.1, six of the nine use cases should affect utilities positively, while two are neutral. The one use case that may have a negative impact is bill reduction, when it reduces net revenues from the utility. Even in such a case that primarily benefits consumers, appropriate pricing and feed-in arrangements can ensure that utilities recover their costs in an equitable way. Provisions to ensure that utilities remain able to recover their costs are easiest to implement when the total amounts of DPV energy produced, and of grid electricity consumed, are accounted for separately, thereby facilitating differentiation of the value of energy consumed and generated at various times of day. Separate accounting can be accomplished with a smart bidirectional meter for arrangements that feed some but not all DPV generation to the grid ("net billing"), or with a generation meter for schemes that feed none or all DPV generation to the grid. The simplicity of the latter makes such schemes particularly suitable for low-income countries. Regulators should also take into account the non-energy benefits that utilities may derive from DPV integration. When all these factors are properly weighed, DPV schemes can reduce bills for consumers while being revenue neutral (if not positive) for utilities—without raising costs for non-DPV consumers.

It should be noted that DPV deployment has evolved from a consumer-driven model focused on the direct ownership of systems, most often installed by rooftop owners (first generation), to ones where utilities are in the driver's seat (third generation) (IFC 2014). All business models are available to public and private stakeholders. For example, a government can acquire systems for public buildings (first generation), lease systems or buy electricity through a power purchase agreement (second generation), or enable a public utility to provide on-bill financing of DPV systems to low-income users (third generation). Utility-driven business models are the latest innovation, but they are not necessarily the best for everyone.

Generally, utility-based implementation models gain prominence when utilities begin to see DPV generation as potential competition. Utilities can build on existing relationships with consumers to play an active role in solar generation and supply. Given their access, scale, size, and industry knowledge, utilities are advantageously positioned to play a role in the life cycle of designing, financing, developing, and maintaining such projects. Under these models, utilities invest directly or via a third party in the deployment of DPV systems, and the DPV generation becomes a part of the utilities' supply.

When utilities are actively involved in DPV business models, they can capture benefits from the solar market. A vertically integrated utility that still manages generation may find it easier to deploy DPV where it provides the most system benefits, as well as capture the entire value that it can provide (Foster and Rana 2020). Where smart-grid technology is deployed, utilities or third-party providers can provide that value by centrally controlling DPV and other distributed resources as VPPs.

There are many opportunities and paths for integrating DPV into a national energy plan. Countries can monetize the benefits with pricing, regulation, and planning that corrects any market imperfections that block sustainable DPV deployment. Additional technical measures can ensure that DPV deployment does not damage utilities. For utilities, the value of DPV can range from avoided grid expenditures to improved grid reliability and flexibility, reduced losses, and more. By investing in smart meters and analytical capabilities to handle the data flowing from those meters, utilities can take an integrated system-wide approach to extracting the location-specific value of deployed DPV (or extract that value through VPP models). Schemes for various use cases can be designed with feed-in arrangements to protect utility finances, while improving the quality and quantity of power available to consumers. In the least-developed countries and those beset by fragility, conflict, and violence, the geographic spread of DPV installations (to ensure supply is collocated with demand) reduces the exposure of power system assets to conflict. Incremental DPV development can also avoid the cost overruns typical of large infrastructure projects in these contexts and allows for learning while doing.

# GLOSSARY

**bidirectional meter** A device that measures both energy fed to grid and energy consumed as two separate gross volumes, and can be used for net metering or net billing.

**distributed PV (DPV)** Any PV system connected to a distribution grid or to a building or facility that consumes grid electricity. DPV may be connected to a distribution grid directly, or to consumers with a connection to a grid. In other words, it can be located on the grid side or the consumer side of a consumer's grid connection point. This definition of DPV does not imply a minimum or maximum capacity. The term DPV may also refer to PV used in off-grid settings, that is, for consumers or facilities with no grid connection. However, off-grid PV is not the primary focus of this report series.

**distribution company** Distribution companies exclusively provide distribution services and retailing (that is, metering and administration services) of electricity to retail consumers, including DPV consumers. They are responsible for maintaining the distribution grid and associated consumer-facing infrastructure for retailing electricity, and for procuring the wholesale electricity that they distribute and sell on. DPV is changing this model, as distribution companies may now purchase from DPV generators or facilitate peer-to-peer trade between DPV generators and consumers within the distribution grid.

**electricity services** Electricity services, in the context of a power system, are activities that enable consumption of electrical energy, or lower the costs associated with consuming electrical energy, or both. Electricity services add economic value when various constraints are satisfied on the supply and delivery of electricity (physical, policy related, etc.) (Jenkins 2018). For example, DPV may be able to provide several **distribution system services,** including targeted load reduction in capacity-constrained areas of the network (distribution capacity), feeder-level voltage management (voltage support), reductions in the frequency and duration of outages (reliability or back-tie), and improved recovery time from outages or system disturbances.

