Dynamics and Challenges of Microgrids Implementation

By

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SUBMITTED TO THE MIT SLOAN SCHOOL OF MANAGEMENT IN PARTIAL FULLFILLMENT OF THE REQUIREMENTS FOR THE DEGREE OF

MASTER OF SCIENCE IN MANAGEMENT STUDIES
AT THE
MASSACHUSETTS INSTITUTE OF TECHNOLOGY

JUNE 2013

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Submitted to MIT Sloan School of Management

on May 16, 2013 in partial fullfillment of the

requirements for the degree of

Master of Science in Management Studies.

ABSTRACT

Microgrids have the capability of operating on an island mode as well as an integrated mode with the smart grid, depending on the requirement and objectives. Recently, microgrids projects have gained popularity both in developed world and developing world because of their ability to lower cost, increase resiliency and overall power quality. However, most of the studies on microgrids till now have focused on the technological challenges associated with design and implementation of microgrids. This study tries to develop an industry perspective on the recent development of microgrids. Several case studies from both developed world and developing world are explained to understand drivers, constraints and challenges of microgrid implementation. A generic model used by Weil and Utterback (2005) forms the basis for this study to develop a conceptual model, mapping different social, technological, market and regulatory factors which influence technology and industry evolution. The same model is used to develop a scenario analysis to predict future development of microgrids as a technology and as an industry.

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ACKNOWLDGEMENTS

First and foremost, I thank my thesis advisor Henry Weil for all the help, guidance and feedback which has guided me throughout the process. He kept me motivated towards my goal and made this learning experience possible in the first place. His insights in industry evolution, technology adoption and consumer behavior will certainly be helpful for me, going forward in my career.

In addition, I am thankful to the various people who agreed to share their perspective on Microgrids industry especially, Peter Asmus (Navigant Researc), Mark Ossel (Echelon Corporation), Prof. Ignacio (MITEI), Tony Coiro (Hope Energy), Reja Amatya (MITEI) and Sagun Saxena (CleanStar Ventures).

I would also like to thank Prof. Michael Cusumano, Chanh Phan, Julia Sargeaunt and the team in charge of the Master of Science in Management Studies program for their unfailing support and commitment to improve my overall experience at MIT Sloan.

Finally, I would like to thank to my family and friends for their support and invaluable suggestions.

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INTRODUCTION

A Microgrid is an autonomous system (with various generation technologies, storage) which is capable of meeting the local load either in a grid connected manner or in an island mode. Department of Energy, US defines microgrids as "A group of interconnected loads and distributed energy resources (DER) with clearly defined electrical boundaries that acts as a single controllable entity with respect to the grid [and can] connect and disconnect from the grid to enable it to operate in both grid connected or island mode". Several projects around the world are testing microgrids on technical metrics like power quality, reliability, resilience etc. Recently though, many projects have made their way into market operations also, as we shall cover later. And hence this study would try and cover deployment of microgrids as a technology into the market to understand this industry's evolution going forward.

Since there aren't many studies which have taken this perspective of market evolution for microgrids, the hope is that this study would form a base for future research into this space. A systems approach is used to pursue current research after deriving motivations from the research methodology of Weil and Utterback (2005) on technology markets evolution. A brief about the same has been covered in the next chapter.

This study covers major (market) segments which are growing across the world – in both developing and developed world; And evaluate these segments in the light of a few case studies. Based on the primary and secondary research carried out, the classification used in this study is as follows:

i. Microgrids projects in Developed country
    a. University/ Campus microgrids
    b. Military microgrids
    c. Community microgrids
ii. Microgrids projects in Developing countries
    a. Remote microgrids
    b. Commercial/ Industrial microgrids

However, it is important to note that since the industry is still evolving, this classification could be fluid in nature. There could easily be development of microgrids in near future which might only broadly be defined within these compartments.

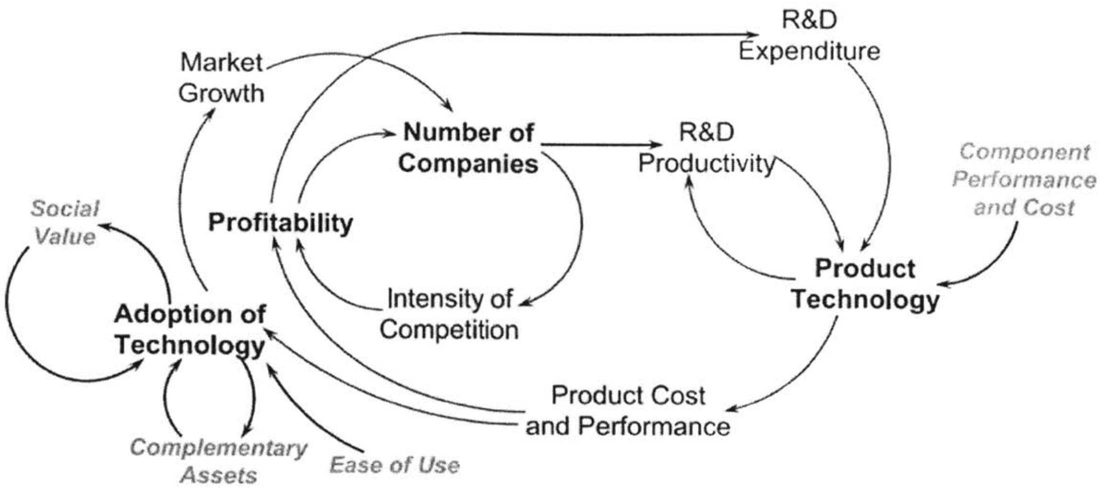
CONCEPTUAL MODEL FOR ANY TECHNOLOGY EVOLUTION

Work by Weil and Utterback[1] formed a conceptual model to analyse fundamental dynamics of innovative industries and modelled the same to run a system dynamics simulation. According to the authors, the work can be extended to a broad range of products and services and the model can be used to explain evolution of most markets. Any market, in its development experiences different dynamics which impact the evolution of the market. A few examples of such dynamics are:

- Technology Evolution
- Emergence of standards and Dominant designs
- Adoption of new technology
- Network effects
- Intensity of competition
- Profitability of companies etc.

In the initial stage, the market remains in a very fluid stage and innovations are at a peak during this stage (as there is no common standard). Later on, a common standard evolves and innovation becomes incremental in nature. As has been discussed by Weil[2] incumbents usually are dismissive of new technologies because the latter does not appear to be a sufficiently large opportunity.

The model as developed by Weil is given below in Figure 1.



Figure

Figure 1. Integrated Conceptual Model, as developed by Weil and Utterback (2005)

The importance of "Lemming effect" is also highlighted in this paper. It is shown that lemming effect works on both supply side (by increasing the rate of entry of firms and thus the technological progress) and on demand side (by increasing willingness to switch). The paper also talks about the role of social factors in adoption of any technology and thus evolution of any market. Intangible factors like timing, brand, trust, sense of urgency etc. are shown to be very important in driving the dynamics of any technology adoption. As described by Sterman[3], bandwagon effects are driven by media coverage and positive word of mouth which create the perception of a hot product. In fact, bandwagon effects, complemented by network effects form reinforcing dynamics of driving adoption.

Microgrids market dynamics can also be studied in a similar way and thus this study tries to map all these dynamics together to come up with a conceptual model for Microgrids market evolution and technology adoption.

MICROGRIDS INDUSTRY

Microgrid projects are increasingly becoming commercial and the market size is now increasing. There are several estimates for the size and growth rate of Microgrid industry available.

According to GlobalData[4], although USA is acknowledged as a leader in global microgrids market but other markets of Europe and Asia are also growing rapidly. The current size (in 2012) of this industry has been estimated at USD 5.3 billion and it is expected to grow by a CAGR of 17.2% to USD 18.9 billion in 2020. Currently USA holds a market share of around 68% in global microgrids market, but going forward Asia Pacific market is expected to grow tremendously. Pike Research (owned by Navigant Research) publishes a Microgrid Deployment tracker regularly and the latest one[5] has identified a total of 3.2 GW of total microgrid capacity throughout the world and recent capacity growth rate has been 22% over last 6 months. According to Navigant, the global size of industry will grow from the current just under USD 10 billion (2013) to USD 40 billion by 2020 (in average scenario)[6]. A cumulative view of different estimates of the microgrids industry is given in Table 1.

A few companies which are pursuing microgrids aggressively are SAIC, GE, Honeywell, Siemens, ABB, SMA International, Pareto Energy, Fumase LLC, Arista Power, Echelon, Younicos, Blue Pillar, Youngblood Capital Group etc.

Research Firm	Year Estimate	Total Installed Capacity (GW)	Market Size (Billion USD)	Market Growth Rate (CAGR)	Region
Reports and Reports[7]	2022	15	-	17 %	Global
Navigant[6]	2020		40	22 %	Global
Zpryme[8]	2020		13.4		Global
GlobalData[4]	2020		18.9	17.2 %	Global

Table 1. Estimates for Microgrids industry growth rate by different sources

It is interesting to note that bigger players like GE, SAIC and Honeywell are involved with military projects while the new entrants like Arista Power and Younicos are focusing more on other markets segments especially off grid stand-alone systems. Also, currently in the early stage of industry evolution, the market opportunity is being pursued by all types of firms – bigger 'traditional' players, new start-ups, system integrators, Venture funds etc.

The current value chain of microgrids industry has the following components: Generation technology, Storage technology, Control systems and System Design and Actual development of projects (EPC). Currently, most of the people are working in the front end of this value chain (Control systems and System Design and EPC) as the other parts are either individually commoditized (solar, wind, natural gas based generation technologies) or have high development costs (storage technologies especially batteries). Going in depth to understand the dynamics of different components of this value chain cannot be carried in the present scope of this study. However, it will be interesting to research where the value currently lies in the value chain and what would be the future scenario. As of now, it seems that value lies in the front part –

- By designing control systems for microgrids: This area has seen the entry of many players - IT firms like IBM[9], Infosys[10], big firms like GE[11], ABB[12] etc. as well as start-ups like Indy Power Systems[13].
- Actual implementation of projects: This area has also seen an entry of several players – Big firms like GE, ABB, Siemens, Lockheed Martin etc., Automation firms like Echelon Corporations as well as Venture Capital firms like Youngblood Capital Group LLC.

Going forward, it would be reasonable to assume that a dominant design for the entire value chain might emerge. This would mean that competition within the industry would be based on cost and benefits which any firm can provide to the demand side. However, as mentioned before, the microgrids industry is still a nascent industry and going forward technology evolution would be dependent on many other factors as well (as we shall see later in this study).

MICROGRIDS CASE STUDIES

There are different objectives behind microgrids concept and projects – Improving reliability of power system, increasing the access of electricity to remote locations, increasing the penetration of renewables, increasing efficiency by cogenerating etc. Navigant has categorized microgrids into the following five categories[14] - Campus, Military, Remote, Community and Commercial & Industrial segments. This study uses a different categorization to map out and analyse the development of projects in different segments:

i. Microgrids projects in Developed country
ii. Microgrids projects in Developing countries

The next section explains various case studies within these two different markets and explains the drivers and challenges for microgrid projects. The following sub segments are covered – University Installations, Military Installations, State/ Community led projects under Developed world market (mostly US) and Remote installations under Developing world market (India, Malaysia, South Africa etc.). Under the developing world market, the study also draws parallel from a similar technology deployment case study of Distributed Solar lighting (particularly in India and Africa).

