BACKGROUND PAPER ON DISTRIBUTED RENEWABLE ENERGY GENERATION AND INTEGRATION

PREPARED FOR

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EXECUTIVE SUMMARY

Most electricity worldwide is produced at large (1-megawatt [MW] to 1,000-MW) power plants and delivered to electricity users via the transmission and distribution system. This is called a 'centralized' electricity system. There is, however, an alternative: the use of smaller (1-kilowatt [kW] to 100-kW) power plants located at or near electricity users. This is known as a 'distributed' system. There are several renewable electricity generating technologies that can provide electricity at distributed levels, including distributed photovoltaic (PV) systems, methane digesters, micro hydropower, and small wind turbines.

Field experience with distributed renewable electricity generating technologies (DREGTs) reveals a number of barriers to greater use of these technologies. These include technical and economic issues such as variability, grid integration, and high capital costs; policy issues such as policy uncertainty and fossil fuel subsidies, and institutional issues such as a lack of installation and maintenance capabilities and resistance from incumbent electricity providers.

Recent field experience has also highlighted enabling environments – specific features or attributes that help explain DREGT project success. Many successful projects:

- Engage utilities as essential partners rather than opponents.
- Leverage peer influences and personal networks within the community.
- Standardize technologies and business practices.
- Reduce perceived risk for investors and system owners.
- Involve and engage the community early, often, and throughout.
- Allow for innovative finance.
- Offer sufficient financial incentives to attract private-sector investment.
- Provide for system O&M.

These barriers and enabling environments point to a number of policy issues and options that could enhance DREGT development and take-up. Several of these relate to the institutional structure of the electricity industry: in many countries, electricity is directly provided by, or regulated by, the public sector. DREGTs, in contrast, have achieved some success through direct investment by individuals and innovative financing using private capital. Governments may want to reassess existing regulatory structures, with a goal of finding the optimal mix of public and private roles in electricity supply. Similarly, governments may want to explore whether current financial regulations provide the appropriate risk and reward to private sector actors. In addition, policies such as fossil fuel subsidies and import duties on renewable technologies could be reexamined in light of the potential for DREGTs to provide economical and lower-carbon electricity.

INTRODUCTION AND OVERVIEW

This background paper provides an overview of distributed renewable energy generation. This paper is intended to assist the Technology Executive Committee (TEC) of the United Nations Framework Convention on Climate Change (UNFCCC), in its efforts to enhance technology development and transfer of distributed renewable electricity generating technologies (DREGTs).

This paper focuses on what can be learned from recent experience in DREGT implementation. Our methodology for this work was to review the primary published literature on implementation: reports, papers, and presentations that describe and assess field experience with DREGTs. We focus on recent (post-2010) literature, as the technologies and policies are evolving rather rapidly in this field, making older work less directly applicable. We emphasize developing country experience, but include lessons learned from industrialized countries as well. This paper distills this literature into a finite and manageable set of findings and policy implications.

Chapter 1 provides definitions of relevant terms, and an overview of the technologies themselves, including cost and performance data as well as market status. As discussed in this chapter, for this report we define distributed to include electricity generating technologies that serve more than one building or entity, are sized up to 100 kW, and can be interconnected with other technologies to create a larger (that is, more than 100 kW) electricity system.

Chapter 2 focuses on the barriers to greater use, including the many issues (technical, economic, political, and social) that have emerged to complicate and/or delay greater use of DREGTs.

Chapter 3 showcases enabling environments for DREGTs. It provides examples and illustrations of how these technologies have succeeded in providing significant electricity supply, both in established large electricity grids and in remote distributed applications.

Chapter 4 discusses policy issues and options, pointing to actions that countries and governments could consider to encourage greater uptake of DREGTs.

1. TECHNOLOGY REVIEW

Most electricity worldwide is produced at large (1-megawatt [MW] to 1,000-MW) power plants and delivered to electricity users via the transmission and distribution (T&D) system. This is called a 'centralized' electricity system. There is, however, an alternative: the use of smaller (1-kilowatt [kW] to 100-kW) power plants located at or near electricity users, known as a 'distributed' system.

Distributed versus centralized electricity systems

This distributed electricity model has both advantages and disadvantages relative to the traditional, centralized model (table 1A). For example, in rural areas without electricity service, the distributed model may be the only option, as the costs of extending the centralized grid may be prohibitive. Similarly, in areas where the centralized grid is already installed, distributed generation (DG) can improve grid resilience by providing reliable electricity during hazards such as extreme weather. It can also provide a path for direct private investment in new generation.

However, distributed electricity has some significant challenges as well. For many electricity-generating technologies, per-kW costs decrease with size (that is, larger power plants have lower per-unit-output costs), meaning distributed systems can have higher costs. And some electricity generating technologies – notably large steam systems, such as those used by large coal and nuclear power plants – do not function well at distributed scales, meaning they cannot be used in distributed systems. These major issues are summarized in table 1A.

Table 1A. Conceptual comparison of centralized and distributed electricity systems

	Advantages
Centralized	-Wide range of mature technologies -Lower per-kW costs -Higher load diversity->flatter demand profile -Well-developed industry
Distributed	-Appropriate for small/remote communities -Greater system resilience due to diversity of supply -Reduced transmission and distribution (T&D) losses -Allows for direct private investment in generation

The decision of whether a distributed system or grid extension is appropriate for a given geographic area is very complex and site-specific, as demonstrated in a recent comprehensive analysis for a rural area in Northwest China (Holtmeyer, M. et al., 2013). Improved, multi-criteria electricity supply planning techniques for rural areas are increasingly used and, although more complex, are more able to incorporate critical environmental and social factors. (Rojas-Zerpa, J. and J. Yusta, 2014).

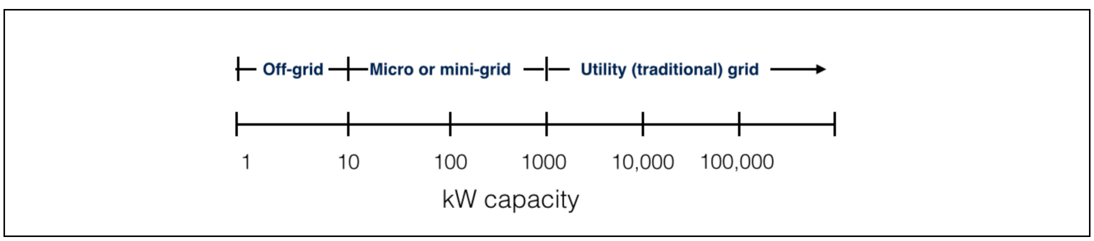
Microgrid, distributed generation…what do these terms mean?

