**Technical assessment for**

**Micro Grids**

Sector: Electricity generation

Agency Level: Community

Keywords: Decentralized, Distributed, Energy Access, Renewable Energy

Version 2 (November 2019)

**Prepared by:**

Dattakiran Jagu, Research fellow

João Pedro Gouveia, Senior Research Fellow



[info@drawdown.org](mailto:info@drawdown.org) [www.drawdown.org](http://www.drawdown.org)

Table of Contents

[List of Figures 3](#_Toc10937136)

[List of Tables 3](#_Toc10937137)

[Acronyms and Symbols 4](#_Toc10937138)

[Executive Summary 5](#_Toc10937139)

[1. Literature Review 6](#_Toc10937140)

[1.1 State of Microgrids 6](#_Toc10937141)

[1.2 Adoption Path 11](#_Toc10937142)

[1.2.1 Current Adoption 11](#_Toc10937143)

[1.2.2 Trends to Accelerate Adoption 12](#_Toc10937144)

[1.2.3 Barriers to Adoption 13](#_Toc10937145)

[1.3 Advantages and disadvantages of Microgrids 14](#_Toc10937146)

[2. Discussion 17](#_Toc10937147)

[3. References 18](#_Toc10937148)

[4. Glossary 21](#_Toc10937149)

# List of Figures

[Figure 1.1 Energy utilization and losses in a centralized energy infrastructure (Greenpeace, 2005) 7](#_Toc10936802)

[Figure 1.2: Components of a micro-grid (Source: www.off-grid.net, ND) 8](#_Toc10936803)

[Figure 1.3 20 countries with the highest deficit in electricity access in 2010 (World Bank and IEA, 2013) 10](#_Toc10936804)

[Figure 1.4 Tiers of electricity service demand (Source: SE4All, 2013) 10](#_Toc10936805)

[Figure 1.5 Global micro-grid capacity market share by region in 2015 (Navigant Research, 2015) 13](#_Toc10936806)

[Figure 1.6 Vicious and virtuous cycles of human-technology interaction for micro-grids (Schnitzer et al. 2014) 14](#_Toc10936807)

# List of Tables

[Table 1.1 Power generation technologies for micro-grids (REN21, 2014) 9](#_Toc10936798)

[Table 1.2 Market segments for micro-grid adoption (ABB Power Generation, 2015) 11](#_Toc10936799)

# Acronyms and Symbols

* AC - Alternating Current
* DC - Direct Current
* DG – Distributed Generation
* GW - Gigawatt
* ICT - Information and Communication Technology
* IRENA – International Renewable Energy Agency
* kWh - kilowatt-hour
* PV – Photovoltaic
* RD&D – Research, Design and Development
* SPIDERS - Smart Power Infrastructure Demonstration for Energy Reliability and Security
* TWh - terawatt-hour
* ROC - Renewables Obligation Certificates

# Executive Summary

Project Drawdown defines *microgrids* as: localized groupings of electricity sources and loads that normally operate connected to and synchronously with the traditional centralized power grid, but can disconnect and function autonomously as physical and/or economic conditions dictate. This solution replaces the conventional practice of powering buildings and communities with electricity from the centralized grid. The defining characteristics of a microgrid are its semi-autonomous capability and the ability to control its loads and supply locally. A typical microgrid could be constituted by distributed generation technologies such as wind, solar, hydropower, or biomass, together with energy storage units or backup generation and load management tools. By enabling the integration of renewable energy sources into the grid, along with storage and demand management, microgrids can play a critical role in the advancement of a flexible and efficient electrical grid. In addition, the use of local sources of energy to serve local loads helps reduce energy loss in transmission and distribution, further increasing the efficiency of the electricity delivery system.

More than one billion people—around 17 percent of the global population—still lack access to a centralized power grid (Greenpeace, 2015). In 2013, more than 95 percent of the people living without electricity were in sub-Saharan Africa and developing Asia countries, mainly living in rural areas (around 80 percent of the world total). At present, population growth is outpacing the efforts of electrification. The International Energy Agency ´anticipates that more than 50 percent of the rural and remote population currently without electricity would be best supplied by mini or microgrids (2014). Providing energy access to these people using low-carbon energy technologies is expected to bring many additional benefits such as improved health, education, and employment. Microgrids also make economic sense in remote and island locations that have historically depended on imported diesel for electricity, in regions with an unreliable conventional grid, and for cell phone towers that rely extensively on expensive diesel-based power. For roughly 300 million un-electrified households globally, kerosene has been the dominant fuel source for lighting. Several studies indicate that the price paid by microgrid customers for electric lighting is far less than the price for lighting using kerosene and candles (Barefoot Power, 2009).

