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International Microgrid Assessment: Governance, INcentives, and Experience (IMAGINE)

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Abstract

Microgrids can provide an avenue for increasing the amount of distributed generation and delivery of electricity, where control is more dispersed and quality of service is locally tailored to end-use requirements, with applications from military bases to campuses to commercial office buildings. Many studies have been done to date on microgrid technology and operations, but few studies exist on the policy barriers present for microgrid demonstration and deployment. In performing this International Microgrid Assessment, we provide an avenue to understand the Governance of a grid environment where microgrids can succeed with the INcentives needed to capture the benefits that microgrids provide, by cataloguing the international Experience to date (IMAGINE). The assessment reviews the key drivers for microgrid development and outlines the main barriers that microgrid demonstrations have faced to date including interconnection issues, financial penalties, and operation constraints. Specific technology and policy pathways for microgrid development to get from the “land of penalties” to the “land of payments” are proposed. The paper provides an overview of policy conditions and microgrid demonstrations in 11 countries across Europe, Asia, and the Americas. It describes in detail the experiences of two well-known microgrid demonstration projects, the Santa Rita “green jail” in Dublin, CA and the Sendai microgrid in Japan, with details on goals, funding, technologies used, operating history, and lessons learned. Finally, the assessment leads to policy recommendations for starting a microgrid demonstration program. The IMAGINE report was prepared for the Chinese Academy of Sciences ahead of their preparations for a 30 microgrid demonstration program. If China can also manage to create incentive policies for microgrids, it will go beyond the establishment of a successful demonstration program and become an international leader in microgrid deployment.

1. Overview of microgrids

1.1. Definition of microgrid

The term microgrid loosely refers to any localized cluster of facilities whose electrical sources (generation), sinks (loads), and possibly storage (both electrical and thermal) function semi-autonomously from the traditional centralized grid, or macrogrid. Researchers have created a wide variety of microgrid definitions depending on the context of technology and function, but few formal definitions exist. Following are two efforts:

Microgrids are electricity distribution systems containing loads and distributed energy resources, (such as distributed generators, storage devices, or controllable loads) that can be operated in a controlled, coordinated way either while connected to the main power network or while islanded (CIGRÉ C6.22 Working Group).

A microgrid is a group of interconnected loads and distributed energy resources within clearly defined electrical boundaries that acts as a single controllable entity with respect to the grid. A microgrid can connect and disconnect from the grid to enable it to operate in both grid-connected or island-mode (U.S. DOE Microgrid Exchange Group, 2010).

The above CIGRÉ and U.S. DOE definitions have two basic requirements: 1) a microgrid must contain both sources and sinks under local control, and 2) a microgrid must be able to function both grid connected and as an island. The key word identifying a microgrid, and particularly differentiating it from traditional distributed generation, is controlled. A microgrid must have semiautonomous capability. Note that the CIGRÉ and U.S. DOE definitions say nothing about the technologies involved, their scale, their motive, their fuels, or the quality of power delivered to loads, but both definitions emphasize control.

The microgrid's ability to present itself to the macrogrid as a controlled entity has two important implications: 1) it can provide complex services, e.g. buffering variable renewable generation or providing ancillary services to the macrogrid, and 2) it can coordinate with other entities in the network, such as other microgrids or other sites with generation, storage and/or controlled loads. In addition to the self-apparent benefits of potentially providing clean and affordable energy under local control and supplying valuable grid services, some microgrids can locally control power quality and reliability (PQR) and tailor it to meet individual load requirements, in contrast to the universal homogeneous PQR service from the macrogrid. For example, this might mean a small local DC system involving solar PV and storage is the best solution even though PQR is poor, whereas in another case it may mean highly reliable and clean power is required, such as for a site whose loads demand it, e.g. a telecom facility. In other words, the PQR of delivered power should be compatible with the PQR requirements of the loads and constrained by what is economically available and environmentally desirable. Matching PQR in this way helps to maximize economic benefit.

Microgrids can be wholly within one traditional utility customer site, and in fact most existing demonstrations are of this type, especially in the U.S. Alternatively, a microgrid might involve several sites connected by a fragment of the existing distribution network. The difference between these two types is critical from the regulatory and policy perspectives. The former is downstream of a single meter or point of common coupling (PCCs), which implies a significantly simpler regulatory environment quite distinct from the latter case in which some part of an existing regulated distribution network is included.