There is a surfeit of confusing and overlapping terminology around DREGTs. Much of the confusion results from the dearth of universally accepted definitions of the many terms. In general, distributed generation refers to electricity generation that occurs at or near where the electricity is used. A common—but by no means universal—use of 'distributed' is to refer to electricity-generating technology with a rated capacity of 100 kW or less. For example, a small (10 kW) wind turbine serving a small village would be considered a distributed electricity system. Note however that the 100 kW refers to the individual technology – not the system overall. For example, a large village served by two hundred 10 kW wind turbines, all interconnected, would also be considered a distributed system, even though the total system capacity exceeds 100 kW.[1]

There is a range of other terms often encountered in relation to DREGTs:

- **Off-grid.** This typically refers to a single structure that provides its own electricity and is not connected to any other electricity users.[2]
- **Nano-, micro-, and minigrids.** These are electricity grids that typically serve anywhere from one to thousands of electricity users. In general, *nano* refers to grids serving one to tens of users, *micro* tens to hundreds, and *mini* hundreds to thousands (Figure 1A). These smaller grids can be connected to larger, centralized grids. However, if they are so connected, the smaller grids typically have the ability to generate some or all of their own electricity, and may be able to "island," or cut their connection to the larger grid.

Figure 1A: Grid size and terminology



For this report, we define distributed to include electricity generating technologies that serve more than one building or entity, are sized up to 100 kW, and can be interconnected with other technologies to create a larger (that is, more than 100 kW) electricity system.

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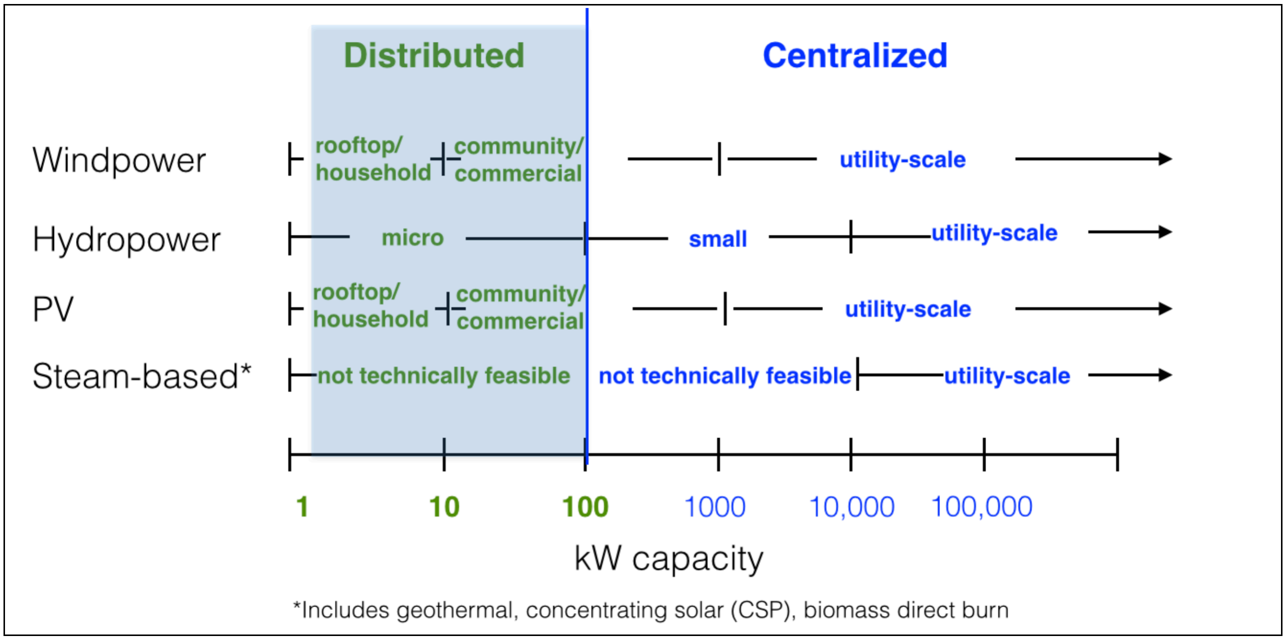
[1] The IPCC define these terms as follows: "The distributed system is made up of a large number of small local power plants, some of which supply the electricity mainly to an on-site customer, and the remaining electricity feeds the grid. The centralized system, on the other hand, works as one large power plant. Off-grid systems are typically dedicated to a single or small group of customers and generally require an electrical storage element or back-up power." (IPCC, 2011, p.62).

[2] A detailed discussion of off-grid renewables can be found in IRENA (January 2015b).

The technologies themselves—such as hydropower and PV panels—are typically described or defined with a range of terms, including "commercial, "micro," and "household." Here again, there are no universally accepted definitions of these terms; however, there are typical uses of them. Figure 1B shows these typical uses as well as how they map to the concept of distributed.

Figure 1B: What counts as distributed?



Distributed renewable electricity generating technologies

There are several renewable technologies that can provide electricity at a distributed (< 100 kW) level. These include distributed photovoltaic (PV) systems, methane digesters, micro hydropower, and small wind turbines. (Table 1A).

Table 1A: DREGT comparison

Technology	Typical Cost (USD/kW)*	Resource or Fuel Needs	O&M Needs	Variability of Output – Diurnal**
Distributed PV system	2 to 5	Sunlight	Low	High
Methane digester	3 to 6	Dung	High	Low
Micro hydropower	3.4 to 10+	Consistent water flows	Medium	Low
Small wind turbine	7	Wind > 3 meters per second (m/s)	Medium	***

*For sources, see discussion in text. These costs do not include storage.
**Other time scales may be of interest as well, notably annual and 'climatic' (longer-term). For these time scales, variability may vary by location. For example, PV output will vary considerably over the course of a year for installations at greater latitudes, but much less so for installations near the Equator.
***Depends on specific location. Some regions show large day/night variability in the wind resource, others much less so.

Distributed PV systems. The global PV market is growing rapidly. Published data on PV technology (including both centralized and distributed generation) help to paint this picture, although these published data typically lag the reality of the current market by a year or more.

- Global PV capacity has grown approximately 40 percent per year since early 2008 (REN21, 2014).
- Global PV capacity reached 139 GW at the end of 2013, with over half that amount installed in 2012 and 2013 (REN21, 2014).
- Industry forecasts show continued growth in the global PV market, exceeding 50 GW per year by 2017 (EPIA, May 2014).

Distributed PV costs are a subject of considerable debate. There are several reasons why cost data appears to be so variable:

- *Costs change very rapidly.* An actual project cost from 2013, for example, may no longer be accurate in 2014.
- *Costs vary by location.* Remote PV systems have a higher per-kW or per-kilowatt-hour (kWh) rate due to increased transport costs; insolation levels vary widely by location.
- *Definitions of what exactly is included in a cost estimate vary.* For example, one cost estimate may be for hardware only, while another may include soft costs such as permitting, marketing, and installation labor.
- *Subsidies (such as tax credits) may or may not be reflected in a cost estimate.*

The most recent published data show that installed residential PV prices vary widely by country, from USD 2/watt in China and Germany to USD 5/watt in France (IRENA, January 2015c, p. 89). Note that these costs are for residential systems; costs for utility-scale systems will generally be lower (IRENA, January 2015c, p. 88). Industry analysts expect PV prices to continue falling, landing anywhere from USD 1.50 to USD 3 per watt by 2016 (Feldman et al., September 2014).