Because the growth and emissions impacts for this solution are accounted for in the models of renewable energy sources and accompanying enabling technologies, including *in-stream hydro*, *micro wind*, *rooftop solar*, and *biomass*, paired with *distributed energy storage*, it is not directly model the growth and impact of *microgrids*. For higher-income countries, the benefits of microgrid systems fall under the *grid flexibility* solution, and also under the impacts of increased adoption of decentralized variable renewable energy sources. Equitable access to energy is a crucial prerequisite for sustainable development. Increasing demand for electricity globally is bound to test the limits of a centralized power system in the near future. Adopting an optimal combination of centralized and decentralized systems can capture both the strength of the central grid and the agility of state-of-the-art technological advancements in a decentralized infrastructure. Microgrids can help bridge this gap while making use of locally available energy resources. Microgrid infrastructure enables a transition to a decentralized power system that is more reliable, affordable, and sustainable. Investing in microgrids for emission reduction is already profitable in many parts of the world that have historically depended on imported diesel for electricity. Microgrid installations in grid-connected regions also offer several key advantages, including: optimized energy consumption through better matching of supply with demand; reduced environmental impact through integration of renewable energy sources; increased security of energy supply; provision of cost-efficient electricity infrastructure; and the ability to locally rank power supply for high-priority needs during times of disruption. In a world that is increasingly dependent on electricity for its very existence, losing access to the power supply due to outages or blackouts is a critical risk that cannot be overlooked. Microgrids, by virtue of being locally managed systems, are resilient against such disruptions in supply and have more control over the local demand.

# Literature Review

## State of Microgrids

Distributed generation, as its name implies, involves the generation of electricity near to points of consumption. Historically, several factors including economies of scale and efficiency of generation have historically led most of the global electricity production towards a centralized generation. The electricity generated from central power stations is transmitted via transmission and distribution lines to end users (Figure 1.1.). However, recent concerns over energy security, a heavy reliance on fossil fuels, the conversion losses from thermal production, transmission and distribution losses and the limitations in providing universal electricity access has led to the re-emergence of a decentralized/distributed paradigm. Micro-grids are a recent development that have the potential to transform the existing centralized electricity network. Fueled by the falling costs of renewable energy technologies and the desire of both individuals and businesses to move toward greater independence in their electricity use, micro-grids have slowly brought back distributed generation into the main stream.



Figure 1.1 Energy utilization and losses in a centralized energy infrastructure (Greenpeace, 2005)

A micro-gridis a “*local combination of electricity sources and loads that normally operates connected to and synchronous with the traditional centralized grid (macro-grid), but can disconnect and function autonomously as physical and/or economic conditions dictate*” (Berkeley Lab, 2015). With respect to the centralized grid, it acts as a single controllable entity that can either be connected or disconnected from the main grid and operate in both grid-connected or island-mode. The defining characteristics of a micro-grid are its semi-autonomous capability and the ability to control its loads and supply locally.

Unlike the traditional, centralized power systems, micro-grids house the power generation and distribution near the load. A typical micro-grid constitutes distributed generation technologies such as wind, solar, hydropower, biomass together with energy storage or backup generation and load management tools. By enabling the integration of renewable sources of energy, along with storage and demand management, micro-grids can play a critical role in the advancement of a flexible and efficient electric grid. In addition, the use of local sources of energy to serve local loads helps reduce energy losses in transmission and distribution, further increasing efficiency of the electricity delivery system (Figure 1.2).

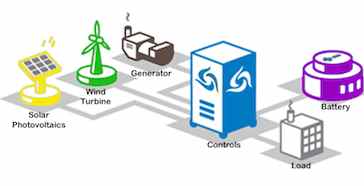


Figure 1.2: Components of a micro-grid (www.off-grid.net, ND)

A typical micro-grid consists of at least five basic components (REN21, 2014):

- Power generation: A wide variety of power generation technologies that use both renewable and non-renewable energy sources (Table 1.1) are currently available in various stages of technological maturity level, costs and performances.

- Storage: The existence and size of the storage depends on the intermittency of power production and the quantity of backup required. Battery banks are the most commonly used form of storage.

- Distribution network: A low-voltage distribution network carries electricity to the consumers in the micro-grid. The distribution system can be either alternating current (AC) or direct current (AC) and can employ single or three phase power transfer depending on the load characteristics.

- End-user subsystem (Loads): This includes all the equipment and appliances at the consumer premises. - - Smart Management Controls: These employ Information and Communication Technology (ICT) for optimization of energy usage, demand-side management and automatization of tariff collection process.

Table 1.1 Power generation technologies for micro-grids (REN21, 2014)

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
|  | Hydro power | Solar PV | Small Wind | Biomass gasifier | Micro turbines | Diesel generator |
| *Technology maturity* | Highly mature | Medium maturity | Medium maturity | Less mature | Less mature | Highly mature |
| *Typical sizes* | Up to 3 MW | Few 100 W to few MW | Few 100 W to 100 kW | Few kW to 1 MW | 1-250 kW | 10 kW to 10 MW |
| *Typical applications* | Village electrification in mountainous areas | * Village electrification * Off-grid power | * Village electrification, * Off-grid power | * Energy for agro-processing industry and plantations * Village electrification | * Industries * Power backup | * Village electrification, * Off-grid power * Power backup |
| *Fuel* | Rivers, streams | Sun | Wind | Biomass residue | Natural gas | Diesel |
| *Advantages* | Low-cost power | Modular;  Easy installation | Easy installation | Low capital costs;  On-site fuel for agro-processing industries | Rapid start-up capability | Low capital investment;  Rapid start-up;  Easy ‘hybridization’ with renewables |
| *Disadvantages* | Requires constant hydro resource;  Location-specific | Require expensive battery storage | Require expensive battery storage;  Location-specific | Location-specific | Low efficiency; Escalating costs for fuel & maintenance | Escalating costs for fuel & maintenance |

**Market for micro-grids**

About 1.3 billion people (i..e around 250-300 million households) globally do not have access to electricity (UN, 2014). 97% of them live in Sub-Saharan Africa and developing Asia. A majority of them live in rural areas, where kerosene lamps are still the main source of lighting. The “Global Tracking Framework” (issued jointly by the World Bank and the International Energy Agency identifies that the achievement of universal access to modern energy will depend critically on the efforts of 20 high-impact countries split between Africa and Asia (Figure 1.3). Together, these countries account for two-thirds of the population presently living without electricity and offer the most potential to make rapid progress towards universal electrification (World Bank and IEA, 2013).



