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Report on Impact Investing Potential in Solar Microgrids

Harvard College Impact Investing Group
Harvard Business School Fellowship in Impact Investing

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ABOUT THE HARVARD COLLEGE IMPACT INVESTING GROUP AND OUR HARVARD BUSINESS SCHOOL FELLOWSHIP IN IMPACT INVESTING

The Harvard College Impact Investing Group (HCIIG) is an undergraduate organization about Harvard University that serves to educate and connect students with impact investing opportunities and experts in the field of impact investing. According to the Global Impact Investing Network, "impact investments are investments made into companies, organizations, and funds with the intention to generate social and environmental impact alongside a financial return."[1] We provide a general education program and expert guest speakers in impact investing from HBS and major financial institutions. We also engage in impact investing idea generation, and we collaborate with corporate partners to gain direct, real-world experience through internships.

The Harvard Business School Fellowship in Impact Investing is part of HCIIG's comprehensive fellowship partnerships. Three core teams work to research different subfields of impact investing and create case studies that inform potential impact investors on the efficacy of investments in that area. We also help to develop frameworks for analysis in particular areas of impact investment.

More specifically, the Climate Action Team of this fellowship focuses on how capital can transform progress in the development of more sustainable energy sources and how such funds can leverage environmental progress more broadly.

This report is the result of a semester-long intensive effort by a team of seven undergraduates. The Harvard College Impact Investing Group does not endorse specific companies, and all opinions throughout this paper are the sole property of its seven authors.

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[1] Cite https://thegiin.org/assets/documents/GIIN_impact_investing_guide.pdf here

MEET THE AUTHORS

Connor Schoen is an undergraduate student at Harvard University working towards his Masters in Applied Mathematics with a specialization in Economics. He is Chairman of the Harvard Business School Impact Investing Fellowship, and he also chairs the Economic Policy Group at the Institute of Politics. Connor is one of the head authors for a weekly impact investing blog, and he is a World Staff Writer for the Harvard Political Review. He just started his own for-profit social enterprise, Breaktime, and he plans to continue exploring other avenues of creating impact within the intersection between philanthropy and business.

Michał Kożuchowski is an undergraduate at Harvard University concentrating in Economics and Energy & Environment. Passionate about climate action, renewable energy solutions and developing ways in which capitalism can have a positive impact on society. He is a Director of the 118 Capital Fellowship and Associate Editor of the HBS Fellowship. Coming from Poland, he strongly cares about air quality solutions and the development of sustainable cities. His hobbies include tennis, meteorology and politics - he is actively involved with the opposition to the current Polish government.

Aidan Gibbons is an undergraduate student at Harvard University from New York City. He is currently considering studying pure or applied mathematics. On campus, he is a member of the Harvard College Impact Investing Group, an associate in the Harvard College Consulting Group, chair of the STEAM (science, technology, engineering, arts, mathematics) branch of the Institute of Politics, and an avid participant in the theater department.

Zachary Dietz is an undergraduate at Harvard College studying Applied Mathematics with a focus in Economics and Computation. Originally from Northampton, Massachusetts, his hobbies include ultimate Frisbee, martial arts, and investing. On campus, he is involved with the Harvard Financial Analysts Club, the Franklin Fellowship, and the Men's Club Ultimate Team.

Regan Brady, from Cleveland, Ohio, is an undergraduate at Harvard College where she is pursuing a concentration in Economics and a secondary in Psychology. At Harvard, apart from conducting research for the Impact Investing Fellowship, she has been very involved with exploring the intersection between public policy, economics, and the social sector through pursuing economic policy research at the Kennedy School's Institute of Politics as well as interning for two social-impact oriented startups. She hopes to pursue a career in public policy and utilize economics to address the world's most pressing challenges.

Esteban Ortiz is an artist, writer, and producer studying English at Harvard College. Originally from Long Island, New York, he has worked in local government to serve communities in Nassau County and South Bronx. He currently heads NEXT Fellows, a nationwide non-profit organization, and hopes to bring youth from every type of neighborhood into productive conversations and concrete action. Esteban, alongside everyone else on the team, is passionate about research-driven change, real impact, and making a better future.

Ivan Vazquez hails from the great city of Boise, Idaho, and is an undergraduate at Harvard College pursuing a concentration in Economics and a secondary in Statistics. Growing up playing soccer and now a member of the Harvard Men's Club Rugby team, Ivan is excited to be involved in impact-investing research. Apart from working with the Impacting Investing Group, he is a member of the Harvard Undergraduate Council, Harvard Investment Association, and loves to talk politics at the Harvard Institute of Politics. He hopes to pursue a career in finance.

CONTENTS

1. Abstract

This paper evaluates the potential opportunity for impact investments in solar microgrids. Microgrids are small, independent networks of electrical loads, which can be connected to a broader utility grid or be isolated from other energy sources. Microgrids are unique in this ability to island from their parent grid and operate on their own. Solar microgrids (SMGs) do this by using

Electronic Storage Systems (ESSs) that usually contain batteries, which can store the energy obtained by the solar panels throughout the day. Their advantages include their reliability and cleanliness, and notable disadvantages include spotty communication with the parent grids and difficulty in implementation Ultimately, this paper identifies how SMGs can be utilized in *both* rural, underdeveloped areas *and* urban, developed areas. In isolated rural areas, multinational companies have been able to exploit local demand for reliable energy sources, driving much-needed access to energy into these areas. Moreover, in highly-populated urban areas, there is a pressure for both utility companies and city governments to invest in reliable, clean, and personalized energy systems; thus, there exists higher demand for SMGs that facilitate energy trading and off-grid power usage throughout these cities. Lastly, from a systems-wide perspective, both cost reductions in inputs such as panels and racking and a continued spike in demand for panels and microgrids have augmented the potential for success for investments in solar technology companies, solar cell makers, and solar panel installers. Therefore, overall, our research team finds a high probability of success in SMG investments -- both in terms of the profitability they can drive from this increased demand as well as the increase in energy access, cleanliness, and reliability for which they provide.