As PV prices fall, PV may eventually reach socket parity (cost-competitive with retail electricity) and grid parity (cost-competitive with wholesale electricity). The moment at which this parity will occur is unclear; recent analyses suggest it may be close. A comprehensive analysis of small-scale PV systems for Brazil found that such systems were not economically viable for the residential sector at a PV price of USD 3200/kW; but were at the threshold of economic viability at a PV price of USD 2870/kW (Holdermann et al. 2014). Notes a recent report, "the levelised cost of electricity of solar PV has halved between 2010 and 2014, so that solar photovoltaics is also increasingly competitive at the utility scale." (IRENA, January 2015c, p.12).

Whether PV reaches socket parity or grid parity first is a nuanced issue. Clearly, socket parity is an easier goal to reach, since retail rates are higher than wholesale rates. However, as noted above, utility-scale PV systems have lower per-kW costs than distributed PV systems, making it unclear which type of parity will first occur.

A major constraint for distributed PV systems is the variability of output. As discussed below in chapter 2, when PV supplies a modest fraction of total electricity, its variability can be managed by various techniques such as ramping of conventional generation. However, for distributed systems without such generation, storage is needed – increasing system costs (see storage discussion below).

The PV industry is undergoing significant change. PV module manufacturing is increasingly dominated by China, with one source reporting that seven of the top ten PV manufacturers are Chinese companies (Solarbuzz, 2014). However, PV module prices dropped 75% from the end of 2009 to the end of 2014, and are now generally under USD 1/watt (IRENA, 2015c, pp. 79-80). Therefore, for many countries, the PV module themselves will be imported; yet the costs of those imports will account for a decreasing fraction of total system costs.[3] The 'balance-of-system' costs, in contrast (hardware such as wires and connectors, installation, permitting, and customer acquisition), are now the bulk of total system costs.

Methane Digesters. There are several routes through which biological material (such as crop wastes, dung, and trash and refuse) can be converted into electricity. The simplest way of doing so—simply burning the material, using the heat to make steam, and using the steam to drive a turbine—is generally not done at distributed capacity levels. This is because steam turbines are not typically used at capacities of less than about 1 MW.

There is, however, an alternative process by which biological materials can be used to make electricity at distributed capacity levels. Biological materials, under the right

[3] Notes a recent report, "BoS costs and financing costs are becoming the crucial determinants of the LCOE of solar PV." (IRENA, 2015c, p.145).

conditions of heat, moisture, and low oxygen, can directly generate methane via anaerobic digestion. That methane can then be used to fuel a reciprocating engine or a small turbine. Such systems are known as methane digesters. The technical components (for example, piping and engines) of methane digesters are commercially available and the principles of design are well known. However, this technology is somewhat constrained by the need for site-specific design, construction work, and a consistent fuel supply.

Cost data for such systems are scarce, and they are complicated by the fact that such projects may use the methane for cooking and water heating as well as for electricity production. One source estimates methane digester electricity systems at USD 2,500 to USD 6,100 per kW; however, this figure includes both small and large systems (IRENA, 2015c, p.130).

Microhydro systems. Typically defined as hydropower systems with a rated capacity of less than 100 kW, microhydro technology can tap the energy of running water to make electricity. These systems are usually "run-of-river," meaning that they do not require a dam or other major modifications to a river in order to harness energy from the charging water. They do, however, require a reliable and consistent water flow and considerable site-specific engineering and design.

Reliable data on global installations or capacities for microhydro systems are scarce. A recent report on small hydro (defined as less than 10 MW) found a current global capacity of 75 GW, with additional resource potential of over 100 GW, mostly in Asia (UNIDO, 2013). This report provides some country-specific data, for example:

- Pakistan has 538 microhydro plants, with a total installed capacity of approximately 8 MW.
- With potential capacity of 29 MW, 149 potential microhydro sites have been identified in Malaysia.
- In recent years, Afghanistan reportedly has seen installations of 160 new microhydro power plants, yet 30 to 40 percent are not operational.

Costs for such systems are highly variable and site-dependent. One source reports capital costs of USD 3,000 per kW for microhydro generation in Afghanistan (UNIDO, 2013). Cost data are complicated by the fact that the turbine itself typically accounts for less than half the total system cost. Civil engineering efforts (such as digging and pipe installation) and electrical lines are major cost components as well, and are very site-dependent. Another source estimates typical costs at approximately USD 3,400 to USD 10,000 or more per kW (IEA-ETSAP, January 2015), however this figure includes hydro facilities of up to 1 MW.

Microhydro can be used only in areas with sufficient water flows and head (that is, elevation change). However, the technology is a promising option for countries that have consistent water flows and sufficient in-country technical expertise to design and install the systems.

Small wind turbines.[4] Wind turbines come in a wide range of sizes, from those producing less than 1 kW (used mostly for residential and street lighting) to those producing more than 7 MW (used for utility-scale power). Small wind turbines are typically less than 100 kW and are sited at or near the point of electricity consumption. As of the end of 2012, there were approximately 1 million small wind turbines installed worldwide, with a total generating capacity of approximately 700 MW (WWEA, 2014). China is the largest market for these turbines, accounting for 39 percent of global capacity (WWEA, 2014). The US (31 percent of global capacity and the UK (9 percent) are second and third, respectively (WWEA, 2014). Most small wind turbine installations in China and the US are off-grid, meaning they serve a single household or building (WWEA 2014; US DOE, 2014).

The average installed cost of new small wind turbines in the US was USD 6,940 per kW in 2013, and the average levelized cost of electricity (LCOE) was USD 0.14 per kWh (US DOE, 2014). Another source estimates the cost of small to medium wind turbine installations for island applications at USD 0.20 to USD 0.50 per kWh (IRENA, 2014a).

A typical small wind turbine has a cut-in speed (that is, a minimum wind speed required to generate electricity) of 3 meters/second (m/s) and it reaches rated output at 11 m/s. Therefore, a turbine will only produce electricity when wind speeds are greater than 3 m/s, and it will only produce reliable, consistent electricity if winds are consistently greater than this speed. This factor limits the geographic applicability of small wind turbines.

In general, the small wind turbine industry is more fragmented than the large wind industry. One database identifies 410 small turbines available from 191 manufacturers. (All Small Wind Turbines, 2015). In the US alone, the distributed wind supply chain includes hundreds of manufacturing facilities and vendors, spread across 34 states. (USDOE, 2014). In contrast, just five manufacturers account for 50% of the large wind market. (REN21, 2014, p.59).

Case Study: Tonga reduces oil dependence by turning to small wind

The Kingdom of Tonga has relied heavily on petroleum imports to meet the country's energy demands. In an effort to reduce Tonga's vulnerability to oil price fluctuations, state-owned energy enterprise Tonga Power Limited (TPL) recently commissioned an 11 kW wind turbine at Nakolo Village. The turbine, capable of supplying power to 23 homes, was installed in June of 2013 and marks the first in a series of TPL's planned wind turbine installations. Construction of the company's next wind turbine (to be located on one of the nation's smaller islands) is planned for March of 2015.