Figure 1.3 20 countries with the highest deficit in electricity access in 2010 (World Bank and IEA, 2013)

Provision of electricity for minimal services such as lighting, television and fan (Tier 2 access in Figure 1.4) requires providing a mere additional 250-500 kilowatt-hour (kWh) per household annually (IEA, 2010).. About 840 terawatt-hour (TWh) of additional energy per year or 220GW of additional power generation capacity needs to be added to achieve universal energy access by 2030. The increase in global energy-related CO2 emissions due to this provision for universal access to electricity is expected to have very little impact on climate change (Pachauri, 2014). Increasing energy access could in fact lead to reduced emissions if fossil fuels were replaced. Utilizing low-carbon energy technologies for energy access, on the other hand, is expected to bring many co-benefits such as improved health, education and employment.

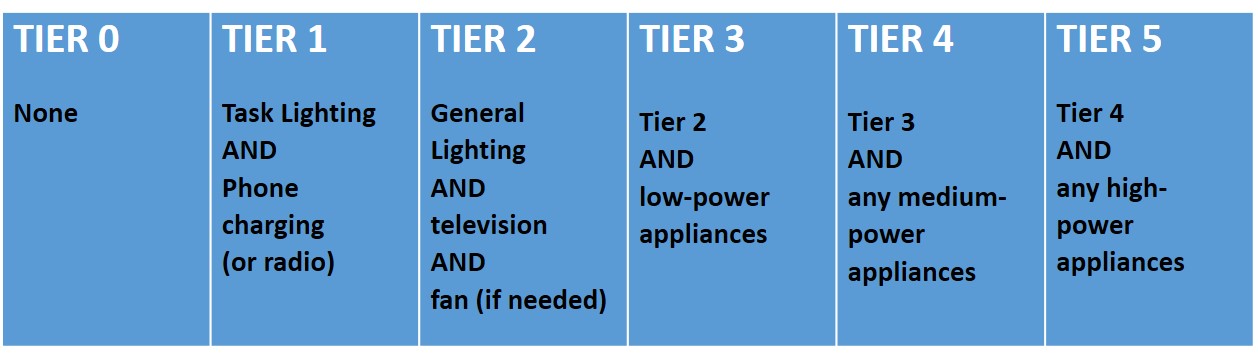
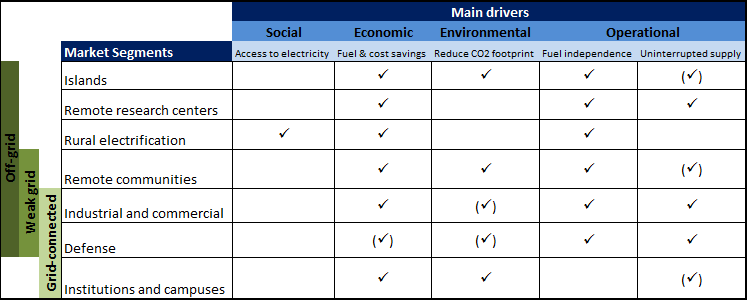


Figure 1.4 Tiers of electricity service demand (Source: SE4All, 2013)

Although the impact of electrification on human development has long been recognized, the progress has remained slow due to high cost of electrification to remote areas and the limited budgets of state-run utilities for electrification. Grid extension is still advisable in most urban areas, where the cost of extension to un-electrified areas makes economic sense. But for remote and rural areas, the IEA (2010) anticipates that more than 50% of the rural population without electricity are best supplied with electricity by mini[[1]](#footnote-2) or micro-grids and the rest by stand-alone systems (such as solar home systems).

The market for micro-grids extends beyond providing electricity access to rural areas. Micro-grids already make economic sense in many areas with high energy prices, in remote locations and islands that have historically depended on imported diesel for electricity, in regions with an unreliable conventional grid and for cellphone towers —particularly in developing countries— that rely extensively on expensive diesel based power. The market for micro-grids can be divided into seven segments (Table 1.2) depending on the state of connection to the central grid and the drivers for micro-grid adoption.

Table 1.2 Market segments for micro-grid adoption (ABB Power Generation, 2015)



✓: Main driver (✓): Secondary driver

## Adoption Path

### Current Adoption

Decentralized energy technologies such as micro-grids are “disruptive” technologies because they do not fit the way the existing centralized electricity system operates (Greenpeace, 2005). These technologies entered the market by serving niche markets such as off-grid rural areas, where they are already cost-competitive with fossil fuels such as kerosene and diesel. Some of the generation technologies are already mature technologies that have been used for decades and can be manufactured all over the world. Although micro-grids will remain the primary alternative for electrifying the rural communities in Sub-Saharan Africa, their applications will by no means be limited to provide energy access in Africa. It is estimated that globally about 400 gigawatts (GW) of diesel capacity is currently in operation in industrial facilities or mines operating remotely (IRENA, 2015). Of this, up to 250 GW could be converted to renewable sources of energy via micro-grids. Hybrid mini/micro-grids currently account for just 2-3% of total installed diesel capacity globally (IRENA, 2015). For islands or rural areas where the mini-grid infrastructure is already in place, there is the economic case to displace or hybridize the use of diesel generators immediately.