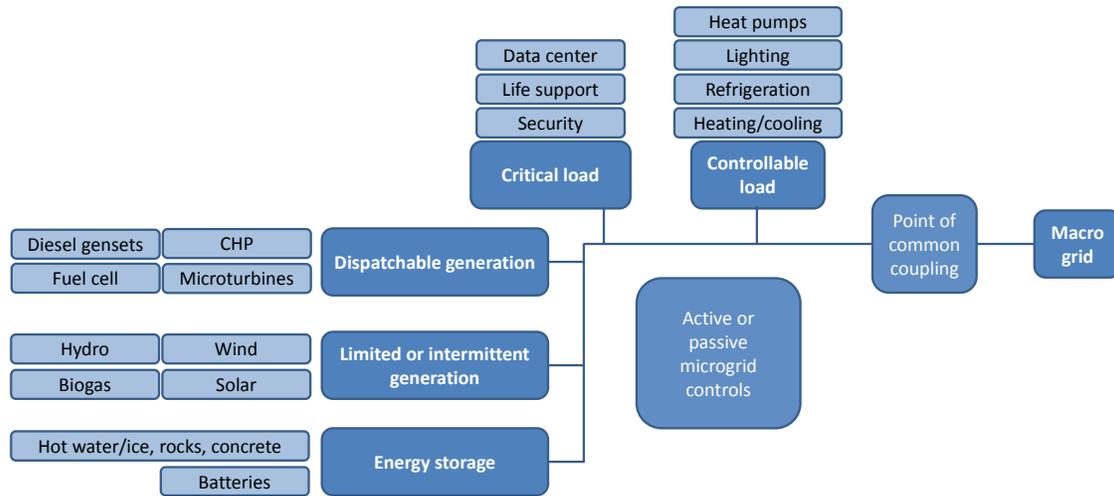


Figure 1 Overview of the main components in a common microgrid

Source: adapted from Siemens 2011

1.2. Common microgrid technologies

Figure 1 displays the components most readily seen in microgrid demonstrations currently. There are both loads and generation sources. Within loads, there may be critical loads which require high or perfect reliability and cannot lose power, such as a security system at a prison or a life support system at a hospital. There may also be controllable loads which either require lower reliability or whose time-of-service may be rescheduled without unjustifiably reducing service quality, such as heating, cooling, or refrigeration. Within generation, there are sources which are dispatchable, such as fuel cells, or microturbines, possibly in CHP systems. Many renewable sources have limited or no dispatchability, such as wind and solar, while others can be dispatchable, such as hydropower or biogas. Energy storage is often incorporated into microgrids as a way to deal with intermittency or to take advantage of pricing structures for macrogrid power. Thermal storage in hot materials or water/ice can also capture arbitrage opportunities. Lastly, there are the microgrid controls, which could range widely in sophistication across different applications. In addition to microgrid variability in availability and cost of supply, fluctuation in loads also creates technical challenges. Small power systems generally have greater load variation, making control and storage particularly crucial to microgrids.

1.3. Deployment drivers

Motivations for promoting distributed generation and microgrids are apparent across at least four distinct stakeholder groups, with many common threads amongst them, as seen in Figure 2. Energy

customers are increasingly interested in improving their energy efficiency and reducing their environmental footprint, while the electricity supply industry is consistently worried about increasing or simply maintaining PQR while serving a growing load base and meeting clean energy mandates. Governments, both at the local and national levels, are driving clean energy adoption, in the interests of climate change mitigation, energy security, and other environmental goals. Additionally, technology providers from many diverse sectors, such as information technology and telecommunications, are playing a disruptive role in microgrid development by seeking out potential opportunities to innovate.

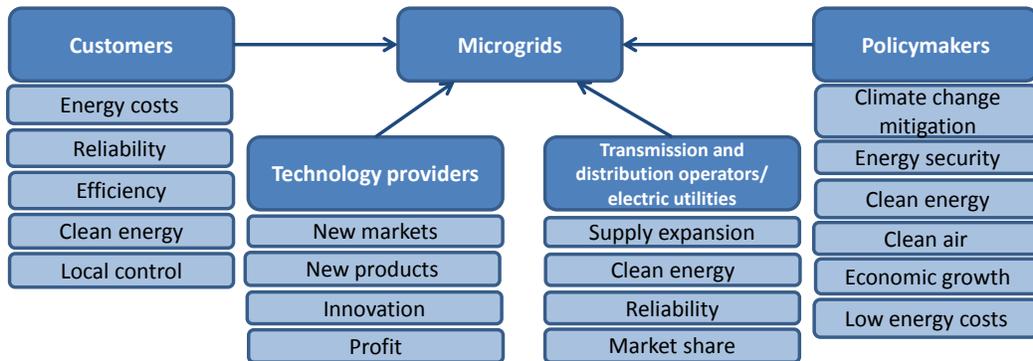


Figure 2 Drivers for microgrids across four stakeholder groups

As seen in Figure 2, the interests of the customer, technology provider, utility, and government stakeholders in a new grid paradigm are profound and have to some extent common motivations of cost, reliability, efficiency, clean energy, and climate change mitigation. Many countries and regions around the world are looking to distributed energy systems and smart grid initiatives to address these challenges. Governments have enacted and implemented a series of policies to increase the share of clean energy and distributed generation (Liebreich, 2011). However, the interconnection of distributed generation to the conventional network brings technical challenges such as circuit protection, maintaining PQR, and stability issues (Siemens AC, 2011). Microgrids could be an enabler of increased distributed generation by creating an electrical ecosystem more amenable to small-scale resources (Marnay, Asano, Papathanassious, & Strbac, 2008).

There is also the question of cost effectiveness for all of these interested stakeholders. For instance, utilities are constantly seeking the most efficient way to comply with new regulations or mandates, such as a renewable portfolio standard (RPS). They worry about the intermittency of renewables and the challenge renewables create for effective distribution planning. Microgrids might offer a solution to some of these concerns. While large renewable energy projects that require extensive environmental review (such as offshore wind or large desert solar installations) often face public opposition, microgrids may reduce siting issues because facilities may be smaller. Finally, reliability poses a concern for many stakeholder groups. Customers certainly value reliability, but how much they are willing to pay for it remains unclear. Note that the cost of universal homogeneous PQR provision in the macrogrid represents a cross-subsidy from customers who value it little towards those who value it highly. That is, the cost of maintaining universal PQR tends to be shared equally among all grid customers.

One of the disruptive forces promoting microgrids is the role of unregulated technology providers. Companies keen to provide both hardware and services to current utility customers are developing and deploying technologies that can increase customer autonomy. Several such technologies are enabling the transformation of electricity production, delivery, and use, but a key enabler of microgrids is power electronics devices. These are making control of small-scale systems feasible, economic, reliable, and safe.

By now, almost all of the major economies of the world have clean energy support policies, usually in the form of an RPS, cap and trade programs or other climate legislation, feed-in tariffs, and other financial support for clean energy such as tax credits or grants (Liebreich, 2011). Yet, renewable energy targets may not be enough to incentivize microgrids specifically, as utilities will seek the lowest cost option to meeting their targets which is likely in utility scale renewables (onshore and offshore wind, solar PV and thermal, biomass, geothermal, etc.) as well as rooftop solar PV, which is becoming increasingly prevalent as solar PV costs reach grid parity. Microgrid development would likely benefit more immediately from specific distributed generation targets beyond rooftop PV as well as targets for CHP. Microgrids offer the abilities to absorb renewable energy at scale, to tailor PQR to the requirements of local loads, and to integrate demand response and control, all of which are abilities that utility-scale renewables cannot directly offer. Lastly, carbon prices as induced by cap and trade or carbon tax legislation should also provide a price signal in the medium-term for more microgrid development.

2. International review of microgrid programs to date

This section summarizes: the policies driving renewable energy, distributed energy, and microgrids; the main microgrid research programs implemented to date; the agencies involved; and the key projects in Europe, Asia, and the Americas. Table 1 on page 10 summarizes this information and Figure 3 provides a timeline of these developments. While there has been significant progress in microgrid technology and interconnection standards, microgrid policy support remains somewhat insufficient for widespread microgrid deployment outside of specific government sponsored programs.