Although Tonga Power Limited's pilot project has proven to generate just two-thirds of the anticipated energy production, several important lessons were learned. The main barrier

[4] This discussion focuses on small wind turbines, which we define as less than 100 kW. This excludes the significant market of wind turbines in the 100 kW to 1 MW range, which some reports consider as 'distributed.'

to realizing predicted energy production was insufficient wind. To better combat issues of variability, the governmental energy provider plans to gather more robust wind data and incorporate these into the siting of future projects. Additionally, increasing the tower height of future wind turbine installations is intended to increase wind exposure. In an effort to reduce the payback period, the Tongan government plans to focus more attention on procuring land void of dense vegetation and unobstructed by topographical impediments.

(Sources: Government of the Kingdom of Tonga, 2010; Tonga Ministry of Information and Communications, 2013)

Enabling technologies

Widespread application of DREGTs will be eased if several enabling technologies achieve widespread commercial success. Such technologies may not be absolutely necessary for DREGT success as there are other methods for easing renewables grid integration (see the discussion in Chapter 2). There's little question, however, that they would certainly be useful. Here we briefly review the status of these technologies.

Storage. Storage to support DREGTs can be either distributed or centralized, as either could support distributed variable generation. In fact, over 99 percent of current installed storage worldwide is centralized pumped hydro, which is a mature technology but very geographically limited, since it requires two large water reservoirs with a significant elevation difference between them (IRENA, May 2012).

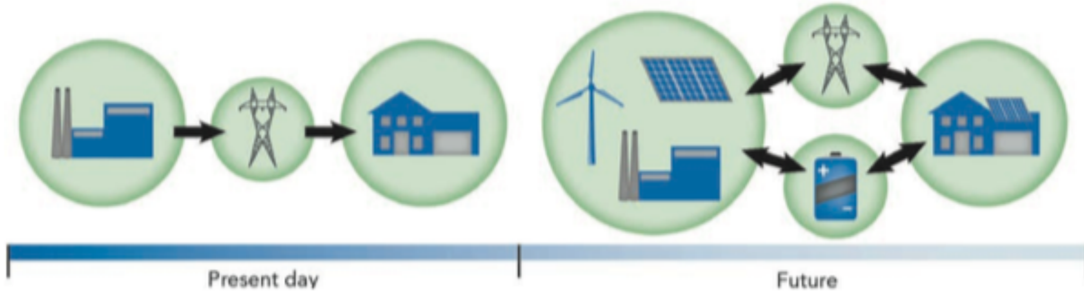
There are many storage technologies in addition to pumped hydro. These include chemical storage (such as batteries), kinetic storage (such as superconducting magnetic energy storage (SMES), heat (or cool) storage (such as ice storage and building precooling), and others. Many reports summarize the cost and performance characteristics of these technologies (see e.g. IRENA, May 2012; IRENA, January 2015a). Batteries are the most widely used storage technology after pumped hydro, however a recent report concluded, "several barriers have to be overcome before battery storage is fully integrated as a mainstream option in the power sector." (IRENA, January 2015a, p.1). That may change as research and development (R&D) continues; however batteries will need to show lower costs and improved performance (notably technical efficiency, reliability, and lifetime) in order for them to achieve widespread use in large, centralized grids.

For smaller (nano-, micro-, and mini-) grids, however, storage is increasingly used in conjunction with distributed renewables. Most such systems use batteries, as they are a mature and widely available technology. Lead-acid batteries are by far the most common; however, newer battery technologies (notably lithium-ion) are showing improved performance and may soon see widespread use (IRENA, January 2015a).

Smart grid. Smart grid refers to information and communication technologies that can be integrated into electricity systems. These technologies offer several benefits, including improved reliability, reduced technical losses, lower operating costs, and—of particular interest to this discussion—eased grid integration of DREGTs. For example, a smart electricity meter can communicate real-time pricing information to specific end uses, allowing electricity demand to be reduced when renewables' output decreases. Similarly, a smart inverter can allow a distributed photovoltaic system to communicate with the grid operator and adjust output in response to grid needs.

The longer-term vision of smart grid is an electricity system where information and electricity flow throughout. This model is unlike the traditional grid, where information plays little or no role, and electricity flows one way from the power plant to the user (Figure 1C).

Figure 1C: The smart grid concept



Source: IRENA, November 2013, p.10

Smart grid technologies can certainly help enable DREGTs, and some of these technologies – notably smart inverters – are widely used. However, for many others, the lack of field experience and associated uncertainties in technology cost and performance, in costs and benefits and in nontechnical issues such as privacy— have slowed market uptake. In addition, as discussed in Chapter 2, renewables integration can be accomplished via other technologies as well, making smart grids useful but not absolutely necessary.

2. BARRIERS TO GREATER USE OF DISTRIBUTED RENEWABLES

Significant increases in DREGT take-up will require support and participation from a wide range of stakeholders: project developers, investors, utilities, regulators, and others. It's useful, then, to think broadly about barriers to greater use, and to consider multiple perspectives on DREGTs.

As summarized in Table 2A, different perspectives on DREGTs correspond to different concerns or issues. The technical and engineering community, for example, is typically concerned with variability and grid integration, while the investment community may see the risk of policy change (for example, the possibility that subsidies may change over the life of the project) as a concern. All these issues deserve attention, as all stakeholders will need to participate in order for DREGTs to achieve widespread take-up.

Table 2A: Stakeholders and their concerns

Perspective, Community, or Stakeholder	Concern or Issue
Technical and engineering	• Variability and grid integration • Technical reliability • Impacts on power quality
Financial and investment	• Policy uncertainty and political risk • Expected financial return • Default risk
Policy and regulatory	• Grid access rules • Equity and distributional impacts • How to allocate costs and benefits
Private sector	• Business risks (e.g., technical performance, regulatory change) • Expected return on investment • Consumer acceptance
Utility	• Grid operational impacts • Potential loss of revenue • Loss of control over generation assets

Our review of recent field experience with DREGTs identified nine distinct barriers, which are summarized in Table 2B and described in greater detail below. These barriers also have potential solutions; these are summarized in Table 2B as well. Note that the list of barriers in Table 2B does not include all possible barriers that could influence DREGT uptake - only those that we found well-documented in the recent literature. Some additional relevant barriers are listed at the end of this chapter.

Table 2B: Barriers and solutions

Barrier	Potential Solution
Outdated perceptions of technology cost and performance	• Educate decision-makers • Provide or publicize current cost and performance data
Policy uncertainty	• Educate policymakers on the importance of policy stability
High first costs	• Reduce first costs through subsidies • Promote innovative financial tools such as leases to translate first costs into operating costs • Reduce first costs through improved technology delivery (e.g., lower installation costs)
Subsidized fossil fuels	• Reduce or eliminate subsidies for mature technologies
Variability	• Publicize best practices
Grid integration	• Publicize best practices
Grid access and interconnection requirements	• Develop standardized requirements
Resistance from utilities	• Allow utilities to invest in DREGTs • Change policy to open generation markets
Unavailability of technically skilled people and organizations to install and maintain DREGT systems	• Provide remote monitoring • Offer training • Align incentives to provide a financial interest in maintenance

Outdated perceptions of technology cost and performance

Recent improvements in DREGTs have led to a gap between perceptions of these technologies and reality. Policy makers and other decision-makers may reject these technologies because they believe that DREGTs are expensive, unreliable, or impractical, even though this assessment may no longer be accurate.