The micro-grid market is maturing and evolving rapidly. Navigant Research, in their micro-grid deployment tracker (Navigant Research, 2015) has identified a total of 12,031 MW of micro-grid capacity throughout the world, as of May 2015 (Figure 1.5), up from 4393 MW in 2Q 2014. This represents a near tripling of the micro-grid market — the largest ever recorded by Navigant during their micro-grid tracking history. The Asia-Pacific region represents 47% of the global capacity, followed by North America’s 44% share (Navigant Research, 2015). Although, this tracker could still be short of the real total, it does provide an estimate on the minimum size of the market and its rapid pace of growth.

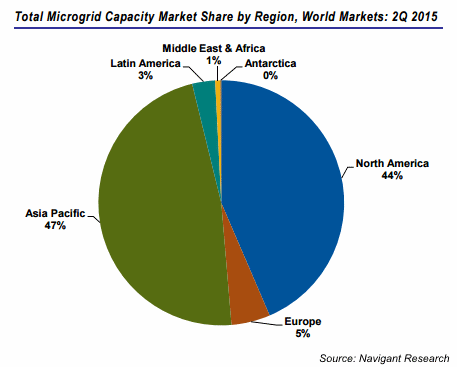


Figure 1.5 Global micro-grid capacity market share by region in 2015 (Navigant Research, 2015)

In the short- to medium-term, the market for off-grid renewable energy systems is expected to increase through the hybridization of existing diesel grids with wind, solar PV, biomass gasification and small hydropower, especially on islands and in rural areas (IRENA, 2015). Small hydro power has historically been the preferred choice for rural electrification of remote areas. However, with half of the potential already been tapped, very few new installations are expected in the future. On the other hand, the falling price of technologies such as solar panels and energy storage is expected to make micro-grids with solar PV and battery storage the dominant choice for off-grid applications. Other technologies such as biomass gasification, micro-turbines and small wind, as well as emerging technologies such as fuel cells are expected to play a small yet significant role in future installations.

### Trends to Accelerate Adoption

Although micro-grids have been researched for decades and distributed power generation been recognized for a multitude of benefits, their uptake until now has been restricted to a few geographies and limited to provide energy access in select developing countries. In the near term, micro-grids are expected to thrive in markets where the geography causes a favorable return on investment and the regulatory set-up permits micro-grids to offer cost-effective service. Other factors that affect the economics of micro-grids include local electricity prices, fuel prices, equipment costs, availability of financing, government incentives and suitable business models. Schnitzer *et al.* (2014) assessed seven micro-grid developers in India, Malaysia and Haiti and highlighted “virtuous” and “vicious” human-technology interactions that can lead to the success or failure of micro-grid projects (Figure 1.6). Critical factors suggested to be considered in micro-grid installations for rural electrification include: tariff design and collection mechanisms, maintenance and contractor performance, theft management, demand growth, load limits and local training and institutionalization (Schnitzer *et al.*, 2014).

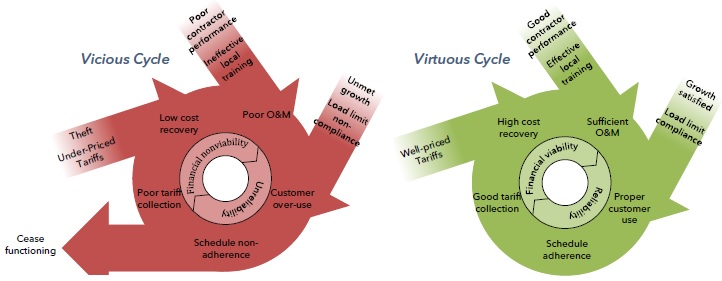


Figure 1.6 Vicious and virtuous cycles of human-technology interaction for micro-grids (Schnitzer et al. 2014)

Micro-grids have been steadily increasing in the developed world as well — given their potential to provide uninterrupted power, their ability to integrate renewable energy and thereby reduce carbon emissions from power generation. Widespread RD&D efforts are being developed in Europe, USA, Japan and Canada to deliver efficient solutions and to demonstrate micro-grid operating concepts. Pilot projects are exploring the potential of micro-grids to make power systems less vulnerable to costly disruptions. For instance, the Smart Power Infrastructure Demonstration for Energy Reliability and Security (SPIDERS) program of the United States Department of Defense is investigating on running several US military bases via micro-grids (Waugaman, 2014). IEEE standards were developed for their design, operation and integration with electrical power systems.

### Barriers to Adoption

Future expansion of micro-grids to newer geographies and their further adoption on a commercial scale depends crucially on overcoming existing barriers. In a review of distributed generation (DG), OFGEM (2007) identifies several key barriers for DG:

* **Cost** – the true cost of carbon is not yet being fully incorporated in electricity prices and this disadvantages lower carbon technologies. Secondly, DG technologies usually have higher capital costs. Furthermore, the rewards for exporting excess electricity produced by distributed generators are seen as small and difficult to access.
* **Lack of reliable information** – there is a low awareness of DG options amongst potential users; grants and financial incentives such as Renewables Obligation Certificates (ROCs) are perceived as being hard to access, and the lack of an accreditation scheme for suppliers and installers put people off untried technologies.
* **Structure of electricity industry** – due to the nature of the existing industry structure, it could be hard for small generators to connect to and operate in the centralized system. The cost to suppliers of rewarding small generators for exporting their excess electricity is a disincentive.
* **Regulatory barriers** – the difficulties of getting planning permission for DG technologies, especially in the context of community developments and new housing, where the associated costs and delays act as disincentives.