Microgrid Projects in Developed Countries

Department of Energy (DOE) held a microgrid workshop in 2011 and stated in its mission for the microgrid initiative "To develop commercial scale microgrid systems (capacity <10 MW) capable of reducing outage time of required loads by >98%, at a cost comparable to non-integrated baseline solutions (uninterrupted power supply [UPS] plus diesel genset), while reducing emissions by >20% and improving system energy efficiencies by >20%, by 2020"[15]. And so DOE has played a significant role in supporting institutions to pursue research and carry out implementations in microgrid area. Galvin Electricity Initiative provides a list of microgrids projects across USA[16]. The list is given in Appendix A.

a. University Campus Microgrids

There seems to be numerous motivations for the microgrid projects at universities. Howard University has recently entered into a joint venture with Pareto Energy and is developing a microgrid for its campus. The Centre for Energy Systems and Control at the university will play an instrumental role in building of the microgrid. The motivations seem to be manifold – the broader aim for the project is to decrease dependence on utility for power requirements by taking the campus 'off-grid'; in short term the project can also serve as a good base for pursuing practical research in the field[17]. University of California at San Diego is already operating its own microgrid combining gas turbines, steam turbine, solar cell installation and some storage[18]. UCSD is also supported strongly by the California Energy Commission (CEC)[19]. In an interesting interview by the Rocky Mountain Institute with UCSD executives[20], it is highlighted how CEC sees UCSD as a laboratory for pursuing and testing new ideas and technologies before planning to roll the same out at a state level. This has significant implications for innovation ecosystem. There are increased efforts to bring new cleaner technologies on to microgrid platform (like Electric Vehicles integration), to improve the predictability and reliability of the system by developing peripheral technologies (like cloud tracking system for predicting solar radiation ahead of time) and testing of policies and standards, thereby reducing large scale deployment risk.

Galvin Center for Electricity Innovation at Illinois Institute of Technology conducts research aimed at 100% reliable power and is pushing frontiers in electricity generation, transmission, distribution and usage. A recent report by Illinois Institute of Technology[21] says, "The IIT Perfect Power project serves as a living laboratory for researchers, corporations, innovators, and entrepreneurs to use IIT's strong smart grid and microgrid infrastructure to speed the development of new innovation in the generation, transmission, distribution, consumption and storage of electricity. The Perfect Power system allows innovators to "plug-in" to IIT's functioning smart grid to use it as a test bed for new technology research and smart grid systems evaluation and a demonstration centre for new technology products. Access to this real world "sandbox" provides technology developers with an unrivalled ability to pursue advances in the smart grid more efficiently, effectively, and collaboratively."

A brief look at system's view (as given in Figure2.) can explain the rapid growth of such projects (especially in US). For the demonstration projects especially in universities, there seems to be two reinforcing loops working to push the evolution of this industry.

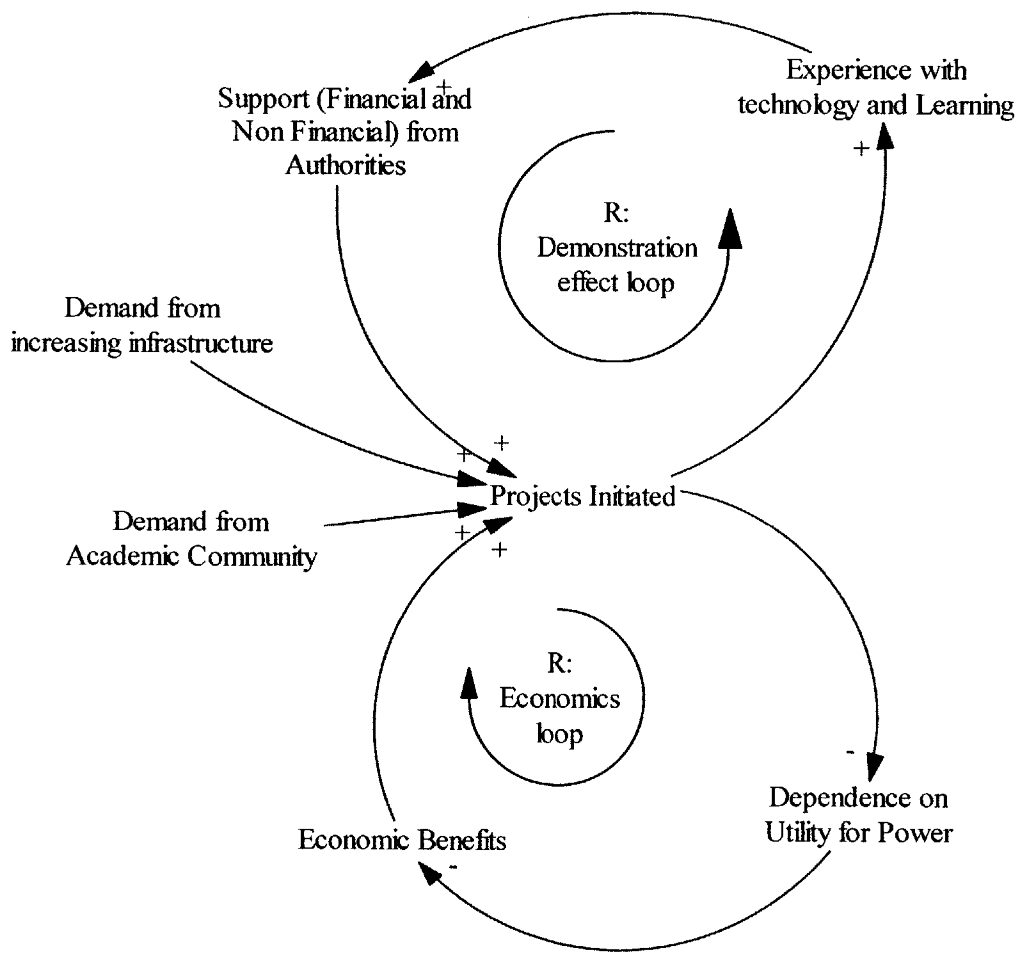


Figure 2. System's view of Campus Microgrid projects

The Demonstration effect loop is fuelled by the support of authorities and regulatory bodies. These bodies (like CEC) want to gain experience in the microgrids technology before pushing a mass adoption for the technology; And using university projects as a 'test bed' for this new technology makes perfect sense to gain experience with the technology. On the other hand, with microgrids gaining popularity in academic world, more academicians (professors and students alike) are motivated to work on this technology. So this makes environment conducive for adoption of microgrids technology. As for the administration of the university, realizing economic benefits by decreasing dependence on local utilities increases their motivation to support the project.

However, this scenario is limited to achieve only a particular scale (size/ demand of university), by the complexity which can be handled by an academic institution and is hinged critically on the support of government or regulatory bodies.

b. Military Installations

As observed by Phil Carson, Editor-in-Chief, Intelligent Utility Daily, adoption of microgrids in military seems to be driven by increasing the energy security for military installations[22,23]. Pike Research (Navigant) reported on military microgrids in September 2011, "Many Army, Navy, Air Force, and other related bases and offices already have vintage microgrids in place. What is new is that these facilities are looking to envelop entire bases with microgrids and integrate renewable distributed energy generation (RDEG) on-site."[24] In a more recent report, Pike identified two dozen military facilities in the U.S. that are involved in smart microgrid implementations[25]. According to the same report, the total capacity of Department of Defense (DoD) microgrids will surpass 600 megawatts (MW) by 2018, a 50 percent increase over 2012.

Lincoln laboratories (MIT) published a study on current microgrids work and projects in DoD installations[26] in 2012. The report provides a good summary about different projects under implementation at different Military bases (like Ft. Bliss, Twentynine Palms and the SPIDERS microgrids at Ft. Carson etc.). A few important insights from the report are:

- DoD microgrids installations have two most important factors to evaluate their performance - the degree of integration of the microgrid with the larger central grid and the technical complexity of the microgrid, particularly its choice of generation resources.
- Most of the microgrids installations at Military sites are being carried out by bigger companies like Honeywell, GE, Siemens, Lockheed Martin etc.
- The integration of different renewable generation technologies and distributed storage would require a very high level of sophistication.

However, DoD is trying to explore such complexity in future - for e.g. testing plug-in EVs on DoD Installations (at Air Force Base Los Angeles). This work would entail high level of technical complexity and would demonstrate ancillary service market for microgrids. A roadmap for the microgrids technology development according to Military's vision is shown in Figure 3.

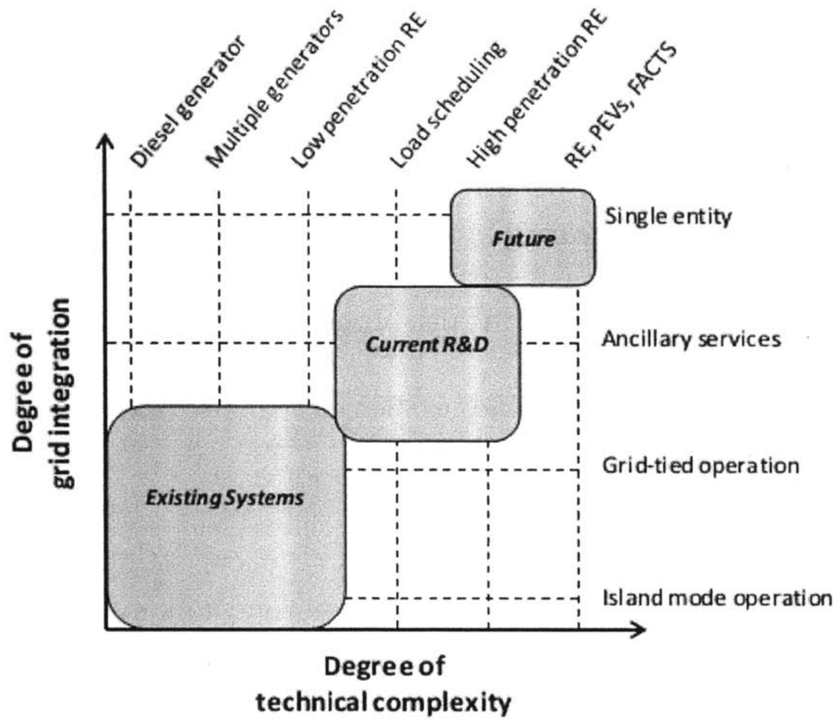


Figure 3. Roadmap for Microgrids technology deployment, as published by Lincoln Laboratories[26]

c. Community/Cooperatives Installations:

State governments and local bodies are also providing impetus to the adoption of microgrids in smaller communities/cooperatives. Under the New Mexico Green Grid

(NMGG) initiative which was initiated in August 2009, New Mexico has developed a few microgrid projects and there are several upcoming ones[27]. These projects are a result of collaboration between cooperative utilities, investors (Toshiba, Kyocera from Japan in this case), universities and research centres alike. State of Connecticut passed the Public Act 12-148 which requires Department of Energy and Environment Protection (DEEP) to establish a microgrid grant and loan pilot program to support local distributed energy generation for critical facilities[28]. Later in this study, drivers for such programs shall be discussed. In 2008, state of Hawaii and US Department of Energy launched Hawaii Clean Energy Initiative (HCEI). One of the working groups within HCEI is working on increasing the use of renewable energy technologies In Hawaii by a) integrating more renewables to the national grid and b) upgrading grid infrastructure[29].