2. Introduction

This paper explores the efficacy of SMG impact investments with consideration of geography, upstream analysis, and current reporting on the market for this technology. The report should be of interest to investors who specialize or are looking into sustainability, as well as other agencies or institutions running sustainability projects. The data and analysis in this paper indicate that the

SMG market has strong potential for growth, in its upstream components and in projects in both the underdeveloped and developed world.

We start by evaluating the pre-existing demand for the introduction of SMG technology. Often, investors are hesitant to invest in alternative energy products and projects due to superior infrastructure and the perception of more reliability in traditional sources, such as natural gas and oil. SMGs offer a potential solution to this by serving as isolated structures, as their use of inverters and an Energy Storage System (ESS) helps them quickly disconnect from the utility grid in the case of a power outage to further improve reliability. Furthermore, blockchain technology has enabled solar energy trading between users of the grid. This paper determines the general advantages which make SMGs an appealing investment reliability, economic feasibility, and cleanliness. This helps improve current energy provision, initiate new sources of energy for "energy deserts," and facilitate disaster recovery in high-risk areas. Nevertheless, SMGs are disadvantaged by their reliance on communication with parent grids in some cases, their cost of implementation at a large scale, and some fundamental lack of knowledge about how to operate/implement them.

Following an exploration of SMG technology, we pursue a systems-wide analysis to fully capture investment potential in this area. Chiefly, SMGs rely on a lot of upstream factors which influence their overall cost of implementation. At the most basic level, SMGs must have solar panels, racking, and one or more power inverters. They are also generally are equipped with some type of battery for energy storage, a generator to supplement the solar panels, a microgrid controller, solar trading technology, and more. Thus, from a systems-wide analysis, there are a variety of potential impact investments that can be made. It was determined that, solar grid production, installation, and management are ripe with potential due to increased demand for these services/technologies.

In addition, the improvement of silicon extraction processes represents a huge opportunity to improve the net impact we're having on the environment through this process. Decreased costs and increased demand within several of these areas make such investments likely to be profitable.

Next, we develop an overall methodology for judging the efficacy of impact investments in SMGs. We look at the market, timing, competition, and business model considerations to develop a greater understanding of potential profitability. Furthermore, we establish and explore metrics that can be used to determine the impact of these investments on society: These include measures of access to electricity, the reliability of energy infrastructure, health problems associated with current energy sources in rural areas, and environmental impact.

We will then dive into two major geographical areas relevant to SMG application: rural, underdeveloped areas and urban, developed areas. Regarding the former, there is a huge need for any sort of access to electricity in these areas. According to the Sustainable Development Goals (SDGs) of the United Nations, this initial provision of energy is essential to attaining the highest human level of development in that such energy produces a large variety of spillover benefits. In general, multinational installers/energy providers work with local business-people and local governments who provide funding for the implementation of islanded energy systems. Due to the cleanness and reliability of SMGs, we evaluate why this technology is ideal in these cases. Moreover, these developing countries have no preexisting energy structure, so there is a huge impact potential in developing novel, decentralized energy systems in this area--steering away from the creation of large, unreliable, centralized grid systems. The current dependence on unreliable, diesel-based power at the moment is damaging the local economies of sub-Saharan Africa, India, Bangladesh, and more regions around the world. We find a huge potential for profitability *and* impact in investing in the introduction of SMGs to these areas. As illustrated by companies like OMC Power and Husk Power, combined investments, market-based incentives for sustainability, and end-user education/contracts coupled with lower capital costs and government incentives creates a huge opportunity for high returns on these investments.

Secondly, we find that this same technology applies to very different, urban areas with pre-existing energy infrastructure. In places like Brooklyn, utility companies like Con Edison have been able to use this technology to diversify their energy sources and appeal to environmentally-conscious consumers and governments. In analyzing these cases, we find a combination of state and private investments along with government policies that are aligned with commercial and social interests have created an environment ripe for investment success for city SMGs.

Overall, the variety of cases and wealth of data used throughout this paper support that there exists a strong potential for both profitability and impact when investing in SMGs and their upstream factors. Hence, investment in SMGs is a prime opportunity for investors to enter the field of sustainability and for investors already specializing in sustainable solutions to create more profit and impact than traditional methods.

3. Microgrid Background and Technology

3.1 Background

3.1.1 What a microgrid is

One of the most restrictive aspects of a shift to green energy lies in poor infrastructure. Energy sources which have been used for centuries, like oil and natural gas, are already well established throughout much of the world, making them the primary energy foundation. The age of oil began in approximately the early 1900's, catalyzed by improved drilling techniques and the discovery of many large oil fields. With its portable, dense nature, as well as lower prices and plentiful subsidies, oil infrastructure is well established, a default source for the vast majority of the world. On top of that, green energy solutions are often seen as unreliable and weak; in harnessing energy from nature, it is subject to unpredictable inconsistencies[2]. A focus on green energy is relatively recent, hence the lack of development of reliable infrastructure. In looking towards sustainable alternative energy solutions, optimizing the infrastructure utilized is paramount.

Solar Microgrids (SMGs) offer a possible solution to the seemingly infeasible implementation of a large-scale grid powered purely by solar energy. The International Council on Large Electric Systems defines microgrids as "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 while connected to the main power network or while islanded."[3] In other words, these are freestanding grids, which could be connected to a broader utility grid (often denoted as the parent grid) or could be "islanded" by itself from this utility. Microgrids vary in size, ranging from large enough to power a small city to as small as w single facility (a nanogrid) or even one person with a solar panel on his or her backpack (a picogrid). Generally, they are embedded in larger grids, often in cities, but due to their independence in function, they are operable in rural areas as well[4].

[2] "Can the World Thrive on 100% Renewable Energy?" The Economist. July 13, 2017. Accessed July 30, 2018. https://www.economist.com/finance-and-economics/2017/07/13/can-the-world-thrive-on-100-renewable-energy.
[3] "Deploying Solar-Plus-Storage Microgrids." SolarPro Magazine. August 2015. Accessed April 22, 2018. https://solarprofessional.com/articles/design-installation/deploying-solar-plus-storage-microgrids#.Ws63_YjwY2w.
[4] Aram, Alireza. "Microgrid Market in the USA." May 2017. http://www.hitachi.com/rev/archive/2017/r2017_05/pdf/P26-30_Global.pdf.