## Advantages and disadvantages of Microgrids

The benefits of rural electrification are highly recognized in literature. Burning of kerosene in lamps leads to deaths of nearly a million people every year (WEF and PWC, 2013) . The detrimental health effects of kerosene use includes accidental fires and severe burns, respiratory diseases, potential links to tuberculosis and cataracts, and child poisoning from unintentional ingestion of kerosene. Several studies indicate that the price paid by micro-grid customers for lighting using electricity is far lesser than the price for lighting using kerosene and candles (Barefoot Power, 2009). A scientific advisory panel briefing on kerosene and short-lived climate pollutants by the UNEP (2014) categorically concludes that “no other major Black Carbon source has such a combination of readily available alternatives and definitive climate forcing effects” as kerosene lamps. Replacement of diesel power generation by micro-grid solutions can reduce power costs by up to 40%. The displacement of diesel in telecom towers alone potentially reduce up to 40 tons of greenhouse gases per year per telecom tower (WEF and PWC, 2013).

While the emission reductions from kerosene and diesel displacement and the resultant cost savings could be numerically estimated, measuring the impact of electrification on the quality of rural life is a challenging task. Lighting alone brings several added benefits such as increased study time, extended hours of business, greater security for rural communities and increased access to entertainment and information through television. For instance, studies in a few developing countries indicate that moving from kerosene to electricity for lighting increased the study hours at home by 93 minutes (Aguirre, 2014) and had a quantifiable health benefit of $2.5 per household (IEG, 2008). Electrification in hitherto un-electrified areas can generate new commercial activities, lead to cheaper and longer mobile charging and increased cell phone usage.

Micro-grid installations in grid-connected regions too offer several key advantages including:

* Optimized energy consumption through better matching of supply with demand
* Reduced environmental impact through integration of renewable energy sources
* Increased security of energy supply
* Provision of cost-efficient electricity infrastructure
* Opportunity to utilize waste heat from power generation for space or water heating
* Ability to locally prioritize power supply for high priority needs during times of disruption

In a world that is increasingly dependent on electricity for its very existence, losing access to the power supply due to outages or blackouts is a critical risk that cannot be overlooked. Economic losses due to power outages in developed countries often run into hundreds of billions of dollars per year (SRR, 2013). More serious social costs accompanying a power outage or blackout include increased crime, transportation problems, food wastage, in addition to the environmental cost of diesel based power back-up. Studies indicate that as the demand for electricity increases, partly owing to the rapidly rising air-conditioning demand and usage of electric vehicles, the existing power systems become frailer. An increased number of blackouts are anticipated in the future, due to the growing global uncertainties in fuel supply and the growing certainties in demand for electricity (Mathhewman and Byrd, 2013). Micro-grids by virtue of being locally managed systems, are resilient to such disruptions in supply and have more control over the local demand. In the event of a supply disruption, a micro-grid can focus only on the critical loads that require uninterrupted service and shed the non-critical loads until adequate supply is restored.

Grid-extension remains the less expensive and preferred choice for electrification in most parts of the world, especially in urban areas with high population densities. The installed costs of renewable energy technologies such as small hydro power, solar and wind are still relatively high. The cost-effectiveness of micro-grids for off-grid settlements depends on the load profile of consumers, the availability and seasonal variability of local energy resources (such as biomass and hydro resources) and the geographical constraints in installing them. The additional costs of battery storage or diesel backup for intermittent sources such as solar and wind is another bottleneck. Furthermore, implementation of micro-grids in off-grid areas faces real uncertainty in accurately forecasting customers’ demand and expectations for the long term and therefore, their design must be flexible to adapt with the loads.

Perhaps the biggest challenge faced by micro-grids is its relationship with the local utility – a relationship that remains largely undefined. Although several studies indicate that micro-grids complement the local utilities, the utilities still have financial and technical concerns about how micro-grids will affect their business model. The micro-grid operator too is faced with a new business risk of customer flight when the main grid reaches its doorstep by grid extension to remote areas. On the technical side, while utilities worry about faulty interconnections from the micro-grid, micro-grid operators have to deal with legacy systems of the utility. These concerns are often legitimate and will require drafting of strict technical standards for interconnection and profitable business models for the two systems to co-exist.

# Discussion

Micro-grid infrastructure enables a transition to a de-centralized power system that is more reliable, affordable and sustainable. The drivers for its adoption are many and the markets for its uptake are varied. In this report, we modeled the adoption of micro-grids for both off-grid residential consumers and grid-connected consumers dependent on diesel power for reliability.

The drivers for micro-grid adoption can be economic, social, environmental or operational; and the adopters include those that requires access to electricity (off-grid consumers) and those in need of a more reliable and more affordable electricity (on-grid consumers). For the on-grid customers adopting micro-grids, the economic and operational aspects of micro-grid infrastructure play the deciding factors. For existing industrial facilities, remote locations and telecom towers having diesel as the primary source, it makes ample economic sense to replace them with micro-grids. With the rapid fall in prices of solar PV and battery storage, it. is believed that there is limited justification even for a RE-diesel hybrid solution.