One common observation across most of these state initiatives/ projects has been that all of them have been triggered from extreme weather events. New Mexico has been facing rolling blackouts because of extreme cold which increases the heating load on supply side. Hawaii and Connecticut have seen strong hurricanes which damaged the infrastructure extensively and exposed the lack of resiliency in the current grid infrastructure. An exception to this scenario is the state of California, which is moving aggressively with its renewable energy deployment. The state policies have forced utilities like Southern California Edison and San Diego Gas and Electric to look into developing microgrids projects.

Microgrids work outside US

Japan has been advancing microgrids concept from quite early on and is a world leader in demonstration projects. New Energy and Technology Development Organization (NEDO) is the research funding and management agency of the Ministry of Economy, Trade and Industry. NEDO started three microgrid demonstration projects in 2003 – Aomori, Aichi and Kyoto projects. These projects focused on integration of renewable energy sources into a local distribution network. The details of these projects have been covered in an overview paper by Nikos Hatziargyriou et. al.[30] The paper also mentions about how these projects have been mostly oriented towards proving the technical feasibility of microgrids with a focus on integration of renewable technologies onto a common network to deliver several levels of Power quality and reliability.

This could also be attributed to NEDO's dual goal of addressing global energy and environmental problems and enhancing competitiveness of Japanese technologies on world stage. The NEDO 2011 annual report[31] highlights NEDO's active role in pursuing several partnerships around the world to increase usage of Japanese technology around the world. Within power grids sector, NEDO is collaborating with US over projects in New Mexico and Hawaii, in Europe over projects in Lyon, France and Malaga, Spain. The latest project development activity has been highlighted in the 2012-13 profile report for NEDO[32].

Sendai Microgrid project

The Sendai Microgrid was built in 2004 by NEDO for a demonstration project called "Experimental Study of Multi Power Quality Supply System (MPQSS)." The demonstration project was conducted by NTT Facilities, Inc. (NTT-F). The microgrid supplied power to different facilities at the Tohoku Fukushi University as well as to a few facilities in the city. After the study was completed in 2008, the microgrid system continued in operation under the management of NTT-F. On March 11, 2011, the devastating Great East Japan Earthquake hit the Tohoku district which caused catastrophic damage on district's energy systems. Despite the extreme devastation and blackout in the district, the microgrid continued its operations to provide heat and electricity to users. The microgrid was designed to provide electricity which was categorized into five classes according to the level of power quality[33]. In case of an outage, the microgrid control system makes decision based on the criticality of the demand. For example, hospitals with Intensive Care Units, MRI facilties would be classified as critical demands.

Microgrids in Developing countries

Most of the developing countries suffer from poor quality and reliability of power. Usually energy cost has been subsidized by the governments because of several motivations (political, developmental, etc.) and this has resulted in a lag for power infrastructure advancement in most of the developing countries in Asia and Africa. This has resulted in development of several projects aimed at improving the access of electricity to people who are still living in dark as well as to improve the reliability of power to people who suffer from blackouts/brownouts. It is interesting to note parallels of microgrid projects with solar lighting projects as covered later in this section.

Remote microgrids projects

a. Bihar (India) Case study

Greenpeace initiated a renewable energy project in the state of Bihar in India, where majority of people lack access to electricity. The mission of Greenpeace reads, "Greenpeace is the leading independent campaigning organization that uses peaceful protest and creative communication to expose global environmental problems and to promote solutions that are essential to a green and peaceful future."[34] The initiative focused on building 'bottom up' energy microgrid clusters so that no village is left without electricity. The case study highlights the following steps to implement a microgrid:

Step 1: Renewable resource assessment – The local geography is mapped out to find out what are the renewable resources are feasible to deploy.

Step 2: Demand Projections – A bottom up demand profile is created for a village by including household load as well as non-household loads like schools, public health stations and public lighting etc.

Step 3: Define optimal generation mix – HOMER[35] software was used to calculate the optimal generation capacities, given the constraints. An important consideration during determining the design was to keep the system modular and use standard components so that scalability is easier in future.

Step 4: Network design – PowerFactory[36] software was used to model the physical network system which would be required for the optimal generation system.

Step 5: Control system considerations – Control system is essential in operation of these integrated technologies as well as for implementation of islanding strategies in future. However, such a control system is quite complex to develop and it has been proposed to use a manual switching mechanism between the 'island' mode and 'connected to the central grid' mode

The first priority as given in the report was to extend lighting hours which can increase productivity hours. The case study also talks about how the expansion of such a system could happen. An example for constraints in the design of the system can be as follows: Biomass systems based on rice husk are available in unit sizes of 32 kW and 52 kW, while hydro power might not profitable for units sizes below 100 kW. On the other hand, solar PV systems could be only limited to roof-top systems, as it should not compete for land space with agricultural production. Therefore the unit sizes are much smaller, in the range of 100-1,000 W.

Greenpeace hopes that this pilot case study in Bihar would serve as a starting point for many other microgrids projects implementations in India to increase access of electricity to people in India.

b. Batu Laut (Malaysia) Case Study

Optimal Power Solutions (OPS), an Australian company, is among the frontrunners in implementation of 'microgrids like systems'. OPS were featured in MIT Technology Review in June 2012[37]. The managing director of the firm said, "Many governments are starting to find that it's cheaper to install solar panels and batteries than it is to connect villages to conventional power plants or install diesel generators. In some areas, diesel power can cost two to three times as much in the city because of transportation costs and problems with theft, he says. That means batteries that cost 55 cents per kilowatt-hour of storage capacity can still undercut diesel power by 60 percent." OPS has since then found many applications for its Solar powered microgrids, as found on the company blog[38].

The Batu Laut case study[39] sheds much insight on the ecosystem development of Microgrids as a technology. Microgrid, it seems, is quite relevant as a technology for remote locations and thus was adopted for the village of Tanjung Batu. This microgrid has been operating for two years now and provides electricity access to around 200 people. Generation technologies used on this microgrid are diesel generators and solar panels. Generation is complemented by storage - lead acid batteries.

A system's view has been developed for a remote location microgrid implementation (as in Batu Laut and Bihar) as seen in Figure 4. Electricity supply results in many dynamics as it triggers demand side by supporting more and more electrical appliances. It also increases productivity and thus results in growth of industries and infrastructure (manufacturing, carpentry, hospitals etc.). And thus as demand increases, investment flows in and the industry grows to expand supply by making more facilities available.

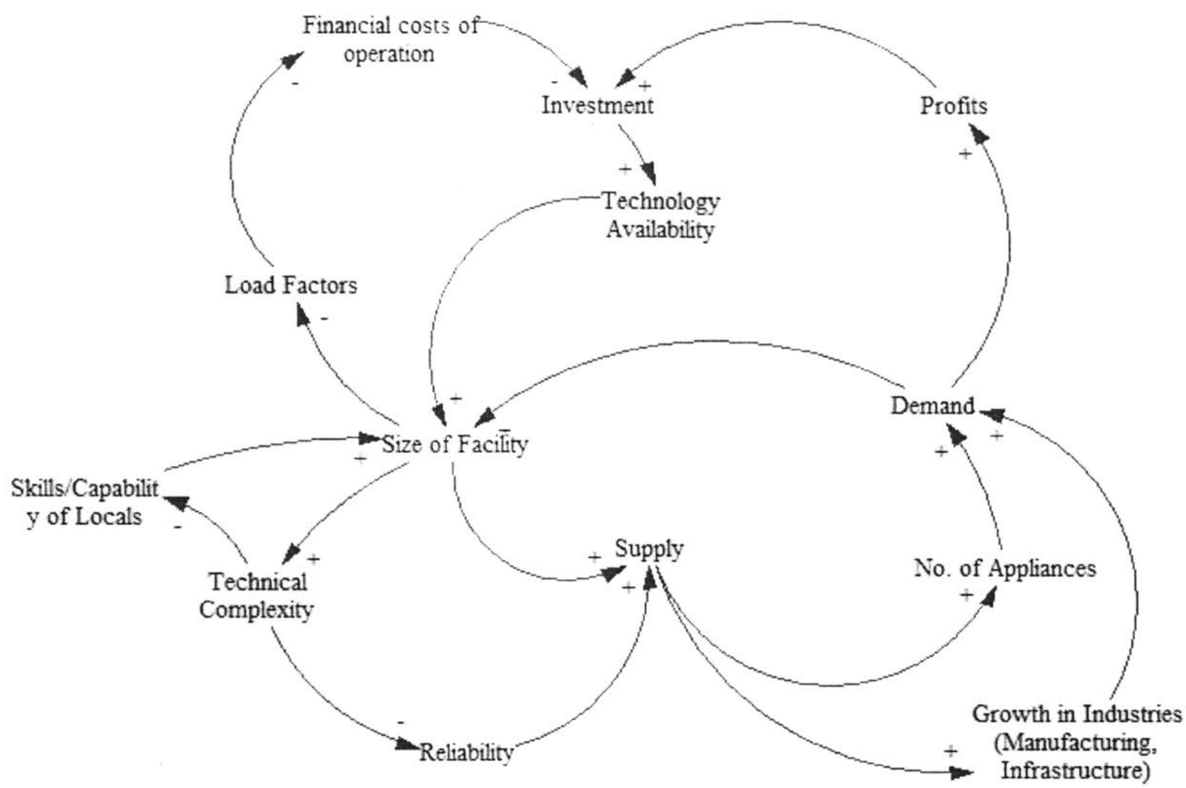


Figure 4. A system's view of Remote microgrid project (example Batu Laut)

However, in case the demand does not ramp up (because of several other factors like limited buying power of customers to buy electrical appliances, accessibility to infrastructure, etc.), load factors remain low and this results in higher financial costs of operation for project owners. As demand increases size of facility (microgrid) has to be increased, which might result in several technical complexities like integration, maintenance, monitoring etc. This causes system reliability to go down and thus has a direct effect on customer behaviour (especially towards pricing of electricity).

Overall, it seems that scalability of such remote projects might lead to several problems and thus it limits the size and scope of microgrids projects (or investment).

c. Distributed Solar Lighting Case studies

Several projects have come up (especially in India and Africa) to provide decentralized solar lighting solutions to people who have no access to lighting (electricity). A few examples of firms/start-ups/ non/for-profit social organizations involved in such efforts are Selco, d.light, M-KOPA etc. The distributed solar lighting 'technology experience' can be viewed using a 2X2 framework as shown in Figure 5.