3.1.2 What microgrid does

An electricity grid in general connects to homes, businesses, and other buildings, providing power from a centrally located source. They key differentiating feature of SMGs is their ability to isolate themselves from the grid[5]. For instance, if the utility grid to which the microgrid is connected experiences a power outage, the microgrid can "island" itself off from the utility grid and generate its own power until the main grid is operational. Figure 1 illustrates a possible interconnected network of facilities which the microgrid powers. The ability to isolate is not unique to urban grids; no matter how distant the microgrid, if it is connected to its parent grid, it can be self-sustainable as well.

3.2 How Solar Microgrids Work

3.2.1 General solar production

In understanding how SMGs work, it is necessary to know how solar panels create energy. Photovoltaic solar panels consist of solar cells, which are made of silicon, with one positive end of the film and one negative, creating an electric field and thus a direct current (DC)[6]. The DC is then converted into an alternating current (AC). Additionally, solar inverters provide certain system statistics, such as voltage and current. This AC is used by most households[7]. The diagram in Figure 2 helps illustrate the process of energy formulation by solar panels. SMGs harness using photovoltaic solar panels just like most solar power, but the difference lies in the configuration.

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[5] *Microgrids: An Assessment of the Value, Opportunities, and Barriers to Deployment in New York State*. New York State Energy Research and Development Authority, Sept. 2010, web.mit.edu/cron/project/EESP-Cambridge/microgrid/NYS-Microgrids-Roadmap.pdf.

[6] Knier, Gill. *How Do Photovoltaics Work?*, NASA, science.nasa.gov/science-news/science-at-nasa/2002/solarcells.

[7] SunPower Corp. "Solar Valuation." 2012. https://us.sunpower.com/sites/sunpower/files/media-library/white-papers/wp-residential-real-estate-appraisers-guide-accurately-valuate-residential-rooftop-solar-electric-pv.pdf.

3.2.2 Key features

The two most general components of any grid, SMGs included, are the power source (solar panels) and the energy consuming devices (homes, businesses, and other facilities which use the power generated). Microgrids have three more specific components: a power management system, an energy storage system (ESS), and a point of common coupling (PCC).

The purpose of the power management system is to handle the power transfer from the PV panels and the energy consuming devices. Modern microgrids tend to include various measures of software integrations and system control, such as smart meters, to balance supply and demand loads on the grid and optimize its efficiency[8]. One of the key features of the power management system are inverters. Inverters are designed to quickly disconnect from the utility grid during an outage, giving SMGs the ability to island themselves[9].

Energy storage systems are vital to the function of SMGs. The ESS contains batteries, and the type of battery chosen the most influential component to the function of the ESS[10]. For instance, power-oriented batteries are best at responding to signals in short intervals, whereas energy oriented ones are better for long term demand shifts. Lithium ion batteries are most commonly used, as they have high-energy densities, low weight, and a good life cycle[11].

The point of common coupling is a point in the electrical circuit in which the microgrid is connected to the main grid. There are several regulations governing the properties of PCC, the

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8 Miret, Santiago. "How To Build A Microgrid." February 25, 2015. http://berc.berkeley.edu/build-microgrid/.

9 Bahramirad, Shay. "Microgrid-Integrated Solar-Storage Technology." 2016. https://www.energy.gov/sites/prod/files/2016/06/f32/SHINES_TKM_ComEd.pdf.

10 "Energy Storage for Distributed Energy Resources Deployments: Financial, Technical, and Operational Challenges and Opportunities." 2015. http://www.activepower.com/en-US/documents/3803/wp118-energy-storage-for-microgrids.

11 "Deploying Solar-Plus-Storage Microgrids." SolarPro Magazine. August 2015. Accessed April 22, 2018. https://solarprofessional.com/articles/design-installation/deploying-solar-plus-storage-microgrids#.Ws63_YjwY2w.

most important of which being IEEE 1547. This law states that microgrids must not actively regulate the voltage of the PCC, not create overvoltages that exceed the ratings of the main grid, and that the interconnection system must measure relevant voltages. Methods of interconnection include directly through switchgear, power electronic surfaces, and static switches[12].

The general function of a SMG can be outlined by the diagram in Figure 3.

3.2.3 Integration of blockchain

Though blockchain is currently associated with cryptocurrency, there is little reason for it to remain that way; its ability to timestamp transactions securely has been used with SMGs to document instances of energy transfer[13]. This largely simplifies energy conduction trading between cells as well as documenting communication within the system, two key component of SMG operations.[14]

One of the crucial benefits which blockchain allows for is enhanced security. Blockchain's ability to create a decentralized accounting system shared among those in the network renders it "virtually unhackable,", according to Lawrence Osini, founder and Chief Executive of LO3 Energy[15].

Another feat of blockchain integration could be providing the broader grid an accounting system to keep track of electricity use of consumers connected via microgrids[16]. Furthermore, this increased transparency spearheaded by distributed ledgers (consensus of replicated, shared, and

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[12] Kwasinski, Alexis. "Grid-Microgrid Interconnections." 2012.
[13] Siemens. "Microgrid on a Blockchain Platform." Siemens. February 16, 2018. https://www.siemens.com/innovation/en/home/pictures-of-the-future/energy-and-efficiency/smart-grids-and-energy-storage-microgrid-in-brooklyn.html.
[14] Siemens. "Microgrid on a Blockchain Platform." Siemens. February 16, 2018. https://www.siemens.com/innovation/en/home/pictures-of-the-future/energy-and-efficiency/smart-grids-and-energy-storage-microgrid-in-brooklyn.html.
[15] https://www.wired.co.uk/article/microgrids-wired-energy
[16] Baraniuk, Chris. "Microgrids and the Blockchain Are Powering Our Energy Future." Wired. September 18, 2017. https://www.wired.co.uk/article/microgrids-wired-energy.

synchronized digital data with no central administrator) allows grid managers to communicate more efficiently. In essence, it facilitates the creation of a network of solar energy trading: users of the SMG can sell each other excess energy, and, conversely, they can buy extra energy from their neighbors when they're low on production/high on usage[17]. This enhanced reliance would be especially advantageous for SMGs due to production being contingent on the ebbs and flows natural weather patterns. Considering the islanding ability of SMGs is contingent on intra/intersystem communication, blockchain's potential to improve transparency may make it integral to the rise of widespread SMG usage.