Micro-grid is not a single technology, but instead encompasses a wide range of technologies including renewable energy, storage and diesel based generation. To arrive at the installed and operating costs of a typical micro-grid technology, it is necessary to take into account the capital and operational cost of each technology, as well as the likely share of each technology within the total micro-gird market over the coming 30 years. The first cost of micro-grid installations vary widely based on the generation technology, the local labor costs, complexity of terrain for laying the distribution network and the scale of the installation.

Equitable access to energy is a crucial prerequisite for sustainable development. Increasing demand for electricity globally is bound to test the limits of a centralized power system in the near future. Adopting an optimal combination of centralized and decentralized system can capture both the strength of the central grid and the agility of state-of-the-art technological advancements in a decentralized infrastructure. Micro-grids can help bridge this gap while making use of locally available energy resources.

# References

ABB Power Generation. (2015). *Microgrids and Renewable Energy Integration ABB Solution and Offering Overview.* ABB Power Generation. Retrieved from: http://new.abb.com/docs/librariesprovider78/documentos-peru/presentaciones-primeras-jornadas-tecnicas-abb-peru/ps/peru-exibition-microgrids-and-pv-ebop-alfredo-diez.pdf?sfvrsn=2.

Aguirre, J. (2014) Impact Of Rural Electrification On Education:  A Case Study From Peru. Retrieved from: http://udep.edu.pe/cceeee/files/2014/07/1B\_3\_Aguirre.pdf.

Bailey, M., Henriques, J., Holmes, J., Jain, R. (2012). Providing Village‐level Energy Services in Developing Countries. Retrieved from: http://www.easac.eu/fileadmin/PDF\_s/reports\_statements/Report\_220113\_PDF.pdf.

Greenpeace (2005). *Decentralising Power: An Energy Revolution For The 21st Century.* Greenpeace International Retrieved from: http://www.greenpeace.org.uk/MultimediaFiles/Live/FullReport/7154.pdf.

IEEE (2015). *IEEE Standard 1547.7.* Retrieved from: http://standards.ieee.org/news/2011/15744.html.

IEG (2008). The Welfare Impact of Rural Electrification: A Reassessment of the Costs and Benefits An Independent Evaluation Group Impact Evaluation. Retrieved from: http://siteresources.worldbank.org/EXTRURELECT/Resources/full\_doc.pdf.

IEA (2010). World Energy Outlook 2010 Energy Poverty - How to Make Modern  Energy Access Universal?. International Energy Agency, Paris, France.

IEA (2014). *World Energy Outlook.* International Energy Agency. Retrieved from: http://www.worldenergyoutlook.org/resources/energydevelopment/definingandmodellingenergyaccess/.

IRENA (2015). *Off-Grid  Renewable Energy  Systems: Status And  Methodological Issues.* International Renewable Energy Agency (IRENA). Retrieved from: http://www.irena.org/DocumentDownloads/Publications/IRENA\_Off-grid\_Renewable\_Systems\_WP\_2015.pdf.

Lam, Nicholas L, Yanju Chen, Cheryl Weyant, Chandra Venkataraman, Pankaj Sadavarte, Michael A. Johnson, Kirk R Smith, et al. (2012). Household Light Makes Global Heat: High Black Carbon Emissions From Kerosene Wick Lamps. *Environmental Science & Technology* 46 (24): 13531–38. doi:10.1021/es302697h.

Matthewman, St., Byrd, H. (2014). Blackouts: A Sociology of Electrical Power Failure. *Social Space*, 1–25.

Berkeley Lab. (2015). *Microgrid Definitions.* Berkeley Lab. Retrieved from: https://building-microgrid.lbl.gov/microgrid-definitions.

Navigant Research. (2015). Microgrid Deployment Tracker 2Q15.” Retrieved from: https://www.navigantresearch.com/research/microgrid-deployment-tracker-2q15.

Ofgem (2007). *Review of Distributed Generation.* Ofgem. Retrieved from: https://www.ofgem.gov.uk/ofgem-publications/52326/review-distributed-generation.pdf.

Owens, B. (2015). “The Rise of Distributed Power.” Accessed August 1. https://www.ge.com/sites/default/files/2014%2002%20Rise%20of%20Distributed%20Power.pdf.

Pachauri, S. (2014). Household Electricity Access a Trivial Contributor to CO2 Emissions Growth in India. *Nature Climate Change* 4: 1073–76. doi:10.1038/nclimate2414.

REN21 (2014). *Mini-Grid Policy Toolkit: Policy and Business Frameworks for Successful Mini-Grid Roll-Outs.* REN21. Retrieved from: http://www.ren21.net/Portals/0/documents/Resources/MGT/MinigridPolicyToolkit\_Sep2014\_EN.pdf.

Barefoot Power. (2009). *50 Ways to End Kerosene Lighting. Renewable Energy and Energy Efficiency Partnership, and Barefoot Power.* Retrieved from: http://global-off-grid-lighting-association.org/wp-content/uploads/2013/09/Fifty-Ways-to-End-Kerosene-Lighting-in-Developming-Countries-REEP.pdf.

SRR (2013). Microgrids and Distributed Energy Resource Software. Saviva Research Review. Retrieved from: http://www.savivaresearch.com/wp-content/uploads/2013/05/April-2013-DERMS.pdf.

Schniter, D., Lounsbury, D., Carvallo, J., Deshmukh, R., Apt, J., Kammen, D. (2014). *Microgrids for Rural Electrification: A Critical Review of Best Practices Based on  Seven Case Studies*. United Nations Foundation.