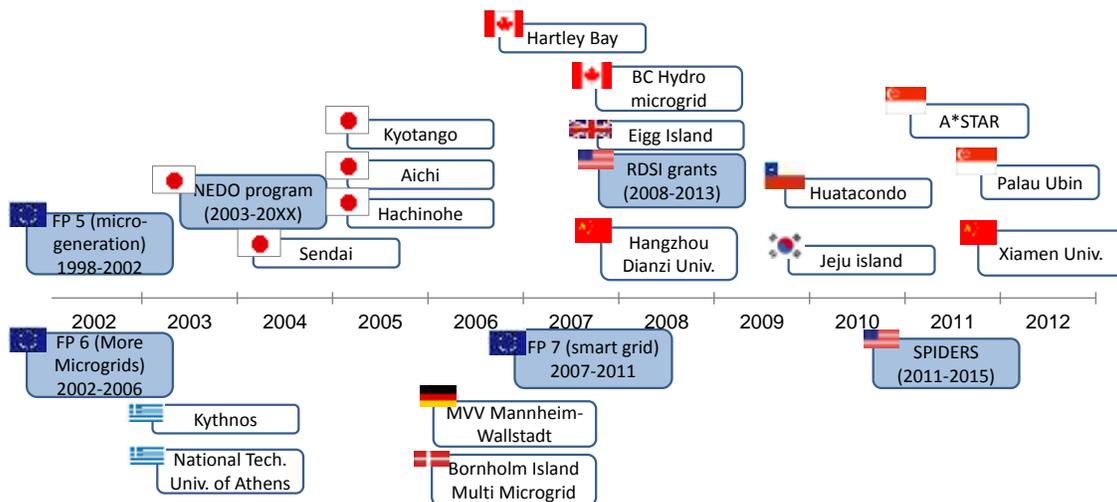


Figure 3 Timeline of microgrid programs (blue) and select projects (white) to date

2.1. Europe

The EU was the earliest leader in microgrid development, with comprehensive R&D efforts dating back to 1998. Under the 5th, 6th, and 7th Framework Programs (FP), comprehensive research and demonstrations have been carried out in the area of microgrids. One project within FP 5 focused on large-scale integration of micro-generation onto low voltage grids while a project within FP 6, known as “More Microgrids,” focused on microgrid control and operations. These research projects have launched many microgrid demonstration projects over the years, most notably the Kythnos Island Microgrid, the National Technical University of Athens Power Systems Laboratory, the MVV utility microgrids in Stuttensee and Mannheim Wallstad, the Bornholm Island Multi Microgrid, and the Eigg Island remote system.

While the EU has strong support for renewable energy (2020 targets for the share of renewables in final energy demand and feed-in tariff programs in many member states), there is not a strong enough policy signal for widespread deployment of microgrids. For instance, the EU has a very strong long-term climate and energy package with an ambitious greenhouse gas target of >80% off 1990 levels by 2050. Yet, the EU Emissions Trading Scheme covers utilities but not buildings, so there is not yet a strong price signal for building owners to consider carbon abatement options such as microgrids.

2.2. Asia

Japan was an early leader in microgrid research, with the New Energy and Industrial Technology Development Organization (NEDO) funding a number of successful demonstration projects starting in 2003 (Ustun, Ozansoy, & Zayegh, 2011). An increasing number of private sector entities are getting engaged in microgrid development, as the major earthquake in March 2011 has caused a resurgence of interest in distributed and renewable energy amidst the downturn of nuclear power. Additionally, one microgrid demonstration project in Sendai successfully operated as an island for two days, providing power and heat to a local hospital and other campus buildings (New Energy and Industrial Technology Development Organization, 2008). Japanese companies such as Shimizu and NT Facilities are also actively seeking microgrid project development opportunities abroad in the US and China (Denda, 2010). Given Japan’s dependence on fossil fuel imports and its ambitious clean energy and climate targets (Ecofys, 2012), microgrids should prove to be an increasingly promising energy option.

In addition to Japan, other Asian countries have been developing microgrid demonstration programs in recent years, such as China, South Korea, and Singapore. Since 2008, a handful of microgrid demonstration projects have been developed in China, mostly at universities around the country. Now, China’s National Energy Administration (NEA) is envisioning a larger scale role for microgrids as it plans a demonstration program featuring 30 microgrids. China has an overall non-fossil energy target of 15% by 2020, as well as CHP target of 50 GW. It is looking at natural gas to provide more opportunities for distributed generation and integration of renewable energy, having recently drafted the Management Methods for Distributed Energy (China National Energy Administration, 2011).

Singapore and South Korea each have one microgrid demonstration project under development, with South Korea showing particular interest in developing more smart grid or microgrid demonstrations similar to its Jeju Island smart grid test bed. Additionally, Singapore's official launch in late 2011 of its Experimental Power Grid Center (EPGC) at the A*STAR Institute of Chemical and Engineering Sciences signals increasing interest and research capability in Asia in the area of microgrids (A*STAR Inst of Chemical and Engineering Sciences, 2008) (Ustun, Ozansoy, & Zayegh, 2011).

2.3. Americas

In recent years, the U.S. has become a leader in microgrid demonstration and technology development, under two flagship microgrid grant programs run by the DOD (SPIDERS) and DOE (RDSI grants). DOD is running a \$38.5 million (€29.2 million) grant program for three different military base microgrid demonstrations, with reliability and energy security as its main goals (Department of Defense, 2011). DOE gave out over \$50 million (€38 million) in grants to nine projects (over \$100 million or €78 million with participant cost share) that all have to demonstrate a 15% peak load reduction in the local distribution feeder (or substation) using demand response and DER (Bossart, 2009).

Additionally, other efforts in standards (IEEE 1547), technology (CERTS), and software (DER-CAM) have filled in certain developmental gaps in the microgrid sector. Various U.S. stakeholders were instrumental in driving the authoring and publication of standards for interconnection of DER to the grid as well as islanding standards for microgrids. CERTS microgrid control technology has enabled spotlight projects at the Santa Rita Jail, the Sacramento Municipal Utility District headquarters, and Maxwell Air Force Base. Finally, the Distributed Energy Resources Customer Adoption Model (DER-CAM) developed by Lawrence Berkeley National Laboratory (LBNL) has been instrumental in helping various microgrid projects to optimize the operation of demand and supply side energy technologies for maximum cost and CO₂ reduction.