There is much investment risk associated with cell 1, when both ownership and operations are controlled by a single firm. If an 'outsider' is trying to enter a local market without involving the local community, the success/ adoption of such a technology becomes difficult because of lack of trust in the community for an outsider. On the other hand, there is technological risk associated with cell 4. There are no controls in such a situation and the technology is bound to get 'fiddled with' which might or might not increase the overall efficiency of the technology.

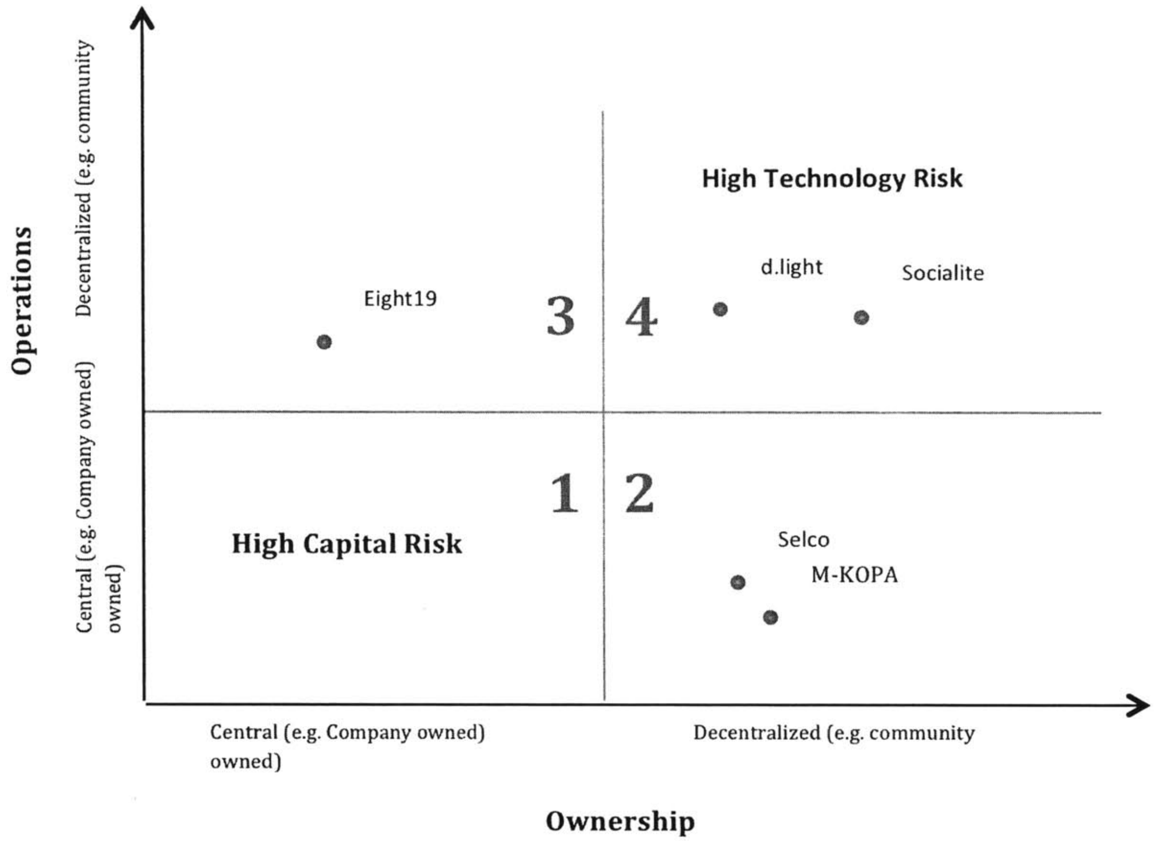


Figure 5. Ownership Vs Operations Framework to map business risk

An example of this is given by Prof. Cumberbatch[40], when he speaks about the solar lantern which he left in Africa for a period of one year. His story about how local people almost ran down the battery of the lantern by connecting the same with radio, mobile phones etc. In hindsight, this looks normal as local people would always try to solve their own pain points with whatever technology is available and in the process experiment, test and modify the original technology. However, such modifications pose major risks to the operations of technology. The only way a technology could survive in this cell would be if it has been developed in the community itself. And this has been the case with Socialite[41]. The Socialite lantern is developed with local resources (empty juice and paint containers) and only the electrical circuitry is developed outside of the local ecosystem.

Because of such high risks associated with cells 1 and 4, any business plan which exists in the domain of cell 2 or 3, might have a higher chance of success. There are indications that newer business models are aiming to operate in these two cells as they either retain complete ownership or retain ownership till the investment has been paid back. For example, M-KOPA, eight19 are amongst many start-ups which are trying to leverage the penetration of mobiles in Africa to help spread the business risk. The ownership is transferred when the investment has been paid back in smaller increments over a period of time by the end user. This completely shifts the capital risk and technology risk away from the start-up. From the end user's perspective, this model gives flexibility for payments and usage while providing with an option to own the technology after some time.

A few major firms which are operating in this industry have been mapped on the above matrix. This gives us a good sense of indication about where the industry is moving. A few case studies[42] also indicate social factors play an important role in evolution of technology when the product gets related to social status in the community. These make features and design of product (or technology) even more important. It would be interesting to look into all these factors - design of product, price of product, functionality of product, social value etc. over time to map how this industry has evolved. However, such a study cannot be covered in the scope of current work.

Overall, from these case studies, it seems like the industry is moving forward with business models which lie in Cell 2 or 3 of the above framework. Following are the hypotheses (which can be applied to a technology like microgrid) from these case studies:

- Increasingly, entrepreneurs would try to create business models which share risk amongst different stakeholders (government, participating community, end users, current infrastructure owners etc.)
- As a technology evolves over time, the same product would give additional features (e.g. mobile charging with Solar lights). These additional functionalities would be contextual. For e.g. in an area where people have to walk for 5 Km to charge their phones, it is attractive to have an additional functionality of mobile charging in the product. In general, increasingly entrepreneurs are looking at technologies as platforms to provide additional value services to users. It is useful to think of technology (already deployed or getting deployed) as fixed costs for any business; the more an investor is able to 'turn it over' or use it in

different contexts to provide additional services, the better business model would be.

- Social / Local factors would continue to spark innovation in technology products. For firms entering the market in a relatively 'mature' phase would be able to establish themselves only be distinguishing themselves from other based on social acceptance of their product.

DYNAMICS FOR MICROGRIDS TECHNOLOGY EVOLUTION

Considering all case studies together, it can be deducted that evolution of Microgrids technology is affected by four major factors – Social, Market, Technical and Regulatory. Each of these factors has manifested itself in the development of Microgrids industry in different segments around the world. Most of the information for these factors has been extracted from the case studies presented above.

Social Factors

1. **Huge increase in demand of electricity:** The village did not have any access to electricity before the microgrid. It seems now that there has been a significant rise in penetration of energy hungry appliances like TV, Freezers, Irons, Rice cookers etc. We can speculate that before access to electricity, these 'new' demand generating activities (like ironing, rice cooking, TV viewing) either did not exist or were carried out inefficiently (e.g. rice cooking using wood as a fuel for stoves). However, access to electricity provided villagers with a choice to switch to more efficient ways (using electricity to cook rice could have a big opportunity cost advantage attached from a villager's perspective) or adopt new useful activities (which might help them in economic terms as well like using machinery to increase productivity). The article talks about a similar story – "On a Saturday afternoon this summer, kids roamed around with cool wedges of

watermelon they'd bought from Tenggiri Bawal, the owner of a tiny store located off one of the most unstable parts of the elevated wooden walkways that link the houses. Three days before, she'd taken delivery of a refrigerator, where she now keeps watermelon, sodas, and other goods. Bawal smiled as the children clustered outside her store and said, in her limited English, "Business is good."".

2. **Productivity Increase:** As has been discussed in the paper by Kirubi, et. al.[43], access to electricity increased productivity and income levels, particularly in small and micro enterprises and agricultural activities in Kenya. Parallels can be easily drawn between the Kenya case and other similar implementations like Batu Laut, although the exact increase in productivity and income levels could vary depending on the village location, available resources, available skills levels and other factors. However, the essence of these implementations is that access to electricity increases the operational efficiency, increases the capital efficiency and increases the margin earned. This is shown in the same paper by Kirubi, et. al. in Table 2A which shows the impact in three dimensions - Increase in productivity per artisan, Price reduction per unit and Increase in gross revenue per day.
3. **Academic Curiosity:** As has been discussed before, academic curiosity to understand the potential of microgrids is also fuelling growth of microgrids, especially in the university campuses.

4. **Extreme Weather events** – Japan and US have seen some very extreme weather events recently (Hurricanes, Storms and earthquakes). This has sparked a support for microgrid projects especially in places like Connecticut which saw widespread power outages[44].
5. **Bandwagon Effects:** There is development of 'cross-industry' bandwagon effect, as microgrid as a concept is becoming popular for different reasons and purposes. Military seems to be adopting it increasingly to ensure energy security to their installations. On the other hand, states like California, Connecticut and Colorado are taking steps either to go green or to increase reliability and resilience of power grids. In developing worlds, microgrids are gaining popularity because of poor reliability of traditional power grids given the surge in demand. This has opened up new market segments like mining, commercial property, residential localities etc. in different parts of the world.
6. **Awareness:** Tony Coiro[45] points out in his interview that awareness about microgrids is also a very important factor for evolution of technology. As more people are finding out about the microgrids concept, they are trying to customize the concept according to their own needs and resources and deploying microgrid technology. Reja Amatya[46] also points out that technology awareness is key for adoption. She refers to her experience in rural India and says that people are

aware about diesel generators running to provide electricity but are unaware about newer cleaner technologies like Solar etc.

Market Factors

1. **Business Model Innovations:** As Peter[47] shared with me in his interview, the increased 'activity' in microgrid market has produced a 'lemming effect' when many entrepreneurs, established businesses and institutions have jumped onto the ship and this is giving rise to very interesting business model dynamics. For example, take the example of business transactions at the ground level. Alzola et.al notes that there are problems in implementation of tarification plans. In developing countries context, metering devices are costly and fee collection systems are hard to implement. Recently, according to Peter, entrepreneurs have stepped in and are tackling this issue by making power 'prepaid'[48]. M-Kopa is another start-up which is using mobile phones for collection of money / extension of credit. After the payment of total cost of the infrastructure, the ownership of the system gets transferred to the end user. Another interesting aspect is the actual ownership of the microgrid. According to Peter, several stakeholders are trying to diversify the risk by breaking up the value chain into several components. For e.g. the financing of the infrastructure could be carried out by banks, while the infrastructure itself would be owned by some bigger player and smaller players can piggy back the infrastructure to operate their own

Microgrid technologies. Development of such an ecosystem would be very interesting as it would entail new opportunities as well as complexities.