3.3 Types of Microgrids

3.3.1 Microgrid Settings

Generally, solar panels need at least four hours of peak sunlight (defined as offering 1,000 watts of photovoltaic power per square meter) per day to function with reliability. Twenty-three states have less than this recommended amount on average, particularly in the north, but certain incentives in states such as Massachusetts and New York has made solar energy relatively affordable, rendering it more popular than in much of the south despite the limited reliance[18].

It is also important to note that SMG project sites must be chosen to minimize environmental/habitat disturbances. The site must avoid the relocation of native animal and plant populations, places of particular scenic beauty, or agriculture[19].

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[17] Cardwell, Diane. "Solar Experiment Lets Neighbors Trade Energy Among Themselves." The New York Times. March 13, 2017. https://www.nytimes.com/2017/03/13/business/energy-environment/brooklyn-solar-grid-energy-trading.html.
[18] https://news.energysage.com/many-sunlight-hours-need-calculating-peak-sun-hours/
[19] Luckow, P.; Fagan, B.; Fields, S.; Whited, M. Technical and Institutional Barriers to the Expansion of Wind and Solar Energy; Synapse: Cambridge, MA, USA, 2015.

Pike Research has identified four key types of market segments in which microgrids are specifically applicable. As long as these locations receive sufficient amounts of sunlight as well, they are viable locations for SMGs.[20]

First, there are campus environment/institutional microgrids, which are co-located in a campus or institutional setting[21]. Thus far, these microgrids are the most commonly used, considering that the owner of the generation and users of the energy are all within one compressed geographical area. This avoids any implementation issues that arise with complex geographies[22].

Second, there are remote "off-grid" microgrids, which do not connect to the parent grid, operating in isolation at all times[23]. For instance, remote diesel and wind microgrids have been widely used in Alaska. Remote arid and semi-arid regions, often located in deserts, have high potential for SMG implementation due to their solar exposure and isolation. SMGs have the potential to become the first ever, electricity-generating systems in many of these locations.

Third, there are military base microgrids. These rely on heightened physical and cyber security as well as independence from the macrogrid[24]. Considering many of these bases are in the Middle East and other dry and warm regions, SMGs would be especially fitting for military bases. Furthermore, SMG usage allows for bases to follow through on greenhouse gas emission reduction goals[25].

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[20] Choube, Shyam H. "Microgrid Act as a Energy Storage Sizing." *International Journal of Electronics, Electrical and Computational System*6, no. 9 (September 2017).
[21] Choube, Shyam H. "Microgrid as Energy Storage."
[22] Choube, Shyam H. "Microgrid as Energy Storage."
[23] Choube, Shyam H. "Microgrid as Energy Storage."
[24] Choube, Shyam H. "Microgrid as Energy Storage."
[25] Maitra, Arindam. "Microgrid Design Considerations." Electric Power Research Institute. September 8, 2016. http://integratedgrid.com/wp-content/uploads/2017/01/8a-Maitra-Microgrid-Design-Consideration.pdf.

The fourth type is commercial and industrial microgrids. The presence of these types of microgrids has been increasing in North America and East Asia; however, they lack clear characteristics and standards[26].

3.3.2 Hybrid SMGs

There are also microgrids which provide power via the use of multiple different types of energy, the most notable relating to SMGs being the combination with hydroelectric power. For one, hydroelectric power is more efficient than photovoltaic cells, with 225 percent the capacity factor (measure of average power generated over maximum power generated). Also, while solar power is completely reliant on the sunlight, varying mostly with time of day, hydroelectric power has more seasonal variation[27]. Thus, the dissonance between the ability to provide power across different time periods makes these hybrid grids less reliant on the diesel generator as a support[28]. The combination of an improvement in efficiency and variance in when peak energy is produced renders hydro/solar microgrids an appealing alternative energy infrastructure.; Wind/solar hybrid microgrids are more difficult in their implementation as the logistics of implementing large turbines as well as communication by planners and decision makers is difficult[29]. Furthermore, at times SMGs are connected to diesel generators for extra support[30]. As these generators create significant amounts of emissions, it is optimal to have as little reliance on them as possible.

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[26] Choube, Shyam H. "Microgrid as Energy Storage."
[27] "Hydropower - Energy Explained, Your Guide To Understanding Energy - Energy Information Administration." June 13, 2017. Accessed May 06, 2018. https://www.eia.gov/energyexplained/index.php?page=hydropower_home.
[28] Caterpillar Inc. *Hybrid Microgrids: The Time Is Now*. Report. 2016. http://s7d2.scene7.com/is/content/Caterpillar/C10868274
[29] Wolsink, Maarten. "Wind Power Implementation: The Nature of Public Attitudes: Equity and Fairness Instead of 'backyard Motives'." *Renewable and Sustainable Energy Reviews*11 (2007): 1188-207. http://citeseerx.ist.psu.edu/viewdoc/download?doi=10.1.1.895.5352&rep=rep1&type=pdf.
[30] "Deploying Solar-Plus-Storage Microgrids." SolarPro Magazine. August 2015. Accessed April 22, 2018. https://solarprofessional.com/articles/design-installation/deploying-solar-plus-storage-microgrids#.Ws63_YjwY2w.

3.4 SMG Advantages

SMGs have key advantages such as reliability, environmental benefits, and utility in disaster relief, rendering them incredibly promising means of alternative energy infrastructure. Furthermore, these advantages translate to the high ceiling for success in impact investment in SMGs; the high demand for reliable energy will help investments in SMGs be profitable, and their limited carbon footprint and application to disaster relief offer powerful positive impacts.

3.4.1 Reliability

The reliability of SMGs lies in the inherent nature of the microgrid technology. The ability to isolate from the parent grid minimizes blackouts and power disturbances, making SMGs even more reliable to their less environmentally-conscious counterparts, especially when other infrastructure experiences disturbances. Additionally, many microgrids include features such as redundant distribution, smart switches, intelligence and automation, and local power generation to increase their reliability.