UNEP (2014). Scientific Advisory Panel Briefing: Kerosene Lamps & Slcps. Scientific Advisory Panel of the Climate and Clean Air, and Coalition. Retrieved from: http://www.unep.org/ccac/Portals/50162/docs/ccac/NOV2014-SAP%20Kerosene%20briefing.pdf.

SE4ALL. (2013). *Global Tracking Framework - Universal Access.* Retrieved from: http://www.se4all.org/wp-content/uploads/2013/09/7-gtf\_ch2.pdf.

United Nations, Department of Economic and Social Affairs, Population Division. (2014). *World Urbanization Prospects: The 2014 Revision*. Retrieved from: http://esa.un.org/unpd/wup/CD-ROM/.

Waugaman, B. (2014). *Smart Power Infrastructure Demonstration for Energy Reliability and Security (SPIDERS) Joint Capabilities Technology Demonstration (JCTD).* Retrieved from: http://www.energy.gov/sites/prod/files/2014/01/f7/fupwg\_winter2014\_Waugaman.pdf.

World Bank, and International Energy Agency. (2013). Progress Toward Sustainable Energy - Global Tracking  Framework. 2013. World Bank, and International Energy Agency.

WEF and PWC. (2013). *Scaling Up Energy Access through Cross-Sector Partnerships.* World Economic Forum, and Pricewaterhouse Coopers. Retrieved from: https://www.pwc.com/gx/en/sustainability/publications/assets/pwc-wef-scaling-up-energy-access-through-cross-sector\_partnerships.pdf.

# Glossary

**Adoption Scenario** – the predicted annual adoption over the period 2015 to 2060, which is usually measured in **Functional Units**. A range of scenarios is programmed in the model, but the user may enter her own. Note that the assumption behind most scenarios is one of growth. If for instance, a solution is one of reduced heating energy usage due to better insulation, then the solution adoption is translated into an increase in the use of insulation. There are two types of adoption scenarios in use: **Reference (REF)** where global adoption remains mostly constant, and **Project Drawdown Scenarios (PDS)** which illustrate the high growth of the solution.

**Approximate PPM Equivalent** – the reduction in the atmospheric concentration of CO2 (in **PPM**) that is expected to result if the **PDS Scenario** occurs. This assumes a discrete avoided pulse model based on the Bern Carbon Cycle model.

**Average Abatement Cost** – the ratio of the present value of the solution (**Net** **Operating Savings** minus **Marginal First Costs**) and the **Total Emissions Reduction**. This is a single value for each solution for each **PDS Scenario** and is used to build the characteristic “*Marginal Abatement Cost*” curves when Average Abatement Cost values for each solution are ordered and graphed.

**Average Annual Use** – the average number of functional units that a single implementation unit typically provides in one year. This is usually a weighted average for all users according to the data available. For instance, the total number of passenger-km driven by a hybrid vehicle in a year depends on the country and the typical number of occupants. We take global weighted averages for this input. This is used to estimate the **Replacement Time**.

**Cumulative First Cost** – the total **First Cost** of solution **Implementation Units** purchased in the **PDS Scenario** in the analysis period. The number of solution implementation units that are available to provide emissions reduction during the analysis period is dependent on the units installed prior to the analysis period, and hence all implementation units installed after the base year are included in the cumulative first costing (that is 2015-2050).

**Direct Emissions** – emissions caused by the operation of the solution, which are typically caused by the lifetime use of the solution. They should be entered into the model normalized per functional unit.

**Discount Rate**- the interest rate used in discounted cash flow (DCF) analysis to determine the present value of future cash flows. The discount rate in DCF analysis takes into account, not just the time value of money, but also the risk or uncertainty of future cash flows; the greater the uncertainty of future cash flows, the higher the discount rate. Most importantly, the greater the discount rate, the more the future savings are devalued (which impacts the financial but not the climate impacts of the solution).

**Emissions** **Factor**– the average normalized emissions resulting from consumption of a unit of electricity across the global grid. Typical units are kg CO2e/kWh.

**First Cost**- the investment cost per **Implementation Unit** which is essentially the full cost of establishing or implementing the solution. This value, measured in 2014$US, is only accurate to the extent that the cost-based analysis is accurate. The financial model assumes that the first cost is made entirely in the first year of establishment and none thereafter (that is, no amortization is included). Thus, both the first cost and operating cost are factored in the financial model for the first year of implementation, all years thereafter simply reflect the operating cost until replacement of the solution at its end of life.

**Functional Unit** – a measurement unit that represents the value, provided to the world, of the function that the solution performs. This depends on the solution. Therefore, LED Lighting provides petalumen-hours of light, Biomass provides tera-watt-hours of electricity and high-speed rail provides billions of passenger-km of mobility.

**Grid Emissions** – emissions caused by the use of the electricity grid in supplying power to any operation associated with a solution. They should be in the units described below each variable entry cell. Drawdown models assume that the global electric grid, even in a Reference Scenario, is slowly getting cleaner and that emissions factors fall over time resulting in lower grid emissions for the same electricity demand.

**Implementation Unit** – a measurement unit that represents how the solution practice or technology will be installed/setup and priced. The implementation unit depends on the solution. For instance, implementing electric vehicles (EV) is measured according to the number of actual EV’s in use, and adoption of Onshore Wind power is measured according to the total terawatts (TW) of capacity installed worldwide.