2. **Substitutes:** Currently, diesel/other non-renewable fuel costs are amongst the main drivers for the microgrids market. On the other hand, as other renewable technologies like solar, wind etc. are intermittent, they face bigger challenges in wide scale deployment especially at smaller and distributed level. Till now, energy cost, especially in developing countries, has been subsidized[49]. But as this is increasing debt on the government, the cost is getting transferred to the end user. So increasingly, microgrids are becoming attractive options for bigger end users.
3. **Financial Transactions:** An increase in financial activity is also indicative of how the industry is evolving. We have the bigger players – ABB, Siemens, GE etc. who have traditionally help these markets but now the new start-ups are working on this concept. According to Peter, the 'biggies' are trying to retrofit their existing control systems to make the same suitable for microgrids. However, new players are building such control systems from scratch and thus are coming up with more efficient and effective control systems. Such a situation would mean that the bigger players would start acquiring smaller companies to acquire the knowledge and experience of smaller players and leverage on their scale to expand their market share. We can see proof of this happening already –

ABB acquired PowerCorp of Australia in 2011 end to expand its reach. ABB's CEO Joe Hogan said that renewables were one area where ABB saw a lot of room for expansion and growth[50].

4. **Pricing:** Actual pricing of microgrid and generated electricity, both are important factors which drive adoption for this technology. If governments believe that implementation of a microgrid would be cheaper than installing transmission lines, they would have an incentive to invest in microgrids. On the other hand, if and only if consumers of electricity believe that that the pricing of electricity is sustainable (by also incorporating their opportunity cost), would they start using electricity. This has major implications for the type of customers. For e.g., paying for electricity even at a 5 times the 'normal rate' might make sense for villagers who otherwise have a big opportunity cost of huge time spent on the same activity. But it might not make any sense for an industry to start its operations in remote locations given the higher cost of electricity would just make their COGS go higher. However, this cost would make sense if there is some additional advantage to having a manufacturing facility in remote location (for e.g. cheaper labor costs).
5. **Operational Complexity**: Alzola et.al.[51] [52] analysed microgrids projects in context of rural electrification in Senegal. In their papers, they note that renewable energy projects like PV systems are already in place in Senegal. However, they

recognize several constraints which have limited microgrids from getting adopted at a large scale. Although a lot of problems are related to administrative procedures and regulatory processes, a major set of problems also come in the form of operational constraints. This includes lack of maintenance systems, spare parts availability, absence of monitoring systems for project assessment and lack of training and local knowledge/expertise. There have been evidences about the problems which any microgrid implementation entails, especially maintenance issues. Peter hypothesises that markets could see entrepreneurs jumping in to solve the running or maintenance issues. This again goes back to the point of ownership vs operational structure of any microgrid.

Apart from the operational complexities for the microgrid, there are also complexities with running generation units. For e.g. because of the dispersed nature of waste/ biomass, especially in rural areas, it is extremely hard to run a generation unit based on biomass/ waste mass (like biomass gasifiers etc.).

Regulatory factors

1. **Energy Security**: As has been discussed before, extreme weather events have increased the number of favourable policies and regulations for technologies like microgrids. For example, as discussed before, the state of Connecticut recently passed Public Act 12-148, An Act Enhancing Emergency Preparedness and Response[53] which not only requires utilities, telecommunication companies Voice

over Internet Protocol Service providers to submit emergency plans for restoring service but also mandates creation of a microgrid program to be administered by the Department of Energy and Environmental Protection (DEEP). Latest articles show how this policy has given a boost to development of microgrid projects[54] by enhancing local entrepreneurship and increasing availability of finance.

2. **Utility Support**: According to Peter, utilities have been usually against microgrids concept. An integration of distributed sources of generation and storage would mean huge technical challenges for utilities as such a scenario could potentially bring the reliability of the entire system down. However, recently utilities have opened up and are looking into microgrids as solutions for meeting their own regulatory mandates. For e.g. a recent article by Navigant[55] talks about the state of California and how two utilities – Southern California Edison and San Diego Gas and Electric have a positive attitude towards microgrids since they think microgrids could help them on the following aspects:
    - A state Renewable Portfolio Standard (RPS) that requires 33% of the state's total electricity comes from large-scale renewable resources by 2020
    - Regulations forcing the retirement of "once through cooling" fossil plants that pepper California's 840-mile-long coast and that could help integrate variable renewables

- The nation's highest per capita deployment of distributed solar photovoltaic (PV) systems (in San Diego)

3. **Standards:** Earlier, all the distributed generators, connected to grid, needed to be shut off when there was a blackout because it could potentially cause damage to the utility infrastructure. However, in 2011, IEEE came up with the standard 1547.4 which specifies how such distributed generators could be safely 'islanded' in case there is a blackout. This standard has drastically increased the overall usefulness of microgrid. Now institutes can not only save money by operating their own generation but also have the energy reliability for their critical facilities (for e.g. hospitals running MRI machines etc. or universities running research facilities etc.). This opens up new opportunities for these institutes and thus the adoption of microgrids is bound to get a boost with such supporting standards.

Technological Factors

1. **Technology Availability:** With a sharp decline in cost of renewable technologies especially solar, systems like microgrids are becoming easier to finance and thus more available. Recent talks have been to include several other solutions within microgrid concept. For example, envisioning microgrids as a combined solution for electricity, water treatment, communications etc. Diversification of generation technologies would presumably solve intermittency problems and make the operations of microgrid more feasible. Similarly a diversification of end use

could possibly lower the overall cost of operation. Storage has remained the Holy Grail to solve the energy problem. Tony Coiro mentions about the technical challenges associated with batteries. Battery life (and thus cost) depends on several factors – charge rate, discharge rate, timing of charging, duration of charging etc. Because of such variability, it is really hard to design an 'optimal' system. The bidirectional inverter is another enabling technology which has made the adoption of microgrids easier and faster.

2. **Feasibility:** As feasibility for any technology depends on several factors like local resources, geographical considerations, load profiles, cost of production etc., there shall be cases when one technology will dominate the other one. In a way the complexity of the control system depends on the load profile which the microgrid is catering to. For example, initially in rural villages, a temporary 'break' in electricity supply might not cause major disruption in activities of people. However, with time, as people become more 'dependent' on electricity, even the smallest disruption in electricity could lead to significant losses (this could involve people using electricity for more critical jobs in industry, hospital, administration buildings etc.). Hence, the control system will have to be designed accordingly.

Factors evolving from one domain to other

It is interesting to note the transition of a few factors from one domain to other. One possible hypothesis is that industry dynamics have strong influences on these factors and these factors evolve from one domain to other; And this would continue to happen (and evolve) as industry moves forward.

Availability of Financing: Availability of financing started out as a market factor which limited the adoption of microgrids technology. However, with extreme weather events happening across the world, local electricity disruptions resulting in big welfare losses and the world leaders moving to provide more access to people in remote areas, the availability of financing has evolved from being a pure market factor to a combination of 'market and regulatory' factor where governments or regulatory authorities are trying to increase the availability of financing. Also, the allocation of capital – amount and speed gets influenced by social factors. An example is the recent string of events in Connecticut (CT)[56]. After the state's experiences with hurricanes Irene and Sandy, the state government launched the Connecticut Microgrid Grant and Loan Pilot Program in July 2012. The state is providing a total funding of around $45 million and has received a total of 36 proposals. As of now, 27 proposals have advanced to the next stage and include a variety of microgrids – for police stations, Schools, few stores etc.

Energy Security: In the beginning, microgrids were seen as a solution to attain energy security for military bases making them less vulnerable to local grid disruptions and fuel supply risks in case of diesel generators. However, the same notion of energy security is getting adopted by other institutions like universities, large commercial users etc. And hence this dynamic has shifted from a regulatory domain (military) to market domain.

Technology Development: Historically, Japan has been pushing the technology frontier in microgrids sector. The Power Quality and Reliability (PQR) levels in Japan are exceptionally high and so primary motivations for pursuing research in microgrids' technology and associated control systems have come from maintaining this exceptional PQR in Japan. This Research and Development triggered several demonstration projects but after the earthquake of 2011, these demonstration projects moved from technical domain to market and regulatory domain owing to a big success in showing resilience (Sendai Microgrid, as discussed before).

CONCEPTUAL MODEL FOR MICROGRIDS

Building an understanding further on the factors identified in earlier section, a conceptual model can map these different factors together to explain the evolution of Microgrids technology/market. As explained before, the motivation for carrying out such a conceptual modelling is to try and get a systems view of industry dynamics and how each factor is playing a role in the industry evolution. Ultimately, it is hoped that this conceptual model can be used in system dynamics modelling for predicting the future growth of the microgrids industry and come up with scenarios based on different input levels for different factors (within market, technical, social and regulatory).

In this study, in different contexts, there are different factors influencing the technology adoption. But we can generalise the conceptual model as shown in Figure 6 to map the factors which influence the industry progression.

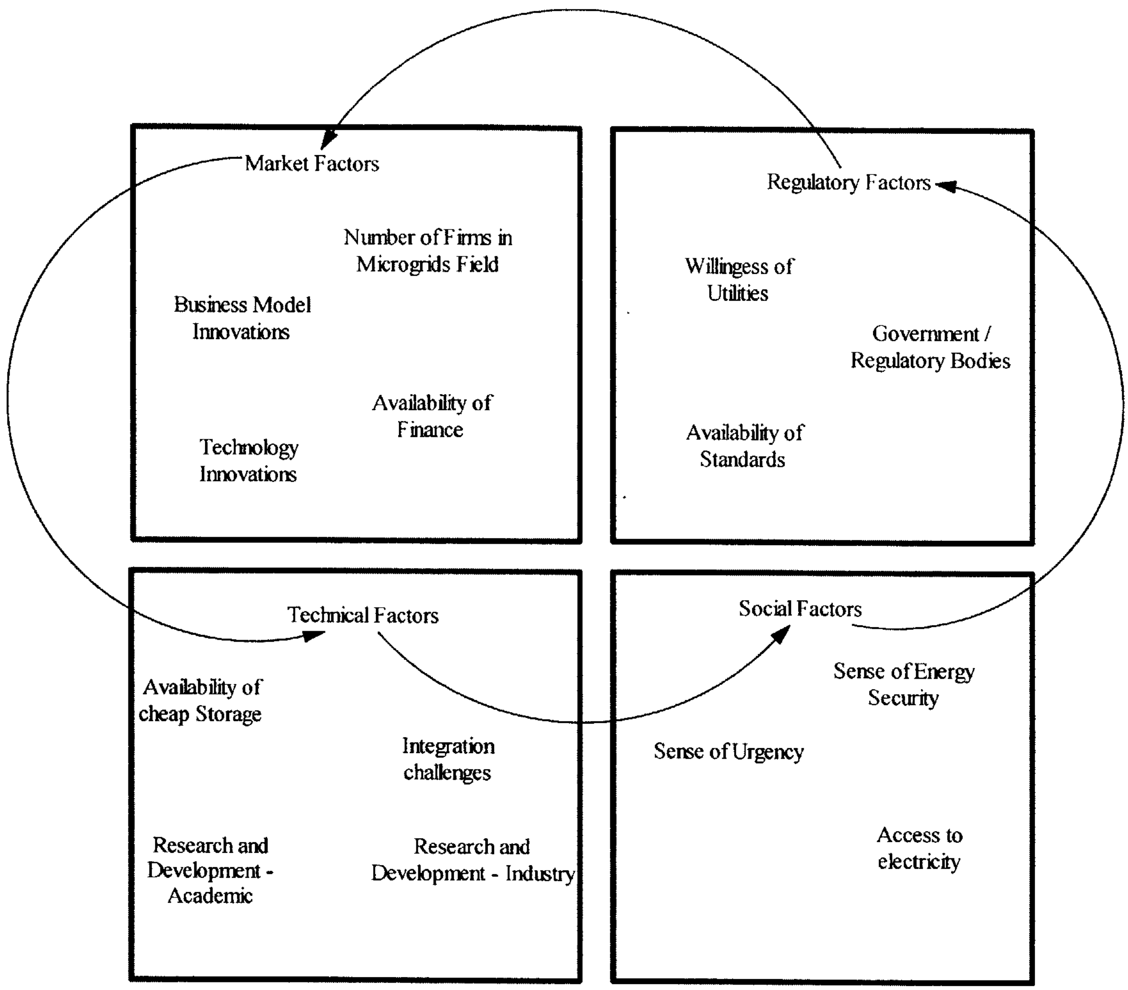


Figure 6. Conceptual Model for Microgrids Industry evolution

Based on the same classification of microgrids which was presented earlier, an example has been elaborated below that substantiates the use of conceptual model:

Scenario Analysis - 'Developed World'

The trigger for microgrids in the developed world (US, Tokyo etc.) has really been the social factors relating to energy security. This social factor has played out each segment – Military, university campuses as well as local communities. Recent extreme events have fuelled this fire and thus the microgrids industry is bound to grow at exceptional rate. First lecture in System Dynamics tell us that any system experiencing huge growth rates must have at least one reinforcing loop within. And this is exactly what the conceptual model illustrates in Figure 7.