In the absence of a comprehensive federal clean energy policy, most states in the U.S. have been pursuing clean energy legislation, with some positive developments for microgrids as well. Net metering laws and interconnection standards exist in 44 states, and RPSs exist in 30 states. A handful of states have specific carve-outs for distributed energy including Illinois, New Mexico, and Arizona. Lastly, California's cap and trade program may provide a promising environment for CHP, distributed generation, and microgrids (U.S. Department of Energy, 2013).

Other geographies throughout the Americas also have developments in the microgrid sector. Canada and Chile both have microgrid projects serving remote communities, increasing reliability and lowering dependence on costly fossil fuel imports by barge or truck. Canada also has an R&D program called the NSERC Smart Microgrid Network, with a total funding of CAD 4.6 million (€ 2.7 million) over five years and a flagship project at the British Columbia Institute of Technology (Wong, 2011).

Table 1 International review of policy drivers and microgrid projects

Region	Country	Renewable energy/ microgrid policies	Other policies, drivers, and interests	Agencies involved	Demonstrations and research facilities
Asia	Japan	RPS (2002), feed in tariff (2012) Interconnection guidelines (1995); electric law amendments allowing IPPs and partial liberalization (1995, 1999, 2003); New Energy Basic Plan (2010)	Highly dependent on fossil fuel imports, partially liberalized electricity market, unofficial nuclear phase out (Fukushima), 25% reduction in greenhouse gas emissions by 2020	NEDO; METI	Hachinohe, Sendai, Aichi, Kyotango, Yokohama (Tokyo Gas), Tokyo (Shimizu) lab/demonstration, Aperture Project (U.S.)
	China	15% non-fossil target for 2020 (2009) Renewable energy law (2006) 100 New Energy cities, 30 microgrid pilots (2011) Draft management methods for distributed energy (2011)	50 GW CHP target, natural gas targets, feed in tariffs for renewable energy, 40-45% carbon intensity reduction target for 2020 (below 2005 levels)	NEA; Chinese Academy of Sciences: Inst. of Electrical Engineering	Hangzhou Dianzi Univ., Hefei Univ. of Technology, Xiamen Univ.
	South Korea	RPS – 2% by 2012, 4% by 2015, 10% by 2022	Focus on smart grid, Green Growth law, 30% below BAU greenhouse gas target for 2020	KERI	KERI microgrid; Jeju Island Smart Grid test bed
	Singapore	Singapore Initiative in New Energy Technology (SINERGY) (2007)	Nearly entirely dependent on fossil fuel imports, 16% below BAU greenhouse gas target for 2020	Energy Market Authority, A*STAR Inst. of Chemical and Engineering Sciences	Pulau Ubin, Experimental Power Grid Center (EPGC) Laboratory
Europe	EU	20% renewable energy by 2020; Framework Programmes 5 (large scale integration of micro-generation), 6 (More Microgrids), and 7 (smart grid), EU Emissions Trading Scheme	20% reduction in greenhouse gas emissions by 2020, feed in tariff programs in Spain, Germany, Italy, etc., unbundling of distribution system operators	European Commission, Director General for Energy and Transport	Kythnos, National Tech. Univ. of Athens, Mannheim Wallstadt, Bornholm Island, Eigg Island, Fraunhofer Inst.
Americas	U.S.	30 states with RPS, 44 states with interconnection policy, 44 states with a net metering policy	Development of CERTS technology, DER-CAM and μ Grid software, IEEE 1547 standard development, proposed 80% clean energy goal by 2035, 17% reduction in greenhouse gas emissions by 2020 off 2005 levels	DOE, CEC, DOD, NREL	SPIDERS (Hickham AFB, Fort Carson, Camp Smith); RDSI grants (Santa Rita Jail, Borrego Springs, Univ of Hawaii, Univ of Nevada Las Vegas, ATK Space Systems, City of Fort Collins, Illinois Institute of Tech, Allegheny Power, ConEd NY); UCSD); CERTS (Univ of Wisconsin, AEP)
	Canada	Green Energy and Green Economy Act of Ontario, Ontario feed in tariff, British Columbia clean energy act (2010), Renewable Energy Standard Offer Program (2006)	Western Climate Initiative, 17% reduction in greenhouse gas emissions by 2020 off 2005 levels for participating provinces; notional clean energy standard – 90% from hydro, nuclear, wind, solar, or CCS by 2020 (from current 77%)	Natural Resources Canada, NSERC Smart Microgrid Network	Hartley Bay, BCIT microgrid, Boston Bar
	Chile	RPS of 20% by 2020	Strong renewable resources (solar, geothermal, wind), 20% below BAU greenhouse gas target for 2020		Huatacondo

3. Barriers to microgrid development

The barriers for large scale microgrid deployment can be broken down into two categories: economic and institutional. Economic barriers concern the balance between the economic benefits microgrids create and the costs they impose. The essential question is whether these benefits and costs can be properly reflected in market prices to incentivize microgrid development that is simultaneously beneficial to the customer, the utility, and society as a whole. Note that analyzing these benefits and costs will also require contextual considerations such as geographic location of the microgrid on the macrogrid, local gas and electricity rates, local policies, and regional macrogrid power supply mix. Institutional barriers refer to those introduced by the need for unfamiliar practices in the industry. These include interconnection procedures, plus utility, building, environmental, and safety codes. The benefits that microgrids offer to the customer, utility, and society at large can be broken down into the following categories: economic, PQR, environmental, energy security, and safety. Table 2 provides an overview of some of the main benefits that microgrids can offer and which stakeholders can benefit.