A recent report noted the need for, "dispelling myths about 'unreliable' and 'expensive' RE (renewable energy) technology using awareness campaigns targeted at stakeholders across the board, from public institutions to end users…[due to] the existence of apparent misconceptions among policy makers about technology reliability and cost." (IRENA, June 2013, p.11).

Policy uncertainty

A recent research survey found that the private sector sees policy uncertainty as the greatest hurdle to investment in renewable minigrids, higher than financing, regulatory barriers, and high costs (IRENA, 2015b). Similarly, a detailed analysis of solar minigrids for rural India found that "[u]ncertainties in the policy environment will slow down private sector investment at this nascent stage" (Thirumurthy et al., 2012).

Policy uncertainty comes not just from policy change (for example, removal of critical subsidies or new taxes), but also from how policies are implemented. A study of island power found that, "duties and taxes for renewable energy systems are applied inconsistently," complicating project implementation (IRENA, 2013, p.20).

High first costs

First (capital) costs for DREGTs are still a significant impediment to wider use. Even when these technologies can be financially justified on a levelized cost of electricity (LCOE) or lifecycle analysis, their higher first costs can make them unaffordable due to capital constraints. And in areas without electricity service, the start-up costs of any electricity system—renewable or otherwise—are a significant barrier, particularly in very poor rural areas with limited economic activity. Innovative leasing programs have allowed rooftop PV to reduce consumer electricity costs. However, such programs require significant marketing investment, in part to overcome the perception of high costs.[5] A study of solar home systems for rural Bangladesh found that, even with significant subsidies and an innovative financing program, the cost for these systems is greater than rural Bangladesh consumers' willingness to pay (Siegel, 2011). Even with the recent price reduction in PVs, a 2014 presentation found that high capital costs remain a significant challenge (Haque, N., 2014).

Subsidized fossil fuels

PV can economically compete with diesel, particularly when PV is combined with storage or when diesel is very expensive due to transport costs, such as in rural areas (IRENA, May 2012). However PV cannot compete with *subsidized* diesel. Two-thirds of rural India's electric capacity is diesel-fueled, for example, and it is heavily subsidized (Thirumurthy et al., 2012). These subsidies make electricity more affordable for the rural poor, but they also complicate efforts to introduce renewables. Although some countries offer subsidies for PV, subsidies for enabling technologies such as batteries and other forms of storage may not be available (Thirumurthy et al., 2012), complicating project finance.

Variability

Some types of DREGTs—notably PV and small wind turbine technologies—suffer from variable (sometimes called *intermittent*) output. Since they are dependent on a naturally fluctuating resource or fuel (sun or wind), their output fluctuates as well. This relates to a fundamental challenge with electricity: it is very difficult to store. Therefore, electricity grids must provide exactly as much electricity as is being used, at all times.

As DREGT penetrations grow, several strategies are emerging to address the variability problem. These fall into three categories:

1. Using other electricity generation technologies to fill in the gaps as needed.
2. Storing electricity, such as with batteries.
3. Changing demand to match generation via demand response programs.

Experience to date suggests that the variability problem is a manageable one at low to moderate renewable penetrations. This isn't to minimize the technical and operational

[5] One estimate puts customer acquisition costs for rooftop solar in the US at USD 0.49 per watt (Kann, S., 2013).

challenges of integrating variable renewables, which has been a difficult task for electricity system operators. However, several countries and states have successfully operated with variable renewables penetrations of over 20 percent, with few if any significant reliability or other operational problems (Table 2C). The renewables shown in the table are largely centralized rather than distributed, but the principle is similar: recent field experience shows that it is feasible to operate a reliable electricity grid with generation assets that have variable output.

Table 2C: Variable renewable penetrations for selected geographic areas

Region	Percentage of electricity from variable renewables
Denmark (wind)	35
Iowa, US state (wind)	27
South Dakota, US state (wind)	26
Spain (wind)	17
Germany (PV and wind)	14
Germany (wind)	9
Germany (PV)	5

Notes: Data shown are annual and represent generation, not capacity. Europe data are for 2012; US data are for 2013. Sources: IEA database, Wiser and Bollinger 2014

A different perspective on variability is that for the nearly 1.3 billion people without access to electricity, even intermittent energy access improves quality of life (IRENA, June 2013). For the nearly 600 million cell phone customers without electricity, for example, intermittent electricity offers an alternative to costly off-site charging stations (Pope, 2012). The discrepancy between cell phone ownership and home energy access is perhaps best demonstrated in Sub-Saharan Africa, where cell phone market penetration is more than 80 percent, but electricity access hovers around 30 percent (CEM, 2013).

Grid integration

Most electricity distribution systems were designed for one-way flow of electricity. The addition of DREGTs that can, at times, push electricity onto the distribution system, can require operational or even hardware modifications to the distribution system. A few countries (notably Germany) have successfully integrated large amounts of DREGTs into their distribution networks, but most electricity systems worldwide are still dominated by centralized generation and utility experience with DREGTs is still quite limited. How distribution systems handle distributed generation, what problems DG might cause, and how to solve them are all questions currently being examined.

A recent study found that critical components of the distribution system stayed within operational limits for PV penetration of up to 30 percent (Hoke, A. et al., 2013). And recent technical developments—notably the widespread availability of smart inverters that can adjust voltage and other outputs in response to distribution system needs—suggest that even higher penetrations are manageable. Nevertheless, it's likely that increased penetration of DREGTs will require operational and hardware changes to electricity distribution systems (UNFCCC, 2014b).

Grid access and interconnection requirements

In many countries, electricity is provided by a government agency or by a regulated monopoly provider. In either case, the electricity provider usually owns the centralized generation (power plants) or contracts directly with the power plant owner via a purchase power agreement. The details vary widely by country, but in some areas new, nonutility generators (such as DREGTs) may be prohibited from connecting to the grid, face expensive interconnection requirements, and/or receive relatively low wholesale rates for the electricity they provide into the grid.

Whether these interconnection requirements and wholesale rates are appropriate is a topic of much debate. This debate does suggest, however, that regulated electricity markets were designed for traditional, centralized generation, and may not easily accommodate DREGTs.

Resistance from utilities

A related barrier is general resistance from utilities and other allied interests. DREGTs can be seen as threatening the fundamental business model of the centralized utility. US utilities, for example, have identified PV and DG as "disruptive challenges" that may lead to "declining utility revenues, increasing costs, and lower profitability potential, particularly over the long term" (EEI, 2013). Another analysis stated, "Over the last several years, the demand for power (in Europe) has fallen while the supply of renewables (including solar) has risen…and depressed the penetration of conventional power sources" (Frankel, 2014). It's therefore not surprising that some utilities may have limited enthusiasm for DREGT.