Lots of the reliability stems from energy storage. Though energy storage is an appealing feature of microgrids of all types, it is most important for solar energy, due to the inconsistencies of solar panels to provide adequate power. Of most conventional forms of energy generation, photovoltaic cells have a capacity factor of 20 percent, less than most other forms of energy (93 and 37 percent for large coal plants and onshore wind power, respectfully)[31]. However, with sufficient energy stored, the lower capacity factor is less of a limitation. On top of that, not only is the supply of solar power inconsistent, but there are significant disparities between the demand for energy and

[31] Lofthouse, Jordan, Randy Simmons, and Ryan Yonk. "Reliability of Renewable Energy: Solar." *Institute of Political Economy at Utah State Univeristy*. https://www.usu.edu/ipe/wp-content/uploads/2015/11/Reliability-Solar-Full-Report.pdf.

the hours of daylight in which solar panels are most effective. This relationship is demonstrated by the duck curve in Figure 4.[32] The storing capabilities help improve the conundrum that the duck curve presents to the growth of solar power. Finally, energy storing capabilities make for a more stable utility grid. Essentially, by providing stored energy during hours with high demand, energy production needed for peak demand in certain grids have been reduced by up to 95 percent.[33]

Economic benefits are created by this increased reliability as well. For instance, the Galvin Electricity Initiative estimated that customers lose at least 150 billion dollars annually due to power outages. The "islanding" ability of microgrids allows units with SMGs to avoid incurring most, if not all, of these costs.

Further economic benefits stem from microgrid isolation, including selling its power to the utility grid when not islanded. Services, which the microgrid can supply to the overall power grid include real-time price response and day-ahead price response (allowing prices alter to according to demand), voltage support (absorbs or produces reactive power to keep voltage consistent), and spinning reserve (reserve power for unexpected demand surges, available to a transition system within 10 minutes)[34].

3.4.2 Cleaner energy

The ability of SMGs to harness energy in an especially clean fashion largely stems from its efficiency relative to standard solar power configurations. The integration distributed energy

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[32] Jones-Albertus, Rebecca. "Confronting the Duck Curve: How to Address Over-Generation of Solar Energy." Energy.gov. Accessed April 22, 2018. https://www.energy.gov/eere/articles/confronting-duck-curve-how-address-over-generation-solar-energy.

[33] "Energy Storage in Microgrids: A Path to Reduce Energy Costs and Improve Grid Resiliency." The Value of Energy Storage in Microgrids. April 08, 2017. Accessed April 22, 2018. https://microgridknowledge.com/value-energy-storage-microgrids/.

[34] Muni-Fed – Antea Group Energy Partners, LLC, and The Port of Long Beach. "Microgrid Technology White Paper." August 2016. http://www.polb.com/civica/filebank/blobdload.asp?BlobID=13595.

generation technologies creates a local power delivery plan, catered to specifically to meet the demand of the constituents, allowing for a cleaner and smarter energy transfer and decreasing the amount of energy wasted[35].

Additionally, the relative efficiency of SMGs stemming from the support of diesel generators makes SMGs a feasible improvement toward cleaner power than the status quo. Especially in a transition from a largely fossil fuel based energy sector, alternative energy cannot be solely relied on, making the coupling of fossil fuels like natural gas necessary in the short-run. With increased efficiency in SMGs, not only can we transition away from carbon-intensive emissions be quicker, but also it makes the process more environmentally advantageous.

3.4.3 Microgrids for Disaster Relief

As natural disasters become much more frequent as a result of climate change, SMGs rise as a valuable solution to the lack of accessible energy which often follows such an event. "Time, and not cost or capacity, is now the most critical factor for why solar power affords a viable, and often superior, alternative to gensets for disaster relief," explains Brain Bougess, founder and CEO of Nuance Energy, a solar power project installation company. As typical backup generators require a continuous supply of fuel to operate in the situation of a natural disaster, SMGs become a compelling option, as there are three main formats in which solar power can be provided in this situation. The suitcase, trailer, and container arrays vary in their configuration, ease of installation, and power capacity, creating a solution for various types of disasters.[36]

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[35] Hayden, Ernie. "Introduction to Microgrids." 2013. http://www.securicon.com/sites/default/files/Introduction to Microgrids - Securicon - 2013_1.pdf.

[36] "Getting Serious about Solar for Disaster Response and Recovery ...." 27 Oct. 2017, http://www.renewableenergyworld.com/articles/2017/10/getting-serious-about-solar-for-disaster-response-and-recovery.html. Accessed 10 Apr. 2018.

After the 2017 Hurricane Maria left large swaths of Puerto Ricans without access to power, SMGs have proven to be a valuable source of alternative energy. Two charitable organizations, Sonnen and Pura Energia, have installed 15 SMGs across the country, each of which has "hundreds of homes whose water was contaminated by the deadly Leptospirosis bacteria" in its network and is used for "power washing machines, refrigerators and some basic electrical outlets."[37] SMGs are being used as an alternative to the electricity grid monopoly, which has been very slow to restore power. Each of these grids were installed after an evaluation of the site and energy needs, and residents have remarked that the microgrids are much more reliable than the traditional grids which were previously used.[38]

In the recent wildfires that ravaged southern California, microgrids were applauded for their durability and reliability as they successfully withstood the adverse conditions. The Stone Edge microgrid ran "islanded for 10 days while areas around it experienced power outages and thousands of homes burned to the ground."[39] Despite the smoke and ash, the microgrid was able to retain 50% of its normal electricity output. The success and resiliency of the microgrid in the face of a wildfire demonstrates their unique potential to operate in conditions where traditional power sources may fail.

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[37] "Solar Plus Storage Microgrids Bring Relief to Puerto Rico." 27 Feb. 2018, https://microgridknowledge.com/solar-plus-storage-microgrids-puerto-rico/. Accessed 16 Apr. 2018.
[38] "Solar Plus Storage Microgrids Bring Relief to Puerto Rico." 27 Feb. 2018, https://microgridknowledge.com/solar-plus-storage-microgrids-puerto-rico/. Accessed 16 Apr. 2018.
[39] "Fire-Torn Northern California Becomes 'Living Lab ... - Greentech Media." 23 Feb. 2018, https://www.greentechmedia.com/articles/read/fire-torn-northern-california-becomes-living-lab-for-microgrids. Accessed 16 Apr. 2018.