**energy as a service** See pay-as-you-go.

**feed-in arrangement** Denotes whether the DPV system feeds some, none, or all of its generated power to the grid.

**generation company** Generation companies generate and sell wholesale electricity directly to distribution companies and wholesale consumers. They may own all their generation assets, or rely on power purchase agreements with independent power producers for a portion of their generation. They typically sell wholesale electricity to distribution companies at regulated wholesale electricity tariffs, while tariffs for direct sale to wholesale consumers (for example, large industrial customers) are typically negotiated. Although generation companies use central power stations as distinct from distributed generation, the latter can also be aggregated to act as a virtual power plant, including to participate in wholesale markets (as is allowed for up to 20 MW in the case of the New York Independent System Operator, for example).

**gross metering** Separate measurement of energy consumed from the grid and energy fed to the grid, typically for a feed-all arrangement (that is, gross production of energy fed to the grid and gross consumption of energy from the grid). Also known as dual metering, implying the use of two separate meter devices (versus a bidirectional meter that integrates both meter functions in a single device).

**microgrid** A small grid system with its own power generation sources to serve one or more consumer facilities, typically with an interconnection to a main grid and capable of operating independently during an outage of the main grid.

**mini grid** A small grid system to serve one or more consumer facilities, typically in an off-grid setting.

**net energy** The vector sum of energy consumed and energy fed by the consumer to the grid over a given period of time (for example, hour, day, or billing cycle). The sum for the given time period may be a net feed-in ("credits" from the consumers' perspective, sometimes called "excess" energy), net consumption, or zero (if the feed-in and grid consumption amounts happen to be equal).

**net billing** Separate measurement and pricing of energy consumed from the grid and energy fed to the grid under a feed-some arrangement (that is, some DPV energy is fed to the grid, and some DPV energy is consumed), each net of self-supply. Typically accounted with a bidirectional meter.

**net meter** A meter of net energy, for example, a meter that can spin forward or backward.

**net metering** The process of accounting for DPV generation fed to grid using a net meter or equivalent, such that energy fed to the grid is compensated at the same rate as the energy component of the retail electricity tariff for the given time period (retail parity compensation). In practice, there are many forms of net metering, and different jurisdictions apply the term in different ways.

**pay-as-you-go** Pay-as-you-go, also known as "energy as a service," is a service payment model where consumers make small monthly payments under a contract with a provider for specified services. It can be used to recover capital costs from consumers. Contracts may vary in their duration and commitment fees.

**value of solar** An estimate of the value of avoided costs of grid electricity—plus wider environmental, social, and financial benefits—of DPV installation in a given context. The assessed value of DPV systems in a given power sector may be used as a benchmark or approach for determining the level of compensation for DPV energy fed to the grid.

**utility** Electricity service company. In the context of DPV, a utility typically refers to a distribution company or a vertically integrated utility.

**vertically integrated utility (VIU)** A company that own assets in all parts of the electricity supply chain, providing retail, distribution, transmission, and generation services within a given service area. Some are also "horizontally integrated," owning all assets in generation, transformation, or distribution in a given power system service area. In power sectors with horizontally unbundled generation, VIUs typically rely on or compete with independent power producers for some portion of power generation needs. In such power sectors, some VIUs may have a retail business selling directly to consumers and a wholesale business selling to local distributors and/or large wholesale customers. All kinds of VIUs are subject to economic regulation, offering regulator approved retail (and/or wholesale) electricity tariffs to consumers. When DPV is deployed in a setting with a VIU, the precise impact on revenue depends on whether the DPV is deployed in a distribution service territory that the VIU operates.

**virtual power plant** A virtual power plant is a network of decentralized generating units, consumers of flexible power, and storage systems, all interconnected and dispatched through central control as if they were one power plant yet independent in operation and ownership.

See also US Energy Information Agency Glossary. Available online at https://www.eia.gov/tools/glossary/.

## REFERENCES


Chew, B., E. H. Myers, T. Adolf, and E. Thomas. 2018. "Non-wires alternatives: Case studies from leading U.S. projects." Smart Electric Power Alliance, Peak Load Management Alliance, and E4TheFuture. https://e4thefuture.org/wp-content/uploads/2018/11/2018-Non-Wires-Alternatives-Report_FINAL.pdf.

ESMAP (Energy Sector Management Assistance Program). 2019. "Energy storage roadmap for the Maldives: Executive summary." World Bank, Washington, DC. http://documents.worldbank.org/curated/en/340311572621106332/pdf/Executive-Summary.pdf.

Figel, T., S. Garren, A. Giancatarino, S. Greschner, R. Jackson, M. Santiago-Mosier, I. Schwingler, and M. Tomic. 2016. "Low-income solar policy guide." GRID Alternatives and Vote Solar. www.lowincomesolar.org/guiding-principles.