Unavailability of technically skilled people and organizations to install and maintain DREGT systems

All DREGTs require some technical skill for installation, and all have some ongoing O&M technical needs. Experts with the skills to work with DREGTs may be unavailable in remote areas, and the need to bring in outside technical expertise raises costs and lengthens downtimes.

An analysis of solar-diesel hybrid systems for remote mines in South Africa concluded that a "… lack of technical capacity in the region is proving to be a major constraint on the ability of South African mining firms to develop renewable energy systems" (Boyse et al., 2014). Similarly, an analysis of solar minigrids for India found that ongoing maintenance, particularly for batteries, is a critical need. The research also showed that many renewable energy projects have failed due in part to inadequate maintenance (Thirumurthy et al., 2012; Millinger et al. 2012).

Additional Barriers

The above list of barriers is drawn from the recent literature and is not comprehensive. Additional barriers of particular relevance to developing countries - including availability/appropriateness of technologies, quality of technologies, and local innovative/entrepreneurial capacity – may influence DREGT take-up as well. These barriers are best understood in the context of innovation as a process. Recent work (e.g. Hekkert et al. 2011) provides an intellectual framework for identifying critical steps in the innovation process, and identifying potential challenges.[6]

[6] A 2014 workshop on national systems of innovations for climate technology provides further insight. See http://unfccc.int/ttclear/templates/render_cms_page?s=events_ws_nsi .

3. ENABLING ENVIRONMENTS FOR DISTRIBUTED RENEWABLES

In the past few years, many utilities, governments, and vendors have implemented DREGT projects worldwide—some successful, some less so. In this chapter, we discuss enabling environments. These are specific features or attributes that help explain DREGT project success. Each project has its own story, but many successful projects:

- Engage utilities as essential partners rather than opponents.
- Leverage peer influences and personal networks within the community.
- Standardize technologies and business practices.
- Reduce perceived risk for investors and system owners.
- Involve and engage the community early, often, and throughout.
- Allow for innovative finance.
- Offer sufficient financial incentives to attract private-sector investment.
- Provide for system O&M.

We describe each of these enabling environments, and provide examples where appropriate.

Engage utilities as essential partners rather than opponents

Utilities—entities providing electricity, typically via traditional, centralized grids—may have a mixed reaction to DREGTs. They may welcome new generation and new technologies, or they may see them as a technical and business threat. In some areas, utilities and DREGT advocates have an adversarial relationship, which has stymied development and use of distributed resources. This is unfortunate, as utilities have much to offer, notably:

- Access to large amounts of low-cost capital, due to utilities' size, financial health, and monopoly status.
- Deep technical expertise and years of experience in operating reliable electricity systems.
- Access to grid-connected customers via physical grid connections and bills.

Therefore, utilities should be pursued as partners rather than adversaries. One report concluded, "Utilities generally have more experience, financial resources, and technical capabilities to carry out rural electrification projects. They can realize economies of scale and use their central position to take advantage of financing options. … [B]ecause of their capacities and experience, utilities should have a role to play in the future" (ARE, March 2011, p. 8).

Some argue that it is in utilities' direct self-interest to pursue DREGTs. Indeed, these technologies can reduce peak loads (for example, distributed PV peak output may correlate with space-cooling demands); postpone the need for new, expensive, and difficult-to-site centralized generation and transmission; and reduce fuel consumption for generation. However, there is as little agreement as to whether the net impacts of DREGTs are, overall, positive or negative from the utility's perspective (Hoke, A. and P. Komor, 2012). The financial impacts of DREGTS on utilities are an active research topic, with some evidence suggesting that customer-sited PV reduces utility revenue more than it reduces utility costs; however these results are very assumption- and situation-dependent (Satchwell et al., September 2014).

Leverage peer influences and personal networks within the community

DREGTs applications worldwide vary tremendously, from remote systems in poor villages to grid-connected rooftop systems on single-family homes. However, it's striking to note that the same peer-to-peer dynamics operate in both settings. A study of rooftop PV installations in Connecticut (U.S.) found that, "spatial neighbor effect conveyed through social interaction and visibility" was a strong influence on PV adoption (Graziano, M. and K. Gilling, 2014). In other words, if your neighbor has a PV system, you're much more likely to put one up on your roof. Similarly, a study of solar home systems in rural Bangladesh identified word-of-mouth as a critical driver for new system adoption, and found that 78 percent of system owners stated that they influenced others to buy a system (Siegel, 2011). Local community influences were also shown to be an important driver for Germany's distributed renewable energy deployment (Dewald, U. and B. Truffer, 2012).

The credibility of a trusted friend or neighbor can work against DREGTs adoption as well: in one telling example from rural Bangladesh, "a customer near Kurigram became so disillusioned with the slow and unreliable after sales service of his partner organization that he convinced his brother and several friends to purchase their solar home system from a different company. The positive word of mouth that stimulates sales can quickly transform into a cycle of negative word of mouth that can decimate future sales" (Siegel, 2011, p.28).

In either case, DREGT adoption by individuals is a complex process, but the evidence does suggest that trusted friends, neighbors, and community opinion leaders can play a critical role.

Standardize technologies and business practices

The benefits of technical standardization are clear: lower technology costs due to mass production, lower installation costs as each project is similar, and less technical training needed for installation and O&M due to a single design. The Pacific island nation of Tokelau recently installed PV/battery systems on four atolls to replace diesel-only systems; a report on this project found, "Having a uniformity of design and of components across several systems makes it easier for the utility to troubleshoot problems (as the same solution can be applied across all systems) and to order and stock spare parts (as the number of different components is low). " (Tokelau, March 2013, p.6).

Similarly, standardization of contracts and other business-related components has emerged as helpful as well:

- Uniformity in land acquisition processes has been shown to help solar minigrid system development in rural India (Thirumurthy et al. 2012).
- An analysis of hybrid (solar/diesel) minigrids concluded that, "power purchase agreements should be as standardized as possible. This decreases administrative costs, increases efficiency and greatly simplifies procedures" (ARE, March 2011, p.50).

Interestingly, other project components are emerging as requiring the exact opposite—*customization* for community needs (see discussion below). Technologies and business/contractual components, however, benefit greatly from standardization.[7]

Reduce perceived risk for investors and system owners

DREGTs, like all new technologies or practices, carry with them a perception of risk. These risks can be related to technical performance, financial return, regulatory change, and other sources of uncertainty. The concept of "derisking"—reducing perceived risk across a wide range of risk types—is emerging as a useful enabling environment for DREGTs. Examples include:

- Renewable energy projects in South Africa were shown to benefit from a 'predictable set of regulations, ' which reduces independent power producers' (IPP's) perceived risk (Boyse et al. 2014).
- For solar home systems in Bangladesh, the existence of a technical standards committee was found to ensure system quality, and thereby enhance customer satisfaction and piece of mind (Siegel 2011).
- For a Pacific Island solar PV/battery project, the PV panels were insured by a large third-party insurance company—meaning if the manufacturer became insolvent, the performance warranty would still be honored (Tokelau 2013).
- SolarCity, a large rooftop PV owner/operator in the US, has a backup service provider that will take over O&M responsibilities if SolarCity fails to do so. This reduces risk as seen by investors, as it ensures the systems will continue to provide electricity even if SolarCity does not maintain them (Hyde, D. and P. Komor, 2014).