3.5 Disadvantages

Although microgrids are a generally promising technology, they are in the early stages of development. Inevitably, the implementation of an SMG is not free of difficulties. The main obstacles preventing widespread use are the lack of communication between the parent and the microgrid, the cost of implementation at a large scale, and lack of knowledge about optimizing the technology for commercial purposes. While these obstacles are common in SMGs, they are not universal. Therefore, these disadvantages should not dissuade investors from looking into SMGs; instead, they should be used as criteria to vet if companies within the market will be successful.

3.5.1 Spotty Communication

Many of the advantages of SMGs rely on communication with the utility grid. Without optimal communication between the two, the microgrid cannot reliably island itself when necessary. For instance, glitches in communication between the parent and microgrid can be perceived as lack of function for the parent grid, which would cause the microgrid to rely on its own energy when it could rely on the utility grid reliably. With improved communication, SMGs can capitalize on their ability to isolate and be a clear, appealing source of alternative energy.

The struggles of communication among the microgrid network is largely due to infancy of the technology itself. It requires advanced power electronics and sophisticated coordination among customers and areas which are still being developed.[40] Successful microgrids are absolutely contingent on this technology, making its development imperative to implementing microgrids in large scale.

[40] "Microgrids - Benefits, Models, Barriers, and Suggested Policy Initiatives for the Commonwealth of Massachusetts." 2014. http://files.masscec.com/research/Microgrids.pdf.

3.5.2 Implementation costs

Implementation costs are not necessarily a disadvantage to SMGs, but their ambiguity prevents the growth of the industry. For instance, there is limited information on the total aggregate cost of microgrid operation as well as expected revenues. Thus, firms attempting to implement microgrids often struggle to find investors that trust the limited ability to estimate margins. One of the reasons for this difficulty is because microgrids can be of varying sizes and geographic footprint, both of which are important factors to cost.

According to Ricky Buch, Commercial Director of Energy Access & Renewable Hybrid Power for GE Power, the most difficult hurdles in SMG implementation is not on supply side (that can be more difficult for other microgrids, such as wind-power); rather, it is gauging demand. In many remote locations, it is necessary to send door to door surveys to the community which will use the microgrid to ensure the system is not overbuilt or underbuilt. Overbuilding is generally more common than underbuilding (to stay on the side of caution), often yielding relatively high implementation costs. Additionally, the dynamic nature of communities yields the possibility of new energy loads materializing, which could put pressure on the SMG and require more installation.

Furthermore, another barrier is the payback time on investment. Investors are often essential to kickstart a successful SMG implementation, yet due to lengthy administrative procedures for approval and permit, policy instability, and the novelty of a much of the communication technology, they are hesitant to contribute. However, with more projects in the works and improving technology, investors may be more comfortable contributing to SMG development.

Finally, according to a World Bank study on grid connection costs and transmission expansion to remote areas in developing countries, grid connection can require $8,000 - $10,000 per kilometer.

3.5.3 Faulty implementation methods

Many accounts of failing SMGs are due to not just implementation costs, but also through the methods in which they are generally built. For one, there is frequently a question of ownership. Most existing SMGs are funded by donations of politicians, leading the community powered by the SMG to often believe the donor will continue funding further maintenance and development. When the donor fails to do so, the SMG inevitably fails as well. Furthermore, a lack of security has been cited as an issue for SMGs in Nigeria, where PV solar modules have been stolen and damaged. Finally, preliminary surveys, mentioned in the previous section, are often not taken seriously enough and lack the comprehensiveness to establish a reliable grid tailored to the community[41].

4. Upstream Analysis

4.1 Overview

There are many upstream factors to consider in order to fully understand the ecosystem within which SMGs exist. Such factors include the equipment that composes an SMG, the raw materials and inputs that form the equipment, the installation of SMGs, and the necessary maintenance over the lifecycle of an SMG. Regarding the equipment used in such installations, no uniform standardization exists for the components of an average SMG. Some generalities can, however, be drawn from past projects and empirical data. Namely, SMGs must have solar panels, racking, and

[41] Akinyele, Daniel, Juri Belikov, and Yoash Levron. "Challenges of Microgrids in Remote Communities: A STEEP Model Application." *Energies*11, no. 2 (February 14, 2018). doi:10.3390/en11020432.

one or more power inverters. Furthermore, many SMGs are equipped with batteries to store energy, a generator to supplement the solar panels or create electricity when the panels cannot do so, and a microgrid controller which can come in varying degrees of sophistication. These will be the main SMG equipment components considered in this paper.

4.2 Solar Panels

The namesake component of an SMG is the solar panels. Most generally, these panels use solar cells to harness energy from the photons in light to produce electricity. Solar cells accomplish this via the photovoltaic process, which requires a photovoltaic material, traditionally a semiconductor. Crystalline silicon (c-Si) was the most popular photovoltaic material in cells on the market in 2016, accounting for over 90% of photovoltaic cell market revenue.[42] Within the category of c-Si cells, there are monocrystalline and polycrystalline (or multicrystalline) cells, also referred to as monosilicon and polysilicon. In 2016, polysilicon cells dominated the c-Si market on account of their efficiency, affordability, and versatility.[43] These benefits are characteristic of the reasons c-Si cells in general continue to dominate the market. In addition, c-Si cells boast a long lifetime of over 25 years, still producing electricity at 80% of their original efficiency at this time. Because of their numerous benefits, c-Si cells remain the most popular cell in the market. The remaining portion of the market is dominated by thin-film cells, of which several varieties exist. Cadmium Telluride (CdTe) is the most popular thin-filmed cell with cheaper production than c-Si cells but a

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[42] Srivastava, Himali. "Crystalline Silicon PV Market by Type (Mono-Crystalline and Multi-Crystalline) and End-User (Residential and Commercial, Utility-Scale) - Global Opportunity Analysis and Industry Forecasts, 2014 - 2022." Allied Market Research. August 2016. https://www.alliedmarketresearch.com/crystalline-silicon-photovoltaic-pv-market.