Table 2 Microgrid value distribution

Benefit class	Specific benefit	Customer	Utility	Society
Economic (direct)	Reduced electricity and fuel costs	X		
Economic (direct)	Sale of excess power to grid	X	X	
Economic (direct)	Participation in demand response markets	X	X	
Economic (indirect)	Reduced system congestion costs		X	X
Economic (indirect)	Reduced transmission and distribution losses		X	X
Economic (indirect)	Reduced operating reserves		X	
Power reliability	Reduced power outages on-site	X		
Power reliability	Potential for black-start capabilities		X	X
Power quality	Potential for reactive power/voltage control	X	X	
Environmental	Increased use of renewable energy		X	X
Environmental	Reduced SO ₂ , NO _x , CO ₂ emissions		X	X
Security and safety	Avoided major system outages	X	X	X

Source: adapted from NY State Energy Research & Development Authority, 2010

The direct economic benefits are perhaps the easiest to understand and generally fall into three categories: reduced electricity and fuel costs, sale of excess power to the grid, and participation in ancillary service (AS) and demand response (DR) markets. If a microgrid is able to produce its own power, heating, and cooling services, it will obviously be able to reduce its electricity and fuel costs, ideally in a manner that makes its investment in distributed generation a cost-effective one overall. If there is time-of-use pricing, then there could be additional energy savings or arbitrage opportunities. There may be instances where microgrid generation exceeds its loads leading to exports. Particularly during peak demand periods, this service could be valuable to the macrogrid. There is a question of whether the microgrid will be compensated for this power, and if so, at what rate: wholesale, retail, or potentially a feed-in tariff (for any renewable, distributed, or other incentivized generation). Indirect economic benefits derive from postponing periodic investments utilities need to make in their transmission and distribution (T&D) systems. By producing the majority or a significant portion of their own energy microgrids are reducing T&D system congestion and losses. As microgrids are deployed, less

will be spent on maintenance and upgrades in the T&D system, and the need for peak generators or operating reserves will be reduced. Microgrids can have a positive impact on macrogrid PQR, partially through the provision of DR and AS. Reliability is a primary concern for many microgrid sites and the ability to produce reliable power on-site and avoid power outages caused by macrogrid disruptions is highly valued by certain customers such as military bases and hospitals. Microgrids may be able to provide services to the distribution grid such as reactive power for voltage control, which could have a positive impact on power quality. Lastly, in the environmental realm, since microgrids can increase energy efficiency and renewable supply, there will normally be associated emissions reductions for carbon dioxide and criteria pollutants such as sulfur dioxide and nitrogen oxides.

4. From the “land of penalties” to the “land of payments”

Historically, many utilities have not welcomed development of microgrids and DER, and in certain situations, have actively inhibited their development, placing them in the “land of penalties.” They have refused to interconnect the projects or have charged prohibitively high connection fees, exit fees (explained below), or backup/standby fees. For microgrids to capture the benefits just discussed, policy and technological remedies need to assist microgrids in getting from the “land of penalties” to the “land of payments.”

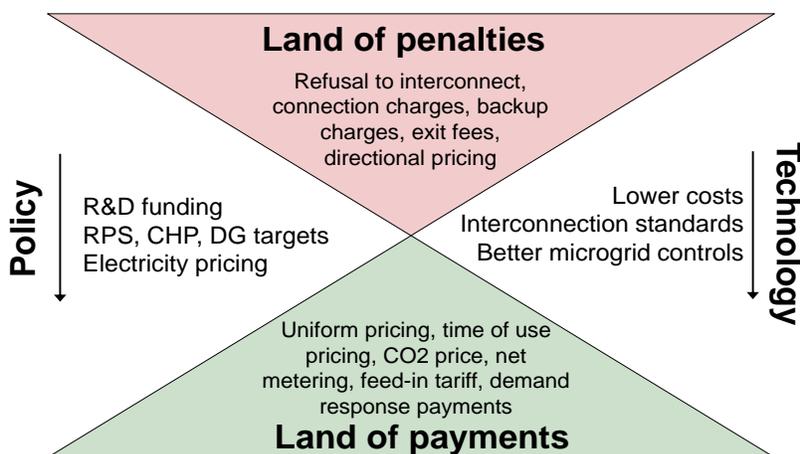


Figure 4 Land of penalties to land of payments using policy and technology remedies

The idea Figure 4 conveys is that technology and policy solutions can help microgrids enter into an environment where the economically valuable services it provides are properly valued with payments or incentives instead of penalties. Technology improvement should consistently lead to improved microgrid functions and services, if properly incentivized. As technology costs come down, interconnection practices become standardized, and microgrid controls (both passive and active) consistently improve, then microgrids will become both increasingly feasible and also of higher quality and robustness. Policy can help incentivize the initial R&D and demonstration phases with funding and targets for microgrid demonstrations (or specific distributed generation and combined heat and power [CHP] targets to be more inclusive). Working on electricity pricing policy will ensure that microgrids can capture a just share of the economic benefits. As seen in Table 3, there are many potential changes on the policy “wish list” relevant to electricity pricing alone. When customers purchase less energy from the

utility, the utility has been inclined to request increased service charges or exit fees due to its lost revenue and consequent stranded assets. These charges often eliminate the benefits the customer had initially gained and therefore should not be allowed by regulators unless clearly justified. Note that under dynamic circumstances, such as if local or regional electricity consumption is rising rapidly (as is the case in many developing world regions), then the utility’s risk of stranded assets is greatly reduced.

Table 3 Valuing the economic benefits of microgrids

Economic benefit of microgrid	Regulatory barrier: “Land of penalties”	Resolution: “Land of payments”
Reduce energy costs	Increased service charges or exit fees	Disallow unwarranted increases in charges due to loss of use-of-service revenue
	No time-of-use pricing	Create time-of-use or real-time pricing scheme
Sell excess power to utility	Interconnection charges	Apply a fair and cost-effective interconnection review process
	No compensation provided	Mandate utility purchase of excess power
	Directional pricing used	Consider uniform pricing
	Net-metering not allowed	Mandate net-metering, consider allowing provisions for a mixture of supply technologies
Participate in demand response markets	No compensation provided	Create incentive payments for demand response (interruptible tariffs or contracts)
	Capacity limit set too high	Lower capacity limit so microgrids of all sizes can participate
Increase use of renewable energy	No incentives for renewable energy	Consider RPS or feed-in tariff policies
Reduce CO ₂ emissions	No CO ₂ price	Consider carbon pricing policy

Source: Schwaegerl, 2009

5. Case studies

The purpose of the following two case studies is to illustrate examples of how microgrid demonstrations have come to fruition. They outline the technologies used, keys to success, and lessons learned from each demonstration.