**Indirect Emissions** – emissions caused by the production or delivery or setup or establishment of the solution in a specified area. These are NOT caused by day to day operations or growth over time, but they should be entered into the model normalized on a per functional unit or per implementation unit basis.

**Learning Rate/Learning Curve** - Learning curves (sometimes called experience curves) are used to analyze a well-known and easily observed phenomenon: humans become increasingly efficient with experience. The first time a product is manufactured, or a service is provided, costs are high, work is inefficient, quality is marginal, and time is wasted. As experienced is acquired, costs decline, efficiency and quality improve, and waste is reduced. The model has a tool for calculating how costs change due to learning. A 2% learning rate means that the cost of producing a good drops by 2% every time total production doubles.

**Lifetime Capacity** – this is the total average functional units that one implementation unit of the solution or conventional technology or practice can provide before replacement is needed. All technologies have an average lifetime usage potential, even considering regular maintenance. This is used to estimate the **Replacement Time**. and has a direct impact on the cost to install/acquire technologies/practices over time. E.g. solar panels generate, on average, a limited amount of electricity (in TWh) per installed capacity (in TW) before a new solar panel must be purchased. Electric vehicles can travel a limited number of passenger kilometers over its lifetime before needing to be replaced.

**Lifetime Operating Savings**–the operating cost in the PDS versus the REF scenarios over the lifetime of the implementation units purchased during the model period regardless of when their useful life ends.

**Lifetime Cashflow NPV**-the present value (PV) of the net cash flows (PDS versus REF) in each year of the model period (2015-2060). The net cash flows include net operating costs and first costs. There are two results in the model: Lifetime Cashflow NPV for a Single **Implementation Unit**, which refers to the installation of one **Implementation Unit**, and Lifetime Cashflow NPV of All Units, which refers to all **Implementation Units** installed in a particular scenario. These calculations are also available using profit inputs instead of operating costs.

**Marginal First Cost** – the difference between the **First Cost** of all units (solution and conventional) installed in the **PDS Scenario** and the **First Cost** of all units installed in the **REF Scenario** during the analysis period. No discounting is performed. The number of solution implementation units that are available to provide emissions reduction during the analysis period is dependent on the units installed prior to the analysis period, and hence all implementation units installed after the base year are included in the cumulative first costing (that is 2015-2050).

**Net Annual Functional Units (NAFU)** – the adoption in the PDS minus the adoption in the REF in each year of analysis. In the model, this represents the additional annual functional demand captured either by the solution in the **PDS Scenario** or the conventional in the **REF Scenario**.

**Net Annual Implementation Units (NAIU)** – the number of **Implementation Units** of the solution that are needed in the PDS to supply the **Net Annual Functional Units (NAFU).** This equals the adoption in the PDS minus the adoption in the REF in each year of analysis divided by the average annual use.

**Net Operating Savings** – The undiscounted difference between the operating cost of all units (solution and conventional) in the **PDS Scenario** minus that of all units in the **REF Scenario**.

**Operating Costs** – the average cost to ensure the operation of an activity (conventional or solution) which is measured in 2014$US/**Functional Unit**. This is needed to estimate how much it would cost to achieve the adoption projected when compared to the **REF Case**. Note that this excludes **First Costs** for implementing the solution.

**Payback Period** – the number of years required to pay all the **First Costs** of the solution using **Net Operating Savings**. There are four specific metrics each with one of **Marginal First Costs** or **First Costs** of the solution only combined with either discounted or non-discounted values. All four are in the model. Additionally, the four outputs are calculated using the increased profit estimation instead of **Net Operating Savings**.

**PDS/ Project Drawdown Scenario** – this is the high growth scenario for the adoption of the solution.

**PPB/ Parts per Billion** – a measure of concentration for atmospheric gases. 10 million PPB = 1%.

**PPM/ Parts per Million** – a measure of concentration for atmospheric gases. 10 thousand PPM = 1%.

**REF/ Reference Scenario** – this is the low growth scenario for the adoption of the solution against which all **PDS scenarios** are compared.

**Regrets solution** has a positive impact on overall carbon emissions being therefore considered in some scenarios; however, the social and environmental costs could be harmful and high.

**Replacement Time**- the length of time in years, from installation/acquisition/setup of the solution through usage until a new installation/acquisition/setup is required to replace the earlier one. This is calculated as the ratio of **Lifetime Capacity** and the **Average Annual Use**.

**TAM/ Total Addressable Market** – represents the total potential market of functional demand provided by the technologies and practices under investigation, adjusting for estimated economic and population growth. For this solutions sector, it represents the world and regional total addressable markets for electricity generation technologies in which the solutions are considered.

**Total Emissions Reduction** – the sum of the grid, fuel, indirect, and other direct emissions reductions over the analysis period. The emissions reduction of each of these is the difference between the emissions that would have resulted in the **REF Scenario** (from both solution and conventional) and the emissions that would result in the **PDS Scenario**. These may also be considered as “emissions avoided” as they may have occurred in the REF Scenario, but not in the PDS Scenario.

**Transition solutions** - are considered till better technologies and less impactful are more cost-effective and mature.

**TWh/ Terawatt-hour** – A unit of energy equal to 1 billion kilowatt-hours.

1. No clear distinction exists between mini and micro-grids in literature, except for their relative size. For the purpose of this report, ‘micro-grids’ refers to nano, micro and mini-grids that can operate independent of a centralised grid. [↑](#footnote-ref-2)