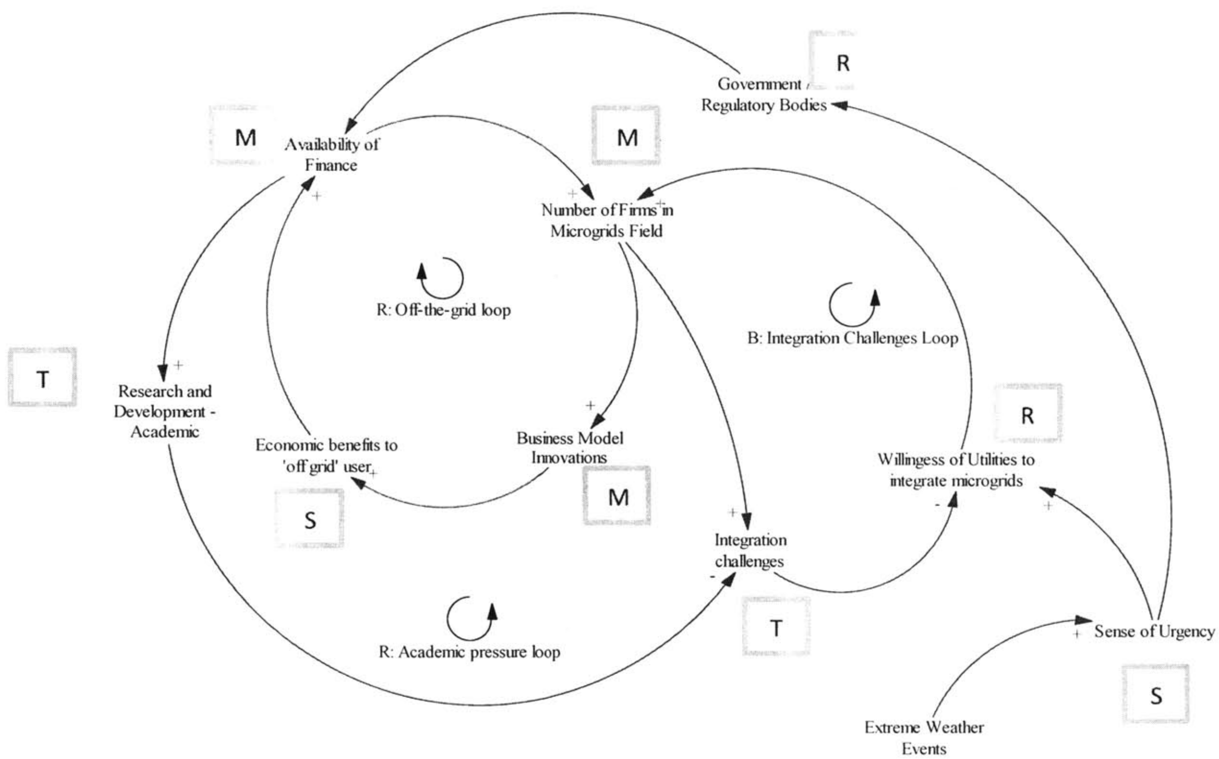


Figure 7. Developed World Model – Scenario Development

There are actually two reinforcing loops – 'Academic pressure' loop and 'Off-the-grid' loop. Each factor has been marked as M/S/T/R for Market, Social, Technical and Regulatory respectively.

We find that the Social (and consequently Regulatory) factors has triggered development of this industry. When regulators and/or government recognize that there is a sense of urgency, they make financing available for demonstration projects and research and development. We have seen this happening in California, Connecticut, Miami, Japan and New Mexico. Availability of finance attracts new players – investors, established businesses, project developers, etc. into the market and this solves market challenges around operations, payment systems, etc. When a microgrid is up and running, local residents benefit from increased reliability and resiliency, decreased energy bills, etc. (as we saw in the case of university grids in California). And so there is a willing buyer and willing seller scenario created which drives the reinforcing loop 'Off-the-Grid'.

Availability of finance also supports research and development (especially in the academic institutions) which solves technical challenges like integration problems, etc. This increases the willingness of utilities to 'open up' their system for microgrids technology. This further encourages private investors, businesses and project developers to come up with new microgrids projects, forming another reinforcing loop – 'Academic pressure' loop.

However, as the number of firms increase in the ecosystem, the integration challenges (or technical complexities) also go up because of different architectures/control systems used and different technologies used. This will reduce the willingness of utilities to allow further integration of microgrids in their system and thus a balancing loop – 'integration challenges' loop is formed.

From the conceptual model for the developed world, two future scenarios could result for the microgrids technology and industry:

Scenario A - Microgrids spread inside and integrated with the central grids:

One of the scenarios could have microgrids as an integral part of the existing infrastructure. This would mean distributed microgrids within the existing network of electricity architecture. As Tony Coiro envisions, microgrids would make the grid infrastructure a 'free market' where anyone can come up with their own generation or storage units and connect the same to the larger grid. The network would use the energy (or store the energy) as efficiently (or reliably) as possible. Tony believes microgrids would have a big role in transitioning the traditional grids into 'Smart Grids' as such a distributed network based 'electricity system' would mean load variances to be handled locally, lesser line losses and overall higher reliability.

This scenario is possible in developed world only as the existing systems have also been designed for high reliability. The conceptual model shows us that although social (and regulatory) factors trigger the adoption of microgrids technology, it is willingness of utilities to determine if microgrids would be integrated in the existing system. As Peter explains in an interview, utilities have just started to change their attitude towards microgrids. And it would depend on the advancement of technical factors like research and development, standards etc. if utilities would face integration and other technical problems while connecting microgrids on to their own network.

Basically, if and only if the 'Academic pressure' loop could overpower the Integration Challenges loop, we would be able to see an integrated electricity system which maintains high levels of reliability and resiliency. In case, this does not happen, we would be seeing the development of Scenario B as explained below:

Scenario B - Microgrids do not spread widely into the markets rather remain as distributed small systems running in isolation:

As explained above, the triggering situation for such a scenario would be lack of support from the utility side. As Peter Asmus notes, utilities have help their reservations against microgrids for decades. The reasons for these reservations are manifold –

1. An increased microgrids adoption in the system also means effective demand (and thus revenues) going down for utilities. Especially with the ability of a

microgrid to manage peak demand locally, the utility could potentially lose the demand charge revenues[57].

2. Integration of several renewable technologies which are intermittent may compromise reliability which is of prime importance for utilities.
3. The control systems required for any distributed generation technology or storage technology to plug into the utility infrastructure are quite complex. Also there are questions around forming standards around technologies to be allowed to plug in and what way.

As per the conceptual model, this would mean the reinforcing loop – Off-the-grid running independently. This would result in mushrooming of independent projects in different geographies and would be accelerated in areas where there are extreme weather events. So if future turns out to be like this, it is possible that microgrids projects might not get enough traction with utilities and they remain in the form of distributed smaller independent projects.

Scenario Analysis – 'Developing World'

The developing world dynamics are entirely different from the developed world in terms of market evolution and triggering elements. As we see a rise of microgrids technology in developed world, the same is being viewed by many developmental banks, investors and Non-profit organizations to be a perfect technology to increase access of electricity to people in remote areas (in developing countries). The model is shown in Figure 8.

It is noteworthy to note presence of several reinforcing loops – 'Awareness' loop, 'Better Livelihood' loop and 'Leapfrog' loop. As Reja Amatya and Tony Coiro mentioned, one of the biggest impediments in adoption of microgrids technology is awareness factor. People still don't know much about solar, biomass and other renewable energy technologies while they are more comfortable with diesel as a fuel and energy source. However, as the model shows, the initial seeds of access to electricity by a microgrid triggers several dynamics in the local market – products and services run and supported by (or to support) the availability of electricity.