5.1. Santa Rita Jail microgrid

Santa Rita Jail is the third-largest jail in California and the fifth largest in the United States. The Jail houses up to 4,500 inmates and is located in Dublin, California, about 75 km east of San Francisco. Due to a series of installed DER and efficiency measures at the Jail, it is also often referred to as the “Green Jail.” The goal of the microgrid project there is to demonstrate the first implementation of the CERTS microgrid technology combined with large-scale energy storage, new and legacy renewable energy sources, and a fuel cell. The goals as outlined by Alameda County (the local county government in charge of the Jail) are as follows:

- Reduce peak electrical load and monthly demand charges
- Store renewable and fuel cell energy overproduction

- Shift electrical loads to off-peak hours
- Improve grid reliability and reduce electrical voltage surges and spikes
- Enable the Jail to be a net-zero electrical facility during the most expensive summer peak hours
- Expand the Jail’s onsite generation capacity to include three renewable energy sources: solar PV, wind turbines, and solar water heaters

Over the past decade, the project has implemented various energy efficiency measures and installed a wide array of distributed energy technologies, which have slowly accumulated into a full microgrid. In the spring of 2002, the Jail installed a 1.2 MW rated rooftop PV array, followed in 2006 by a 1 MW molten carbonate fuel cell (MCFC) with CHP capability. Most recently, with the aid of DOE and California Energy Commission (CEC) grant money, as well as funding and participation from industry partners Chevron Energy Solutions, Satcon Power Systems, and Pacific Gas and Electric, the Jail has gained full microgrid capabilities with the installation of a large 2 MW – 4 MWh lithium iron phosphate battery, an islanding switch, and associated power electronic upgrades. In addition to generation equipment, the Jail has also implemented a series of building equipment retrofits (in lighting, HVAC, refrigeration, and other end uses) to improve efficiency and reduce peak electricity demand (General Services Agency, 2012) (DeForest, Lai, Stadler, Mendes, Marnay, & Donadee, 2011) (Marnay, et al., 2011).

Table 4 Main characteristics of Santa Rita Jail microgrid

Criterion	Description
Technologies used (supply)	1.2 MW rooftop solar PV, 240 kW ground mounted tracking solar PV, 1 MW multi-carbonate fuel cell, two 1.2 MW emergency diesel generators, four 2 kW wind turbines, 2 MW – 4 MWh battery, static disconnect switch
Load sources (demand)	HVAC, lighting, computers and servers, security systems, cooking, refrigeration, hot water
Electrical storage	2 MW – 4 MWh lithium iron phosphate battery
Thermal storage	Solar water heating
Total supply	Solar PV and fuel cell only: 604 kW (average), 1,474 kW (peak)
Total demand	3 MW (peak)
Heating/cooling equipment	Fuel cell has waste heat that can be utilized
Investment	\$14 million [€10.6 million] (does not include solar PV and energy efficiency measures)
Grants received	DOE, CEC, DOD, and PG&E
Dates of operation	2002-present
General energy conversion efficiency	Electrical efficiency 35%, thermal efficiency 17% (of fuel cell)

Sources: (DeForest, Lai, Stadler, Mendes, Marnay, & Donadee, 2011) (Marnay, et al., 2011)

A major element to the Santa Rita Jail microgrid’s success was the central role of a local government entity, Alameda County. The facilities of local governments often make good host sites for microgrid projects. Federal and state governments are keen to support a progressive local authority whose resources are fewer and budgets are smaller. The County was seeking to be innovative from the start, being a first mover for demand side energy efficiency measures and on-site generation with solar PV and fuel cells.

A second element of the microgrid’s success was the diversity of partners involved. Local, state, and federal government entities were all involved plus partnership with the local utility (PG&E), technology providers (Satcon and S&C Electric), an engineering services company focused on renewable energy and

CHP (Chevron Energy Solutions), and multiple laboratories (University of Wisconsin, LBNL, and NREL). Many of the partners had a large financial stake in the project while others were seeking pilot projects for microgrid technology that had only been demonstrated in the laboratory. The University of Wisconsin, with its involvement in the development of CERTS microgrid technology, had tested its approach at a utility-owned laboratory, American Electric Power's Dolan Laboratory. Satcon, S&C Electric, and Chevron were very capable technology and engineering companies who were able to execute the implementation properly. With the combination of the static switch, droop control in the battery inverter, and new controls in the diesel generators, the CERTS microgrid functioned properly in the field. The jail's involvement of LBNL as a partner helped them to optimize the economics and risk involved in the project, which is another key element of any successful demonstration. Data collection was key, as proper analysis cannot be performed without a sufficient amount of historic data.

The major lesson learned is that the costs of the battery were very high and its purchase was only made possible through federal and state government grants. Storage costs still need to fall before its widespread adoption can take place. The jail has very high requirements for reliability and now can operate without worry about the consequences of future macrogrid outages since it can island and provide its own electricity. Large electrical storage applications will only make economic sense where ultra-high reliability requirements are in place. Smaller, more affordable size battery installations can be used for sites with lower reliability requirements and still potentially have a net positive economic impact given the price arbitrage opportunities of purchasing lower cost electricity during off-peak periods.

5.2. Sendai microgrid

The Sendai project is a microgrid located in Sendai, Japan that can supply multiple levels of PQR. The project was supported by Japan's NEDO under the Ministry of Economy, Trade, and Industry (METI) from 2004 to 2008. The main collaborators on the project were Nippon Telegraph and Telephone Corporation (NTT), the NTT Facilities Research Institute, Tohoku Fukushi University, and the city of Sendai. The goal of the project was to build a microgrid system that could supply multiple power quality (PQ) levels of AC power as well as DC power to various consumer loads at the same time. Ideally, the cost, equipment space, and electrical power losses of the system would be less than those of pre-existing PQ countermeasures which included an uninterruptible power supply. The microgrid was completed in October 2006 and operated until 2008. After completion of the NEDO demonstration phase, some changes were made to the microgrid, and it continues to operate today as a university-owned installation. The campus belongs to a small private university specialized in medical training.

The loads served during the NEDO phase are those on either side of a city street. On one side are municipal facilities, a water plant, and a high school. The University is on the other side and includes a hospital with communication apparatus, medical instruments, nursing care facilities, computers, etc. as well as university buildings with computers, servers, lighting, ventilation, and fans. This project includes its own solar PV array, fuel cell, and gas-powered generators to provide electricity to these customer loads. The project was estimated to cost \$25 million (€19 million) from 2004-2008 and was almost

entirely funded by NEDO. Further improvements after the demonstration phase ended were made using Tohoku Fukushi University funds. Table 5 details the main characteristics of the microgrid.