[43] Research, Zion Market. "Global Solar Panel Market Will Reach USD 57.5 Billion by 2022: Zion Market Research." GlobeNewswire. October 04, 2017. https://globenewswire.com/news-release/2017/10/04/1140565/0/en/Global-Solar-Panel-Market-Will-Reach-USD-57-5-Billion-by-2022-Zion-Market-Research.html.

lower efficiency and shorter lifetime.[44] Historical solar module production by cell type is presented in Figure 7. Promising research exists for the effectiveness of thin-film Perovskite solar cells, which have demonstrated a 50% increase in efficiency over c-Si cells. However, these cells have a number of drawbacks to be addressed before they are widely deployed in commercial use.[45] Since silicon continues to be the most popular material in photovoltaic cells on the market, this paper will only consider silicon in its upstream analysis.

4.3 Silicon Production

The silicon in solar cells originates from silica mines, frequently in the form of silica quartzite. After being extracted, the quartzite is heated so that the oxygen within it is released, bringing it to its more pure metallurgical grade. Then this material undergoes a chemical process with hydrochloric acid, copper, hydrogen and more heat, which ultimately produces the crystalline silicon. In this form, the silicon is between 99.99999% to 99.9999999% pure, which is of critical importance for the efficiency of the cells. Then, this pure c-Si is doped with phosphorus and boron to form a semiconductor. This semiconductor material is sawed into discs, coated with titanium dioxide, and arranged in a frame, typically made of aluminum due to its low weight which leads to easy installation of the panels. The final step of the process is to cover the cell with glass. It should be noted that this process is not without significant environmental cost. Sawing silicon into discs creates dust with up to 50% waste, and this dust poses a significant health risk when inhaled. Furthermore, silicon production reactors are cleaned with sulfur hexafluoride, which is the most

[44] "Solar Photovoltaic Cell Basics." U.S. Department of Energy. August 13, 2016. https://www.energy.gov/eere/solar/articles/solar-photovoltaic-cell-basics.
[45] Bullis, Kevin. "A Cheap Material Is Set to Cut the Cost of Solar." MIT Technology Review. February 03, 2015. https://www.technologyreview.com/s/534511/a-cheap-material-boosts-solar-cells-by-50-percent/; "Perovskite Solar." Perovskite Solar Panels: Introduction and Market Status | Perovskite-Info. January 8, 2018. https://www.perovskite-info.com/perovskite-solar.

potent greenhouse gas per molecule as well as an indirect contributor to acid rain.[46] There are ideas to replace hydrofluoric acid with ammonium bifluoride, supported by literature that proves its validity, which is promising for the future. The environmental costs linked to the production of silicon are definitely areas for future improvement from an impact perspective.

4.4 Crystalline Silicon & Solar Module Markets

In order to analyze the global silicon production market, the solar module production and installation markets must also be considered in tandem. In 2016, the global solar panel market accounted for USD 30.8 billion and was expected to reach USD 57.3 billion by 2022 with a 10.9% implied compound annual growth rate (CAGR) over this period. This growth was forecasted to stem mainly from continued government incentives as well as growth from technological advances and a desire to produce more electricity in an environmentally friendly manner. The major setbacks to the market's growth were expected to be high installation and maintenance costs.[47] Solar panel installation was expected to see slightly less growth during the first half of this period, with less than 10% growth forecasted from 2017 - 2019.[48] This was a sizable decrease from the 40% CAGR the installation market experienced from 2010 to 2016.[49]

As a result of this slowing growth, polysilicon producers, which depend on photovoltaic cell installers for 90% of global polysilicon consumption, were expected to experience extreme

[46] Gree, Adam De. "Materials Used in Solar Panels." AZoM.com. May 07, 2015. https://www.azom.com/article.aspx?ArticleID=12014.
[47] Research, Zion Market. "Global Solar Panel Market Will Reach USD 57.5 Billion by 2022: Zion Market Research." GlobeNewswire. October 04, 2017. https://globenewswire.com/news-release/2017/10/04/1140565/0/en/Global-Solar-Panel-Market-Will-Reach-USD-57-5-Billion-by-2022-Zion-Market-Research.html.
[48] "Polysilicon Market Outlook 2020." Bernreuter Research. November 24, 2016. http://www.bernreuter.com/en/news/press-releases/polysilicon-market-outlook-2020.html.
[49] "Photovoltaics Report." Fraunhofer Institute for Solar Energy Systems, ISE. February 26, 2018. https://www.ise.fraunhofer.de/content/dam/ise/de/documents/publications/studies/Photovoltaics-Report.pdf.

competition in 2018 and onward. In addition, further decreases in the price of polysilicon were expected to increase this competition.[50] In September of 2016, several years of polysilicon supply growth outpacing demand drove down its price to $12.65/kg which caused at least eight Chinese manufacturers to temporarily stop production until prices recovered.[51] This oversupply of polysilicon was expected to continue until at least 2019, with new production capacities entering the market, 70% of which would be in China.[52] Monosilicon, on the other hand, was expected to see an increased demand growth as a result of its higher efficiency and the increasing use of diamond wire saws, which allow for production of silicon wafers with decreased kerf waste. These saws were already popular in the production of monosilicon cells, and they were expected to gain popularity in the production of polysilicon as well, meaning that the silicon consumption per solar cell was expected to decrease.[53] This expectation was a continuation of the historic trend, as shown in Figure 8. In summary, a combination of decreased demand for polysilicon for photovoltaic cells, oversupply of polysilicon, and more efficient use of polysilicon in cell production was expected to contribute to an extremely cutthroat polysilicon production market. Meanwhile, the demand for monosilicon cells was expected to grow faster, making the monosilicon market an increasingly more favorable environment for producers.

In 2016, the production of solar cells was dominated by China and Taiwan with 68% of module production occurring in these two countries. The remaining countries in the Pacific and Central

[50] "Photovoltaics Report." Fraunhofer Institute for Solar Energy Systems, ISE. February 26, 2018. https://www.ise.fraunhofer.de/content/dam/ise/de/documents/publications/studies/Photovoltaics-Report.pdf.
[51] "Polysilicon & Wafer Rankings 2016." PV Magazine. March 2017. http://www.bernreuter.com/fileadmin/user_upload/library/Polysilicon-and-wafer-rankings-2016_pv-magazine-03-2017.pdf.
[52] "Polysilicon Market Outlook 2020." Bernreuter Research. November 24, 2016. http://www.bernreuter.com/en/news/press-releases/polysilicon-market-outlook-2020.html.
[53] "Silicon Consumption to Drop to 3.6 Grams per Watt by 2020." Bernreuter Research. June 20, 2017. http://www.bernreuter.com/fileadmin/user_upload/polysilicon-report/Bernreuter-Research-Polysilicon-Consumption-for-Solar-Cells.pdf.