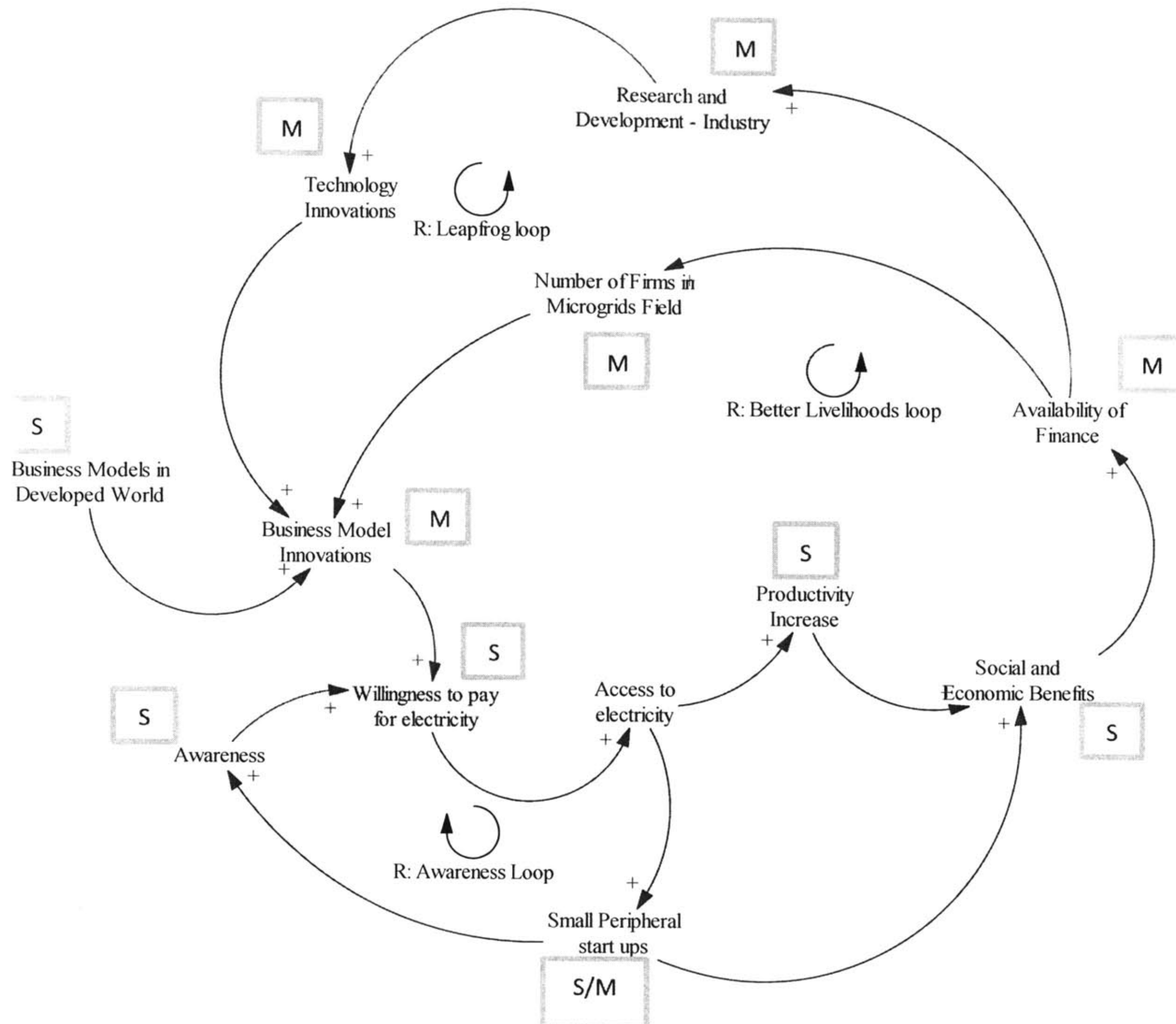


Figure 8. Developing World Model – Scenario Development

For example, someone would take up the job of local maintenance of microgrids; someone would bring in batteries, charge them with the microgrid and charge per use to the local people, etc. These dynamics would create rapid awareness in and around the areas where microgrid technology is deployed and this increases the adoption rate.

On the other hand, as we discussed, the increased productivity levels for farmers, carpenters, etc. would result in higher income levels and thus would better the standards of living for people. This would drive the 'Better livelihoods' loop as people would be willing to pay for electricity and this would make the industry attractive.

Another important dynamic is the research and development by industry to increase technological innovations with end objective of lowering costs, prices and increased access of electricity. These factors would lead to better business models where firms would try and take advantage of existing infrastructure and piggyback on the same to achieve these objectives. Peter Asmus mentions in his interview about how the industry in thinking about DC microgrids, using telecommunication towers for transmitting electricity, Nano grids for each house etc. Such factors would lead to an even richer ecosystem where there would be multiple technologies competing with each other. This could result in the developing markets leapfrogging developed markets in terms of technological advancement and market maturity (as happened with the telecommunications market).

Scenario A: Microgrids first evolve into a network of projects connected together which can then be extended to the Central grid:

There are projects going on in different parts of worlds which are aiming towards an integration of Microgrids amongst themselves to support each other. Peter talks about Spirae[58], a Denmark based company which is pushing frontiers in grid technology. He also talks about how California state universities are trying to build microgrids at their 23 respective campuses and how they plan to interconnect these microgrids together. But for achieving this, microgrids as a technology needs to be standardized in terms of control software for inter connections and smooth integration with national grid. GE/Siemens/ABB are trying to develop their own proprietary software and control system. This matches with what Weil[2] noted in his paper – "established companies may participate in the new technology they usually focus most of their resources and attention to older generation". This would make interconnection between different microgrids very difficult. And hence, if there is a rise in several technologies in the market, evolution of a dominant design would depend on regulations and standards which would support such technologies. If the regulatory bodies and standards allow (or are able to handle) integration of different technologies (AC microgrids, DC microgrids, etc.) together on the same platform, we can see different networks of different technologies connected together through the common architecture (national grid). This would eventually lead to an ecosystem which would be similar to Scenario A (which we discussed in the developed world model) – complete integration of several microgrid projects on the same platform, with the only difference that this ecosystem would be richer because of existence of several technologies. Different project owners would start offering services to end customer to differentiate themselves and capture market. If this proves to be technically (or regulatory) infeasible or financially prohibitive, we would see a different scenario.

Scenario B: Microgrids evolve into a network of projects connected together but are not extended to the Central grid:

In case, regulation does not allow or is not able to handle the technical complexity of integrating different technologies, we could see a rise in clusters of microgrids based on different technologies in different geographies. Theoretically, this would be detrimental to the end consumer as it would prohibit competition between different technologies. Such a case would eventually become an extension of current scenario where utilities in developing countries do not have the incentives to provide better service to their customers.

CONCLUSION

The study forms a basis for future thinking and work in the microgrids' industry research. It shows how technological, market, social and regulatory factors are intricately linked together in Microgrids' industry context. It also highlights the idiosyncrasies of Microgrids' industry in the forms of standards, attitudes of utilities, social constraints and support etc.

The study also hypothesizes about the relevant triggers for different markets - developed and developing. In developed markets, there is as much leverage in the technology lever as there is in the regulatory lever. So firms should think about working with utilities and regulatory bodies to increase their presence and influence in the market. On the other hand, social and technological levers in developing world can bring much more leverage for firms.

Overall discussions throughout this study have indicated a long term convergence of views in the direction to make grids smarter. This could happen either by deploying several interconnected microgrids or by deploying grid integrated independent microgrid projects or by deploying smarter grids themselves (as in Europe).

Perspective for Investors and Entrepreneurs

Forming a business case in the microgrids' market can be seen as risky right now because of high investment requirement, high regulatory risk and high business risk in terms of operations and revenue generation. However, the conceptual model developed shows how to think about different markets in developed and developing world and take a strategic view on Microgrids industry.

For developed world, regulatory action has been a key driver for the market. However, as awareness is building in the society, the business case for 'Off-the-Grid' models could be quite compelling. And so in short term, there is an opportunity for both investors and entrepreneurs to enter this space and come up with projects to provide customers reliability and economic benefits. But such businesses would face scaling up problems and thus a better approach might be to coordinate with utilities in order to rapidly scale up the business. As discussed before, utilities hold many reservations against microgrids and an entrepreneur should look into allaying those reservations by working with the utilities. For example, for the concern of loss in revenue for utilities, an entrepreneur should work with the utility to implement smart metering to charge dynamic pricing to microgrids customers. Working with the utilities would also help a firm in establishing a favourable standard in the market and thus come out as a dominant design. Instead of fighting with other firms, a company should definitely seek partners (especially utilities) in Microgrids industry.

A favourable environment for microgrid business models would be geographies where extreme weather events, high utility electricity prices and poor utility reliability are prevalent. These business models could also be successful in places where social attitude towards carbon footprint of fossil fuels is changing. People might want to switch to an independent system of electricity which provides reliable electricity at comparable prices but has very low carbon footprint. This would be a case where the entrepreneur could drive the social adoption of technology and should approach market segments which would respond to such 'signals' – for e.g. businesses with huge campuses (like Walmart, Google data centres etc.) could be more willing to adopt microgrids for better reliability, lower overall cost and lower carbon footprint.

Professor Ignacio[59] explains about the situations around microgrids in Europe. European markets do not require Microgrids because till now there has been no drivers (and incentives) to develop autonomous systems to provide power. The power quality is already very high and there is already a fairly high level of renewable integration in Europe; And so the case to make grids smarter is much stronger than making it autonomous. According to Professor Ignacio, there is definitely a move towards building the grid into 'an intelligent distributed system' (rather than many autonomous systems connected together) which could provide frequency response or other ancillary services which are valuable when there are network congestions. This means existence of the microgrid - not physically but within the network. It will be able to support the network as and when the need be. Hence, there is a real opportunity for entrepreneurs in the control system and software space in Europe.

It is also important to think about the peripheral hardware and infrastructure which needs to be upgraded (or replaced) while making the transition from current grid to micro (or smart) grids. Especially, there is a big opportunity for entrepreneurs to capture value at the Transformers' level of architecture. If projects are rolled out to make grids resilient and reliable, the first stage would be modification requirements at transformers' level. There are already a few firms, based out of Massachusetts (anonymity requested), which are working with utilities to upgrade Transformers' infrastructure in order to support the smart meters on one side and a smarter grid on the other.

In longer term, entrepreneurs and investors must keep a lookout for the research and development in this industry and how it would address integration and other technical challenges like control, monitoring and measurement. In US, utilities hold the power to 'enable' this entire infrastructure into a real time smart electricity network with higher efficiency, higher resiliency and reliability. Existence of such a platform would mean that any generation technology which can 'plug-in' to the network and provide electricity efficiently and reliably would make a good investment. Thus this industry might further spark innovation in generation technologies (Solar, Wind, Biomass etc.) which currently seem to have been commoditized.

Developing markets, on the other hand, are in dire need of independent energy systems like microgrids. There are several factors which would make microgrids technology adoption in developing countries much easier and faster. For e.g. most of the research shows that utilities in developing countries suffer from financial deficits, transmission losses and capital insufficiency for technology improvements. Energy demand in these countries is increasing, so increasingly a supply gap is getting created. Social factors seem to play a much bigger role in developing markets and entrepreneurs should always remain cognizant of this fact at every stage of technology deployment.

Entrepreneurs and investors should create value for the community and take a longer term view instead of looking for short term returns. As has been highlighted in the conceptual model, access of electricity can unlock the potential of these markets but providing access means taking on business risk as of now. Again, low social awareness and low willingness to pay might turn the tide against the entrepreneurs who venture into this space. A major problem with most of the Distributed Energy Sources with renewables is the requirement of high initial investments with long payback period.

Moreover, since people in remote areas do not even have the capability of paying money for electricity, this situation leads to a dead-lock. Let us assume a situation where an entrepreneur steps in and builds a microgrid in a remote area. The adoption of technology takes time and so initially the microgrid continues to run on low load factors. This means low operating income for the entrepreneur and thus the financial costs of operations also goes up. It is highly likely that before a substantial mass of people become familiar with the system and realize benefits of electricity, the entrepreneur winds up his setup because of not being able to finance the project any longer.

This delay in getting familiar with the system can deter technology adoption. But this has several implications for an entrepreneur who is looking to setup a microgrid in remote areas. First implication is related to create awareness by educating local people and opinion leaders. This also means building up capacity for training of local people to increase their skills and handling capabilities. On the customer side, increasing the utility of the product by making it more efficient, increasing the functionality or by making the design more elegant, could help drive awareness and thus adoption. Having a social status attached to the technology always helps in creating a lemming effect on the customers' side.