Table 5 Main characteristics of Sendai microgrid

Criterion	Description
Technologies used (supply)	Two 350 kW gas gensets, 250 kW molten carbonate fuel cell, 50 kW rooftop solar PV
Load sources (demand)	City buildings (water plant, high school), hospital (communication apparatus, medical instruments, nursing care facilities, computers) university buildings (computers, servers, lighting, ventilation)
Electrical storage	Lead-acid battery: 600 Ah
Total demand	University: 1,170 kW (peak), 260 kW (minimum), City: 420 kW (peak), 80 kW (minimum) [Data from 2005-2007]
Investment	\$25 million (€19 million) (estimate)
Local electricity price	12 ¥/kWh (€0.10/kWh)
Local gas price	60 ¥/ nominal m ³ (€0.50/ nominal m ³)
Grants received	NEDO
Dates of operation	2007-2008 (city + university), 2009-present (university only)
Heat recovery efficiency	Gas gensets: 34.5%; fuel cell: 18%
General energy conversion efficiency	Gas gensets: 75%; fuel cell: 65%

Source: (New Energy and Industrial Technology Organization, 2008)

From 2007 to March 2008, after various validation tests using dummy loads for the system, electrical power was supplied to facilities in the city and university zones. During this period, many tests were conducted to verify microgrid performance, including power outages, voltage dips, and other types of tests. Results throughout eight months of testing showed that the system met its evaluation criteria and was able to provide stable electrical power to loads. Meanwhile, the cost, space, power loss, and CO₂ emissions were compared with a baseline of 15 years of cost and performance data. It was found that the system could reduce energy costs by 14-30%, reduce equipment space by 23-42%, cut CO₂ emission by 12%, and have equivalent or slightly decreased electrical loss compared to the pre-existing system.

The microgrid continues to function today, but only supplies power to the university zone. Its reliability was dramatically tested by the March 2011 Japan earthquake and tsunami. The microgrid functioned successfully as an island for the duration of a two-day blackout that followed the disaster, providing uninterrupted DC power and heat to the sensitive loads in the hospital as well as AC power to other loads. It successfully reconnected to the grid and continued to function until natural gas supply was disrupted two weeks later due to further complications from the earthquake. The Sendai area has a reinforced high-pressure natural gas distribution network (Ustun, Ozansoy, & Zayegh, 2011) (New Energy and Industrial Technology Organization, 2008).

Similar to the Santa Rita Jail microgrid, the Sendai microgrid also benefited from having a supportive local government host. The supply of power to both city and university zones involved crossing a public road. Normally, this would invoke utility codes making the microgrid subject to public utility regulation. Fortunately, the city was able to sidestep the regulation and create an exception for the microgrid. The Sendai microgrid benefited from the oversight and consistent involvement of NTT Facilities. NTT

Facilities sought to make their project a success and sees great potential for widespread microgrid deployment in the future in Japan and other regions.

The project also benefited from very generous funding from NEDO, without which, much of the demonstration would not have been possible. Given the generosity of funding, Sendai lost some focus regarding economics of the project, although it did meet all of its designed goals as described in the previous section. Additionally, NEDO was somewhat constrained in its vision for their series of demonstration projects. NEDO wanted each microgrid to demonstrate one aspect of microgrid functionality. Hachinohe was the all-renewables microgrid, for instance, while Sendai's focus was solely on delivering multiple levels of PQR. However, microgrids are designed to have multiple technologies providing a number of functionalities. Because Sendai was constrained by NEDO in its scope, it did not consider the additional benefit of CHP. When the NEDO demonstration phase ended in 2008, NTT Facilities reduced the microgrid's scope to only the university zone. It also added CHP capacity to take advantage of the gas genset and fuel cell waste heat to heat university and hospital buildings. This experience offers a vital lesson. Microgrid demonstrations should be planned to be either as economic as possible, or to represent anticipated economic operation. Designing and executing demonstrations based solely on specific technical goals are likely to prove highly uneconomic, and this outcome can overshadow any technical achievement and impede future deployment.

6. Policy recommendations for a microgrid program

Providing the right policy and technology remedies to go from the land of penalties to the land of payments is the last step in a country's microgrid program, as it is the step that leads to widespread deployment. In fact, no country is yet at a deployment stage for microgrids, but many have completed R&D programs and field demonstration projects. Yet, any country embarking on a microgrid development program should start with this end in mind. Helping to decide the end goal for microgrids in terms of purpose and functionality within a country's grid system can help to determine the initial steps in setting up a demonstration program and commissioning initial demonstration projects. The demonstration program will help to set the long-term goal and an initial foundation for microgrid development. Demonstration projects will help a country identify what functions the microgrid can serve within the specific energy landscape. If it seems that the microgrid can achieve economic benefits for customers, utilities, and society at large, then policies can be implemented to ensure the microgrid owner receives incentives or other support to monetize those benefits.

The key policy recommendations can be broken down into those for A) the demonstration program as a whole, B) the individual demonstration projects, and C) deployment policies.

Recommendations for microgrid demonstration program:

1. *Set goals for the demonstration program:* Based on the benefits sought and the stakeholders involved, the program administrator can set overall goals for the microgrid demonstration program in reliability (ability to island, power outages), energy efficiency (both supply and demand side), renewable energy use, energy savings (for both microgrid participants and utilities), or CO₂ emissions reduction.

2. *Promote results-oriented demonstrations based on overall goals:* Microgrid development has reached the stage where potential benefits are known and have been demonstrated, but they have been rarely quantified in a rigorous manner. Once overall programmatic goals have been set, quantifiable goals and metrics should be set for the individual demonstration projects. For instance, the U.S. Department of Energy identified a peak load reduction goal of 15% for a series of microgrids it helped to fund. Share of renewable energy production in the microgrid could also be a demonstration goal. Additionally, cost sharing between government and private sector partners is another way to promote results-oriented demonstrations.
3. *Allow for post-demonstration analysis and peer review:* A key component of any demonstration should be analysis following completion of the project. Amassing enough data during a demonstration, and providing budget and opportunity for ex-post analysis can produce valuable results for the project itself, future projects, and overall policy.