Foster, V., and A. Rana. 2020. *Rethinking power sector reform in the developing world*. World Bank, Washington, DC. https://openknowledge.worldbank.org/bitstream/handle/10986/32335/9781464814426.pdf?sequence=10&isAllowed=y.

Gillard, R., A. Sudmant, A. Gouldson, and L. Oates. 2018. *Affordable and clean energy for all: Lessons on rooftop solar from Delhi, India*. Coalition for Urban Transitions. http://newclimateeconomy.net/content/cities-working-papers.

Graber, Sachiko, Patricia Mong, and James Sherwood. 2018. *Under the grid: Improving the economics and reliability of rural electricity service with undergrid minigrids.* Rocky Mountain Institute. http://www.rmi.org/insight/under-the-grid/.

Graber, Sachiko, Oladiran Adesua, Chibuikem Agbaegbu, Ifeoma Malo, and James Sherwood. 2019. *Electrifying the underserved: Collaborative business models for developing minigrids under the grid.* Rocky Mountain Institute. http://www.rmi.org/insight/undergrid-business-models/.

Grid Alternatives. 2019. "Nepal Women in Solar Program." https://www.youtube.com/watch?time_continue=16&v=3rmh036jnTk&feature=emb_logo.

ICF. 2018. *Review of recent cost-benefit studies related to net metering and distributed solar.* Report by ICF for the U.S. Department of Energy.

IEA (International Energy Agency). 2019a. *Renewables 2019: Analysis and forecast to 2024*. IEA, Paris.

IEA (International Energy Agency). 2019b. *World energy outlook*. https://www.iea.org/reports/world-energy-outlook-2019.

IEA (International Energy Agency). 2020a. *Renewables 2020: Analysis and forecast to 2025*. IEA, Paris.

IEA (International Energy Agency). 2020b. *Sustainable recovery: World energy outlook special report*. https://www.iea.org/reports/sustainable-recovery.

IEA and CEEW. 2019. *Women working in the rooftop solar sector: A look at India's transition to clean energy*. https://www.iea.org/reports/women-working-in-the-rooftop-solar-sector.

IFC (International Finance Corporation). 2014. "Harnessing energy from the sun: Empowering rooftop owners." White Paper on Grid-Connected Rooftop Solar Photovoltaic Development Models. https://www.ifc.org/wps/

wcm/connect/a78df7b2-e727-4b2b-b57b-54d36283fb28/Harnessing+Energy+From+The+Sun_Final.pdf?MOD=AJPERES&CVID=kMcwHBR.

IFC (International Finance Corporation). 2019. "The dirty footprint of the broken grid: The impacts of fossil fuel back-up generators in developing countries." https://www.ifc.org/wps/wcm/connect/2cd3d83d-4f00-4d42-9bdc-4afdc2f5dbc7/20190919-Full-Report-The-Dirty-Footprint-of-the-Broken-Grid.pdf?MOD=AJPERES&CVID=mR9UpXC.

IRENA. 2019a. *Renewable energy: A gender perspective*. IRENA, Dubai. https://www.irena.org/publications/2019/Jan/Renewable-Energy-A-Gender-Perspective.

IRENA. 2019b. *Future of solar photovoltaic: Deployment, investment, technology, grid integration and socio-economic aspects.* IRENA, Dubai. https://www.irena.org/publications/2019/Nov/Future-of-Solar-Photovoltaic.

IRENA. 2020. *Renewable energy and jobs: Annual review 2020*. IRENA, Dubai. https://www.irena.org/publications/2020/Sep/Renewable-Energy-and-Jobs-Annual-Review-2020.

Jenkins, J. D. 2018. *Electricity system planning with distributed energy resources: New methods and insights for economics, regulation, and policy.* PhD thesis. Massachusetts Institute of Technology.

Lempriere, Molly. 2020. "India adds 883 MW of rooftop solar in first nine months of 2020 despite COVID-19." PV Tech. https://www.pv-tech.org/india-adds-883mw-of-rooftop-solar-in-first-nine-months-of-2020-despite-covid-19/.

Lighting Global. 2019. *Market analysis: Energy access for Syrian refugees in Lebanon.* https://www.lightingglobal.org/wp-content/uploads/2019/02/Space-for-Solar-Energy-in-the-Syrian-Refugee-Crisis-09102019.pdf.

Maier, Elisabeth, Samantha Constant, and Ali Ahmad; 2020. *Gender in energy interventions in fragile and conflict states in the Middle East and North Africa Region: Insights from Iraq, Lebanon, Yemen and the West Bank and Gaza*. World Bank Group (forthcoming).