All stakeholders have different perceived risks; an enabling environment for DREGTs is one in which all stakeholders' perceived risks are reduced as much as possible.

'Bundling' is one example of derisking through investment diversification. Bundling numerous small projects into single loans mitigates risk by distributing repayment amongst various loan recipients and augments profit potential through increased loan amounts. In Senegal, for example, a competitive bidding process is used to award RE financing projects to the private firm willing to offer the highest number of connections in a three-year period (World Bank, 2009).

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[7] Differences in technology standards have been identified as a challenge for mini-grid development – see IRENA (June 2013, p.34).

Involve and engage the community early, often, and throughout

DREGTs, by definition, are implemented at the community level. They therefore require buy-in from stakeholders throughout the community. Experience to date shows the importance of all involving local/community stakeholders early in program design and planning, extensively in program implementation, and maintaining that engagement throughout. Similarly, project details (such as finances) and even the technologies themselves may need to be customized for the specific needs of the community. Noted one report on rural solar /diesel minigrids, "projects must adapt to the local conditions, instead of the local people adapting to the project. To be successful, projects must respect the local traditions and local leadership structures" (ARE, March 2011, p.14).

One option for incentivizing community involvement is through "sweat equity" –in which customers receive monetary discounts for their participation in system installation and O&M training. Sweat equity schemes make systems more affordable, increase supply chain sustainability by training local mechanics, and encourage proper use and maintenance by creating an emotional connection between user and system. The Ghanaian government has encouraged in-kind participation for rural electrification project end-users, through the creation of a self-help scheme. The program prioritizes and expedites projects willing to provide labor for installation and distribution (ARE, March 2011).

Allow for innovative finance

PV systems have come down considerably in price. However they still typically cost USD 1000s, and few individual homeowners may have that kind of capital available—even if such an investment is "cost-effective" from a lifecycle, societal, or LCOE perspective. Fortunately, there are a wide variety of innovative ways to finance such systems. Examples are numerous, including:

- On-bill financing, in which the utility (which can access low-cost capital) provides the up-front capital and the homeowner pays this loan back via a charge on the monthly electricity bill. In some settings, the total monthly bill may actually go down (as the electricity savings can exceed the loan payment).
- Long-term leases, in which a private company owns a rooftop PV system and charges the building owner a set monthly lease fee. In return the homeowners gets the PV system output. Here again, the monthly total costs as seen by the homeowner may actually decrease.
- Community—owned systems, in which the community as a whole invests in a somewhat larger system, and shares the electricity output. This concept has been used in projects in Morocco and Senegal (ARE, March 2011, pp.22-23).

At a level higher up the financing chain, the concept of 'securitization' is just starting to provide large amounts of low-cost capital for DREGTs. The concept is similar to that for houses, automobiles, and other types of consumer debt: individual debts are packaged into large and diverse 'debt instruments,' which are then sold on the wholesale debt market. Abuse of this type of debt financing did play a role in the global economic crisis of 2008-2009, and showed that appropriate regulations must be in place. Since then, however, securitization has provided USD 100s of millions of low cost capital for residential PV financing (Hyde, D. and P. Komor, 2014).

A further example of innovative finance—not yet widely implemented, but deserving of further analysis—is based on what has been learned from kerosene sales. The fear of defaulting on monthly payments can deter investment from poor individuals with inconsistent incomes. For these populations, the ability to purchase energy when finances allow may be the most appropriate model. Thus, selling a single-day's worth of fuel, as is done with kerosene in many communities, is a viable alternative. One model for DREGTs is the construction of minigrids, with power sold on an as-needed basis. Similar to daily kerosene tanks, customers with variable incomes would be afforded energy access in line with their ability and willingness to pay. Cell phones could be used to make purchases, which would allow for flexibility and convenience (Pope, 2012). Pre-paid meters are another payment option that can accommodate fluctuating incomes.[8]

Experience to date has shown the power innovative financing has in overcoming the relatively high first costs of DREGTs. As discussed in chapter 4, the challenge for policy-makers is to unleash this power while providing appropriate regulations and controls to avoid abuse.

Offer sufficient financial incentives to attract private-sector investment

Private sector participation can be quite helpful in DREGT implementation, as the private sector can provide capital, innovative financing, O&M services, and other critical components (Sovacool et al., 2011). In order for the private sector to participate, however, it must see the possibility of profit. Examples of how this can be provided include:

- Appropriate tariffs that balance commercial viability and electricity users' ability and willingness to pay (ARE, March 2011).
- Policy/regulatory stability to minimize perceived risk (e.g., tariff change or loss of subsidies).
- Market rules that allow for and encourage private sector participation, with appropriate risk and reward incentives.

An enhanced private role in electricity provision can be controversial, as it raises questions about the appropriate roles of the public and private sectors in providing essential services (electricity, in this case). It's useful however to consider the private sector as a source of innovation, technical knowledge, and financing, that can supplement (not replace) the essential public role.

Provide for system O&M

In order for DREGT systems to be technically sustainable, there must be an arrangement to

[8] See Mwangi (2012) for a non-renewable energy example of using prepaid meters to provide electricity in low-income areas without reliable electricity access.

provide O&M. This arrangement needs to include:

- Incentives and/or ownership. Someone must have a direct financial interest in continued system operation, or be given that responsibility through some other mechanism (e.g., a contract).
- Technical knowledge and skills. Similarly, someone must have the know-how, tools and system access in order to provide any needed O&M services.
- A source of financing O&M costs. One promising approach is to design tariffs that incorporate a set-aside that provides a continuing source of funds for O&M.

Without an O&M infrastructure, technical failure—sooner or later—is all but certain.

Case Study: Engaging the community in Mozambique

One hurdle to the sustainable implementation and use of DREGT remains a shortage of locally trained maintenance workers. To address this, a recent PV project in Mozambique trained local residents in PV maintenance and repair.

The project, funded in part by the German Ministry for Economic Cooperation and Development, trained local residents in technical skills. University students, dealers of the electronic equipment used in the systems, and local technicians were targeted for training. The students, dealers, and technicians were taught how to install and size, as well as repair and maintain the PV systems.

In addition to educating locals about maintenance and operation, focus was also placed on developing a sustainable business infrastructure to promote the distribution of the PV Systems. Local business leaders and entrepreneurs were instructed in business administration, which ultimately fostered the development of a functioning retail market.