Another recommendation for such an entrepreneur will be to try and make this transition for customers easier. One way to do this could be to integrate the new technology with an already adopted technology. For e.g. by providing an option of using mobile to operate the microgrid will make it much easier for customers to quickly gain familiarity with the system. Using business models which use existing infrastructure and technology to support or run the new business would also help the entrepreneur to mitigate other problems like financial transactions, especially for areas like Kenya, India etc. where penetration of mobiles is very high. There are examples of similar development - M-Kopa can get easy money transfers from customers using M-Pesa in Kenya; Indian start-ups are leveraging on the extensive telecommunication network and marrying the same with strong IT capabilities of employees to provide people with pre-paid electricity at their homes; Business model of 'Shared Solar' which is operating in Uganda, Mali and India. The operations around the microgrids' projects like collection, maintenance etc. could be owned by the entrepreneur making it a variable cost business rather than a fixed cost business.

It is important to note that the longer term market dynamics are heavily based on the formative nature of short term dynamics. And hence it would be strategic to enter the market right now and be a part of the ecosystem. The industry is set to grow exceptionally in these markets unless there is a major roadblock from the regulatory factors (which is unexpected, given the benefits of microgrids to different stakeholders).

At the same time, it is important not to get locked in some technology and thus remain an agile entrepreneur who can pivot according to market conditions.

APPENDIX

Appendix A: List of Microgrid projects in US (Galvin Power Initiative)

Project	Type
Ansonia (Ansonia, CT)	Commercial
Borrego Springs (Borrego Springs, CA)	Utility
Colonias (La Presa, TX)	Institute
Drexel University (Philadelphia, PA)	University
Fort Bliss (Fort Bliss, TX)	Military
Fort Bragg (Fort Bragg, NC)	Military
Howard University (Washington, D.C.)	University
Los Alamos (Los Alamos County, NM)	County/Community
Marin County (San Rafael, CA)	County/Community
Naperville (Naperville, IL)	County/Community
New Mexico Green Grid Initiative (NM)	County/Community
Pecan Street Project, Inc. (Austin, TX)	University
Perfect Power at the Illinois Institute of Technology (Chicago, IL)	University
Perfect Power at Mesa del Sol (Albuquerque, NM)	County/Community
Sacramento Municipal Utility District (Sacramento, CA)	Utility
Stamford Energy Improvement District (Stamford, CT)	County/Community
Twentynine Palms (Twentynine Palms, CA)	Military
University of California, San Diego (San Diego, CA)	University

REFERENCES

[1] Weil, H.B. and Utterback, J.M.. "The Dynamics of Innovative Industries". 2005.

[2] Weil, H.B. "Application of system dynamics to corporate strategy: an evolution of issues and frameworks". 2007.

[3] Sterman JD. Business Dynamics: Systems Thinking and Modeling for a Complex World. Irwin McGraw-Hill: New York. 2000.

[4] "Smart Grids: Microgrid Market Boom on the Way as Europe and Asia Catch-up to US". Global Data. 19 March 2013. Web. 10 May 2013.

[5] "Microgrid Deployment Tracker 4Q12".Navigant Research. Web. 10 May 2013.

[6] "Market Data: Microgrids". Navigant Research. Web. 10 May 2013.

[7] "Microgrid Market Forecast & Analysis (2012-2022): By Types (Hybrid, Off-Grid, Grid Connected); Technology (Switch Gears, Pv Inverter, Storage (Batteries, Flywheels, Super Capacitors), Microturbines); Application (Campus, Commercial, Defense)". MarketsandMarkets. January 2013. Web. 10 May 2013.

[8] "MICROGRID BRICS MARKET $4.5B BY 2020, CHINA LEADS $2B, ZPRYME SMART GRID INSIGHTS REPORTS". Zpryme Research and Consulting. 11 July 2012. Web. 10 May 2013.

[9] Livio de Santoli, La Sapienza and Carlo Maria Drago, IBM . "Generating Insights - Microgrids in Rome". 31 May 2010. Web. 10 May 2013.

[10] Balantrapu, Satish, Consultant, Infosys. "Role of Artificial Neural Networks in Microgrid". 2 November 2010. Web. 10 May 2013.

[11] "GE introduces an optimization solution for microgrids". PennEnergy. 30 October 2012. Web. 10 May 2013.

[12] "Renewable Microgrid Controller RMC 600". ABB. Web. 10 May 2013.

[13] "Microgrid Management Systems, Featuring the Energy Router and Multi-Flex". Indy Power Systems. Web. 10 May 2013.

[14] "Microgrids". Navigant Research. Web. 10 May 2013.

[15] "DOE Microgrid Workshop Report". DOE. 30 August 2011. Web. 10 May 2013.

[16] "Microgrid Projects". Galvin Electricity Initiative. Web. 10 May 2013

[17] Aratani, Lori. "Howard University considers microgrid as a power source". 1 July 2011. Web. 10 May 2013.

[18] "Smart Grid Today: UC San Diego gears up for smart microgrid". Power Analytics. 1 March 2010. Web. 10 May 2013.

[19] Clarke, Chris. "UC San Diego's Microgrid Gets Boost from State". KCET. 10 January 2013. Web. 10 May 2013.

[20] Newcomb, James. "The UCSD Microgrid - Showing the Future of Electricity ... Today" Rocky Mountain Institute. Web. 10 May 2013.

[21] Shahidehpour, M., Ph.D. "Summary Report on IIT Microgrid". Robert W Galvin center for electricity innovation - Microgrid at IIT. 28 July 2011. Web. 10 May 2013.

[22] Carson, Phil. "Military microgrids: a journey". Intelligent Utility. 17 January 2011. Web. 10 May 2013.

[23] Carson, Phil. "Happiness is a military microgrid:. Intelligent Utility. 15 August 2011. Web. 10 May 2013.

[24] "Military Microgrid Capacity To Experience More Than 700% Growth By 2017, Forecasts Pike Research". The Smart Grid Times. 20 September 2011. Web. 10 May 2013.

[25] Asmus, Peter. "Executive Summary: Military Microgrids". Navigant Research.. Web. 10 May 2013. <http://www.navigantresearch.com/wordpress/wp-content/uploads/2012/12/MMG-12-Executive-Summary.pdf>

[26] Van Broekhoven S.B., Judson N., Nguyen S.V.T., Ross, W.D. "Microgrid Study: Energy Security for DoD Installations". Lincoln Laboratory. 18 June 2012. Web. 10 May 2013.

[27] Robinson-Avila, Kevin. "Microgrids around state help New Mexico prep for 'smart grid' era". Albuquerque Business First. 2 September 2011. Web. 10 May 2013.

[28] "Microgrid Grant and Loan Pilot Program". Department of Energy and Environmental Protection. Web. 10 May 2013

[29] "Hawaii Clean Energy Initiative". Hawaii Clean Energy Initiative. Web. 10 May 2013.

[30] Hatziargyriou, Nikos, Asano, Hiroshi, Iravani, Reza and Marnay, Chris. "Microgrids – An overview of ongoing research, development and demonstration projects".

ERNEST ORLANDO LAWRENCE BERKELEY NATIONAL LABORATORY. July 2007. Web. 10 May 2013.

[31] "NEDO Activity report" Annual Report 2011.NEDO. September 2011. Web. 10 May 2013.

[32] "Profile of NEDO".NEDO. September 2012. Web. 10 May 2013.

[33] Hirose, Keiichi, Shimakage, Toyonari (NTT Facilities), Reilly, James T. (Reilly Associates), Irie, Hiroshi (Mitsubishi Research Institute). "The Sendai Microgrid Operational Experience in the Aftermath of the Tohoku Earthquake: A Case Study". Web. 10 May 2013. <http://der.lbl.gov/sites/der.lbl.gov/files/Sendai%20paper%20jan%2013.pdf>

[34] "Mission Statement". Greenpeace USA. Web. 10 May 2013.

[35] "Energy Modeling Software for Hybrid Renewable Energy Systems". Homer Energy. Web. 10 May 2013.

[36] "DigSlient PowerFactory". Web. 10 May 2013.

[37] Bullis, Kevin. "SunEdison Turns to Big New Markets for Solar Power". MIT Technology Review. 8 June 2012. Web. 10 May 2013.

[38] "Optimal Power Solutions Blog Exploring the issues of sustainability and Renewable Energy". Web. 10 May 2013.

[39] Bullis, Kevin. "A Billion people in the Dark". MIT Technology Review. 24 October 2012. Web. 10 May 2013.

[40] Cumberbatch, Toby. "Engineering for the Middle of Nowhere". TEDxColumbiaEngineering. November 2011. Web. 10 May 2013.

[41] "SociaLite – Solar LED lantern". DETAIL Daily. 2 November 2011. Web. 10 May 2013.

[42] "Lighting the way". The Economist. 1 September 2012. Web. 10 May 2013.

[43] Kirubi, Charles, Jacobson, Arne, Kammen, Daniel M. and Mills, Andrew. "Community-Based Electric Micro-Grids Can Contribute to Rural Development: Evidence from Kenya". World DevelopmentVol. 37, No. 7, pp. 1208–1221, 2009 Web. 10 May 2013.

[44] "Irene inflicts severe damage on Connecticut shore, leaves 700,000 without power". New Haven Register. 28 August 2011. Web. 10 May 2013.

[45] Hope Energy. Tony 'Danger' Coiro. Personal Interview. April 2013.

[46] MITEI. Reja Amatya. Personal Interview. January 2013

[47] Navigant Research. Peter Asmus. Personal Interview. April 2013

[48] "Shared Solar Pay as you go Electricity", Modi Research Group. Web. 10 May 2013 http://sharedsolar.org/

[49] "Subsidies in the Energy Sector: An Overview". World Bank. July 2010. Web. 10 May 2013.

[50] "ABB Buys Powercorp for Integrating Renewables". Katherine Tweed. 15 November 2011. Greentechmedia (grid). Web. 10 May 2013.

---

[51] Camblong , H., Sarr, J., Niang, A.T., Curea, O., Alzola, J.A., Sylla, E.H., Santos, M. "Micro-grids project, Part 1: Analysis of rural electrification with high content of renewable energy sources in Senegal". Renewable Energy 34 2141–2150. (2009). Web. 10 May 2013.

[52] Alzola, J.A., Vechiu, I., Camblong, H., Santos, M., Sall, M., Sow, G. "Microgrids project, Part 2: Design of an electrification kit with high content of renewable energy sources in Senegal". Renewable Energy 34 2151–2159. (2009). Web. 10 May 2013.

[53] "New law to improve state's disaster response". West Hartford News. 26 July 2012. Web. 10 May 2013.

[54] Kane, Brad. "CT microgrid program seeks full financing". 18 March 2013. Hartford Business.com. Web. 10 May 2013.

[55] Asmus, Peter. "Why California Will Lead the World on Microgrids". 25 March 2013. Navigant Research. Web. 10 May 2013.

[56] Lauderbaugh, Alex. "In Wake of Sandy, Connecticut Expands Microgrid Program". 12 March 2013. Navigant Research. Web. 10 May 2013.

[57] "Explanation of Demand Charges". North Western Energy. Web. 10 May 2013.

[58] "Spirae – Not only possible. Proven.". Web. 10 May 2013. http://www.spirae.com/

[59] MITEI. Prof. Ignacio Perez Arriaga. Personal Interview. May 2013.