Recommendations for individual microgrid demonstration projects

4. *Ensure project is close to economic viability:* Various tools have been developed internationally to assess a project's economic viability (pre-implementation) from the perspective of a microgrid customer who is usually seeking to cut energy costs and/or change PQR, while increasing control over electricity delivery on their site.
5. *Include customer microgrids:* Many of the successful microgrid demonstration projects have been located at customer sites downstream of one meter, where there are fewer regulatory barriers. Maxwell Air Force Base, Illinois Institute of Technology, and Santa Rita green jail projects are all great examples of successful microgrid projects downstream of one meter.
6. *Match technology with end-use requirements:* Demonstrations built around energy supply resources not suitable for the site's energy loads are misguided. Matching PQR of the energy supply to the requirements of end use loads is a defining feature of a successful microgrid, such as the Santa Rita green jail. On the one hand, sensitive loads (military bases, hospitals, data centers, etc.) require very high PQR while on the other hand, some customers' sites may not even need PQR as high as the legacy centralized grid, or macrogrid, provides.
7. *Integrate energy functions, such as CHP and CCHP:* Demands for electricity, heating, cooling, and other fuel use, should all be taken into account when designing an optimal microgrid. Even though there is often a policy preference for renewables, some of the best economic and carbon abatement opportunities (for low to moderate abatement targets) lie with CHP as well as combined cooling, heating, and power, technologies (CCHP), deployed successfully by the Sendai and University of California San Diego (UCSD) projects, respectively.

Recommendations for policies to support microgrid deployment

8. *Develop standards and processes for interconnection of microgrids:* Any policymaker considering a microgrid program should put standards in place (potentially based off of IEEE's 1547 standard) as soon as possible. Additionally, they should develop a process for streamlining interconnection reviews in the short-term but evaluating large scale impacts of distributed generation in the long-term and coming up with a cost-effective response. The amount of distributed generation will rise in most regions of the world, so utilities and policymakers should plan proactively for their impact.

9. *Consider modifications to electricity rate design:* Microgrids must be able to monetize the benefits they create to incentivize their successful widespread deployment. Suggestions in this regard focus on modifications to electricity rate design, including measures for both the purchase and sale of electricity by the microgrid. On the purchase side, time-of-use pricing and demand charges can be used to incentivize load shifting and energy efficiency. On the sale side, uniform pricing, net-metering, and DR payments can be used to incentivize the sale of energy and services from the microgrid to the macrogrid.
10. *Inventory current incentive policies and analyze barriers and opportunities for widespread microgrid deployment:* Utilities who have to comply with an RPS or cap and trade policies currently pursue utility-scale solutions (such as large wind farms or solar thermal generation plants) as opposed to distributed-scale solutions for economic reasons. Eventually, distributed-scale solutions may become cost competitive with utility-scale solutions, but in the interim, mandated policy targets and targeted incentives for CHP or microgrids will help these technology solutions get a foot up as market players gain experience and costs come down.

7. Specific recommendations for China's microgrid program

China has a wide array of policy drivers for low-carbon growth and clean energy. At the highest level, China has its targets to reduce carbon intensity by 40-45% by 2020 off 2005 levels as well as to increase the percentage of non-fossil fuel energy usage (nuclear, hydropower, renewables) up to 15% by 2020. The NEA plans to build 100 "New Energy City" pilots as well as 30 microgrid pilots (China National Energy Administration, 2011). As China develops these demonstration microgrid projects as well as new regulations to promote widespread microgrid development, policymakers should bear in mind the ten recommendations laid forth in the previous section and apply them to China's situation.

There is a possibility that China will approach microgrids solely as a supply side solution (a way to balance out intermittent renewables), but for microgrids to realize the maximum amount of benefit in reliability, energy efficiency, and use of renewable energy, they must integrate supply solutions with demand side efficiency and storage as well, where appropriate. As China develops its microgrid demonstration program and plans for more widespread microgrid deployment, there are a number of policy adjustments that China will need to consider: forming interconnection standards, establishing a central authority on distributed generation and the microgrid demonstration program, and aligning incentives to encourage microgrid deployment.

The NEA has played the most active role to date in promoting microgrids within China's renewable and clean energy development. Recently, NEA drafted the Management Methods for Distributed Energy, but this has yet to become an official piece of legislation (China National Energy Administration, 2011). Given that the various functions involving distributed energy are scattered across many different departments, there is a lack of unified management and policy guidance, posing some developmental barriers to distributed energy and microgrids. NEA could take the lead on the microgrid demonstration program and be responsible for its successful implementation, yet work closely with other agencies that are also interested in microgrid deployment, such as the National Development and Reform Commission (NDRC), Ministry of Housing and Urban Rural Development (MOHURD), and Ministry of Finance (MOF).

Those three agencies, in conjunction with NEA, released a policy document in 2011 on natural-gas based distributed generation that would be amenable to renewable energy integration (NEA, NDRC, MOF, MOHURD, 2011). These developments could produce positive momentum for utility-scale microgrid applications. MOHURD has set goals for renewable energy deployment in buildings, but many buildings with renewable energy installations have not been successfully interconnected with the grid. MOHURD is exploring microgrids as a possible avenue to facilitate its policy objective. Finally, MOF will play a key role in establishing the needed funding for microgrid demonstrations.

China's general policy direction provides positive indications for distributed generation and CHP, but concrete incentive policies for these areas are currently lacking. Wider considerations need to be given to electricity pricing policy as a whole to ensure it incentivizes microgrid deployment. Time-of-use pricing, demand response contracts, uniform pricing, and net-metering policies can all be considered as each would play a positive role in promoting successful microgrids that increase reliability and energy efficiency while lowering carbon emissions.

8. Conclusions

Microgrids can provide an avenue for increasing the amount of distributed generation and delivery of electricity, where control is more dispersed and quality of service is locally tailored to end-use requirements. Much of this functionality is very different from the predominant utility model to date of centralized power production which is then transmitted and distributed across long distances with a uniform quality of service. This different functionality holds much promise for positive change, in terms of increasing reliability, energy efficiency, and renewable energy while decreasing carbon emissions. All of these functions should provide direct cost savings for customers and utilities as well as positive externalities for society. As outlined in this paper, allowing microgrids to function in parallel with the grid requires some changes in electricity governance and incentives to capture cost savings and actively price in positive externalities. If China can manage to implement these governance changes and create those incentive policies, it will go beyond the establishment of a successful microgrid demonstration program and become an international leader in microgrid deployment.

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