Navigant. 2017. "Non-wires alternatives: What's up next in utility business model evolution." Utility Dive. https://www.utilitydive.com/news/non-wires-alternatives-whats-up-next-in-utility-business-model-evolution/446933/.

NREL (National Renewable Energy Laboratory). 2014. "Distributed solar PV for electricity system resiliency policy and regulatory considerations." NREL, Golden, CO. https://www.nrel.gov/docs/fy15osti/62631.pdf.

NYISO (New York Independent System Operator). 2017. "Distributed energy resources market design concept proposal." https://www.nyiso.com/documents/20142/1391862/Distributed-Energy-Resources-2017-Market-Design-Concept-Proposal.pdf/122a815f-b767-e67f-0a8f-323e5489c2b1.

PwC (PricewaterhouseCoopers). 2019. "Developing sustainable rooftop PV in Vietnam #1259789: HCMC and Danang." Internal report for the World Bank.

REA (Rural Electrification Agency). 2020. "The Federal Ministry of Power installs 24-hours solar powered mini-grids in four COVID-19 isolation centers across Nigeria." Press release, Nigerian Rural Electrification Agency, April 16. https://rea.gov.ng/press-release-federal-ministry-power-installs-24-hours-solar-powered-minigrids-four-covid-19-isolation-centers-across-nigeria/.

RMI. 2013. *A review of solar PV benefit and cost studies,* 2nd edition. https://rmi.org/wp-content/uploads/2017/05/RMI_Document_Repository_Public-Reprts_eLab-DER-Benefit-Cost-Deck_2nd_Edition131015.pdf.

UNHCR (United Nations High Commissioner for Refugees). 2017. “UNHCR diagnostic tool for alternatives to camps: 2017 global results.” UNHCR, Geneva. https://www.unhcr.org/en-us/59b2a6f07.

UNHCR (United Nations High Commissioner for Refugees). 2018. *Global trends: Forced displacement in 2018*. UNHCR, Geneva. https://www.unhcr.org/5d08d7ee7.pdf.

UNHCR (United Nations High Commissioner for Refugees). 2020. *Global Appeal 2020–2021*. UNHCR, Geneva. http://reporting.unhcr.org/sites/default/files/ga2020/pdf/Global_Appeal_2020_full_lowres.pdf.

World Bank. 2013. China Beijing Rooftop Solar Photovoltaic Scale-Up (Sunshine Schools) Project Appraisal Document. http://documents.worldbank.org/curated/en/131691468219305697/China-Beijing-Rooftop-Solar-Photovoltaic-Scale-Up-Sunshine-Schools-Project.

World Bank. 2014. Maldives: Accelerating sustainable private investments in renewable energy (ASPIRE) project appraisal document. World Bank, Washington, DC. http://documents.worldbank.org/curated/en/402251468300650153/Maldives-Accelerating-Sustainable-Private-Investments-in-Renewable-Energy-ASPIRE-Project.

World Bank. 2017a. “West Bank and Gaza electricity sector performance improvement project appraisal document.” World Bank, Washington, DC. http://documents.worldbank.org/curated/en/297361501380046131/West-Bank-and-Gaza-Electricity-Sector-Performance-Improvement-Project.

World Bank. 2017b. “Haiti renewable energy for all project appraisal document.” World Bank, Washington, DC. http://documents.worldbank.org/curated/en/606711509156039620/Haiti-Renewable-Energy-for-All-Project.

World Bank. 2018a. “Pakistan: Sindh Solar Energy project appraisal document.” World Bank, Washington, DC. http://documents.worldbank.org/curated/en/136231529206242617/Pakistan-Sindh-Solar-Energy-Project.

World Bank. 2018b. Yemen: Emergency Electricity Access project appraisal document. http://documents.worldbank.org/curated/en/845691523844015143/Yemen-Emergency-Electricity-Access-Project.

World Bank. 2020. “Solar power provides a lifeline to Afghanistan’s hospitals.” World Bank, Washington, DC. https://www.worldbank.org/en/news/feature/2020/12/06/solar-power-provides-a-lifeline-to-afghanistans-hospitals.

World Bank. 2021. “Living in the dark no more: How solar power helps Yemenis resume their lives.” World Bank, Washington, DC. https://www.worldbank.org/en/news/feature/2021/01/20/how-solar-power-helps-yemenis-resume-their-lives.

## ESMAP MISSION

ESMAP is a partnership between the World Bank and 22 partners to help low- and middle-income countries reduce poverty and boost growth through sustainable energy solutions. ESMAP's analytical and advisory services are fully integrated within the World Bank's country financing and policy dialogue in the energy sector. Through the World Bank Group (WBG), ESMAP works to accelerate the energy transition required to achieve Sustainable Development Goal 7 (SDG7) to ensure access to affordable, reliable, sustainable, and modern energy for all. It helps to shape WBG strategies and programs to achieve the WBG Climate Change Action Plan targets.

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