(Source: United Nations – Energy, 2011)

4. POLICY ISSUES AND OPTIONS

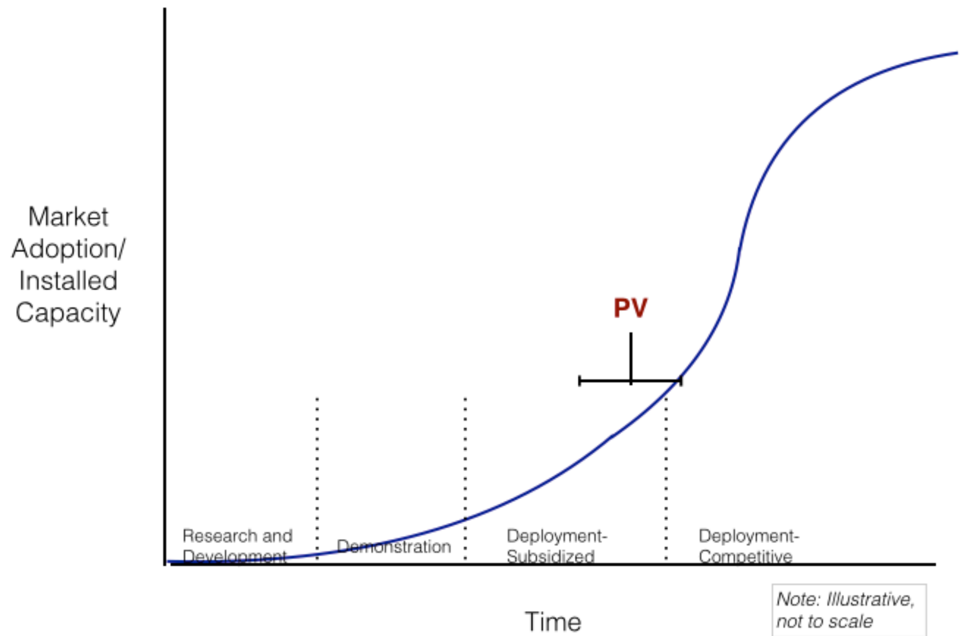
The rapid changes in DREGT cost and performance in recent years, and the growing body of on-the-ground experience with these technologies, have uncovered a number of policy issues that deserve consideration. Here we highlight those issues, which are drawn from the barriers (chapter 2) and enabling environments (chapter 3) discussions. Our intent is to provide countries with some direction on what decisions they could make and which policy options they could consider to promote optimal use of these promising technologies. We do not recommend specific policies, nor do we assume any specific country goals or priorities. Rather, our intent is to clarify the issues that have emerged in recent years and to provide some guidance in how they might be addressed. This list of policy issues and options is not intended to be comprehensive nor prescriptive.

Find the balance of technology development and implementation

As discussed in chapter 1, there is some evidence that PV may be close to cost-competitiveness with centralized generation technologies (Figure 4A). This will of course vary widely by specific application, however it does point to the need to find an appropriate balance between technology development and implementation.

This relates to a fundamental policy and philosophical debate about the appropriate role of government in technology development. One could argue, for example, that PV technology's growing market penetration means that public support for this renewable source should be reduced or eliminated, as it is time for market forces to determine PV technology's appropriate role in electricity supply. On the other hand, one could argue the opposite—namely, that PV solutions have significant short-term potential for CO_2 reduction, and governments should focus on this technology as a promising partial solution to climate change. These are admittedly extreme positions on what is a continuum; nevertheless it may be useful to recognize that philosophical differences about the appropriate role of government can underlie different policy beliefs.

Figure 4A: Stages of technology development



Balance financial innovation and regulation

As discussed above, financial innovation from the private sector is supporting DREGT installations in some areas. Examples include leases for rooftop PV systems, aggregation and securitization of debt, and community-owned systems. With this innovation comes risk and the need for appropriate regulation. Governments may want to address the challenging topic of how to balance their support of innovation with their responsibility to provide appropriate regulation, attempting to strike equilibrium between risk and reward for private-sector investors and financiers.

Rethink public and private roles in electricity supply

In many countries, electricity supply is historically a public function: electricity is generated and delivered by a public entity or a strictly regulated utility. However, the continued development of DREGTs means that opportunities for direct private-sector investment in electricity supply will expand. At some point in the future, electricity users may find it less expensive to generate their own electricity via DREGT technologies than to buy it from the utility. Now is the time to think through the implications of this and consider carefully the current regulatory frameworks for electricity, which were designed for traditional, centralized generation and may not easily accommodate direct private sector investment in electricity generation. New institutional mechanisms may be needed to allow for both public and private participation in electricity generation.

Reassess the utility role

In particular, the role of the utility deserves particular scrutiny. Utilities are key stakeholders in DREGT implementation, and they are in a position to either aid or hinder DREGT implementation. Which path they choose depends on the incentives they face, which are largely an outcome of policy.

In some countries, utilities may not be predisposed to favor or support DREGTs. Regulated utilities or government agencies may see little or no reward for technological innovation. Their expertise is in large, centralized power plants, and they may see little advantage in opening up electricity grids to new generation that they cannot control or operate. Governments may want to reassess those incentives and consider how utilities can be encouraged to support appropriate DREGT implementation. Such an assessment could also consider fundamental questions of utility industry structure, such as the appropriate role for competitive markets and the optimal level of vertical integration in the electricity industry.

Rethink fossil fuel subsidies

Historically, some governments have subsidized diesel for electricity generation in order to provide electricity to those who do not have it or are unable to pay for it. Governments may now want to reexamine these diesel subsidies and consider other technological routes—specifically, DREGTs—that can provide electricity at a lower economic and environmental cost. Such analyses should also consider the benefits of limiting import dependence and reducing exposure to fuel price variability.

Reassess import duties and taxes

Import taxes and duties on DREGTs raise the costs of these technologies and thereby delay their implementation. Governments may want to reconsider these taxes and duties, and determine whether their potential benefits (presumably support and protection of domestic manufacturing) outweigh the costs of delayed implementation. The recent price decreases for PV systems is due in part to large-scale manufacturing in Asia, and many countries may find it difficult to compete financially with these plants. An alternative path is to view low-cost imported PV technology as an opportunity (as it can provide electricity at a lower economic and environmental cost), and consider other aspects of the supply chain—such as system design and installation—as areas for domestic industry growth.

Derisk to attract private sector investment

Robust private-sector investment and activity is critical to DREGT success (Schmidt et al., 2013). There must be appropriate risks and rewards to attract the private sector; however, experience to date has suggested that the perceived risks may be higher than investors consider optimal. Policy can reduce these risks by guaranteeing loans, establishing industry-funded insurance pools, providing liability limits, and other similar steps. Care must be taken to not push too much risk to the public, but some "derisking" certainly deserves further consideration.

Limit policy uncertainty

Policy and regulatory uncertainty is emerging as a barrier to private sector investment in DREGTs. When considering DREGT-related policy change, governments may want to consider mechanisms that will keep the new policies in place for a minimum, guaranteed time period.

Build in-country capabilities

In order for DREGTs to achieve widespread use, it will be necessary to build both short-term and long-term capabilities for operation and maintenance, repair, adaptation and innovation on all components of DREGTs in many more countries in the world (UNFCCC, 2014a). "Service markets" for DREGTs – the consultants, technical firms, financiers, and others who set up and support these technologies – are critical to their future success.

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