Asian region accounted for 14% of production while the United States and Canada contributed 6% and Europe contributed 4%.[54] A list of the largest panel manufacturers by shipment volume as well as their headquarters' locations can be found in Figure 9, and historic production by region can be found in Figure 10 and Figure 11. The growth in China's production of panels is the most remarkable feature of these graphs. This growth was spurred on by heavy federal government incentives, estimated to be $47 billion. As a result of this extraordinary growth of panel producers in China, the price of panels globally dropped by 80% from 2008 to 2013.[55]

The demand for panels can be divided into three sources: residential, commercial, and utility. In 2016, commercial application accounted for the largest market share by revenue and was expected to hold its lead until at least 2022. Meanwhile, the residential and utility segments, although smaller in size, were expected to experience higher growth rates. The largest markets for solar panels in 2016 were the Asia Pacific region and North America, respectively. The Asian market was expected to continue dominating the market as a result of growing urbanization, expanding populations, and the decreasing costs of production of panels. North American demand was also expected to continue growing as a result of favorable government regulations[56] and large residential solar demand, which was notably the largest source of demand from the region.[57] Figure

[54] "Photovoltaics Report." Fraunhofer Institute for Solar Energy Systems, ISE. February 26, 2018. https://www.ise.fraunhofer.de/content/dam/ise/de/documents/publications/studies/Photovoltaics-Report.pdf.
[55] Fialka, John. "Why China Is Dominating the Solar Industry." Scientific American. December 19, 2016. https://www.scientificamerican.com/article/why-china-is-dominating-the-solar-industry/.
[56] Government policies regarding solar energy change rapidly. This forecast of expected demand growth was from October, 2017 while in January, 2018 new U.S. legislation passed imposing increased tariffs on imported panels. This legislation is discussed in the next section regarding installation, but at the time of this writing it was unclear what trajectory U.S. solar demand, and hence world demand, was most likely to follow.
[57] Research, Zion Market. "Global Solar Panel Market Will Reach USD 57.5 Billion by 2022: Zion Market Research." GlobeNewswire. October 04, 2017. https://globenewswire.com/news-release/2017/10/04/1140565/0/en/Global-Solar-Panel-Market-Will-Reach-USD-57-5-Billion-by-2022-Zion-Market-Research.html.

12 and Figure 13 show cumulative photovoltaic cell installation by region and installation numbers for 2016.

4.5 Installation

In the United States market alone, there were over 3,340 firms offering solar installation in 2018. This market was extremely fragmented with the four largest players accounting for less than 20% of market share as of 2018. By and large, the market was dominated by small operators that served buyers within narrow geographic areas. As a result of this saturation of suppliers, the stiff competition between them, and the decreasing prices of photovoltaic panels, the price of solar installation in the U.S. fell 9.1% annually between 2015 and 2018. U.S. solar installation prices were expected to decrease a further 2.8% annually in the period from 2018 to 2021 for these same reasons. The expected rate of price decrease was forecasted to slow down mainly as a result of new U.S. import tariffs.[58] Specifically, in January, 2018, the U.S. congress passed a 30% duty on imported solar panels for the rest of the year that would decrease 5% annually until reaching 15% in 2021. This tariff caused U.S. solar installation to become more costly since the price of panels increased for suppliers. However, the strongest impact of this tariff was partially mitigated since foreign suppliers shipped excess panels into the country in preparation of the January decision, which were expected to fulfill U.S. panel demand for the first half of 2018.

At the same time, the U.S. panel installation market was expected to be strongly affected by other solar policies: namely, an IRS business investment tax credit equal to 30% of the cost of solar panel installation. The U.S. Congress passed an extension of these tax credits, originally scheduled to end in 2017, in December 2015, which made them available for any solar energy system in

[58] Windle, Sean. *Solar Panel Installation*. IBISWorld. Report no. 48646111. February, 2018.

operation by the end of 2019. The credit would then be reduced to 26% in 2020, to 22% in 2021, and to 10% in 2022 where it would remain permanently.[59] In preparation of the ending tax credits, U.S. installation demand is expected to surge which would partially counteract the price effects of the import tariff. Notably, U.S. businesses that begin installation on their solar energy systems before the end of 2021 can claim the larger 22.0% credit, so long as the system is operational by the end of 2023.[60]

Despite its dependence on government policy, the U.S. installation market displayed several signs of maturity in 2018. Advances in technology and cost reductions in manufacturing solar panels had lowered installation costs, and many suppliers were able to utilize economies of scale with the increased demand. Furthermore, as solar panels became an evermore popular source of energy, capital markets were providing more competitive financing for buyers wanting to install solar energy generation systems.[61]

4.6 Batteries

Besides solar panels and their installation, SMGs typically require batteries, power inverters, and racking, which all add significant cost to any solar energy system. In 2016, lithium ion batteries were the most popular battery for solar cells, accounting for 99% of all grid-tied storage deployments in the second quarter. Because of their popularity, this paper will only consider lithium ion batteries although it should be noted that some microgrids use different batteries, such as lead acid ones or various flow batteries. Alternatives to traditional lithium ion batteries are an area of increased focus, since lithium ion batteries can typically only store energy for up to four

[59] Darker Skies Ahead? How Procurement Can...ariffs | IBISWorld Procurement Insider.pdf
[60] Solar Panel Installation [48646111] in the US procurement report.pdf
[61] Solar Panel Installation [48646111] in the US procurement report.pdf

hours and degrade substantially over time. Batteries that can store energy for more than four hours, called long-duration energy storage systems, are important because this is crucial for a microgrid to provide reliability when it is either not connected to a larger grid or the larger grid it is connected to is down.[62] Lithium ion battery degradation is also a relevant issue because most solar panels have a lifetime of 20-25 years while batteries typically last between 6-10 years. As a result, battery replacement is a recurrent cost for SMG owners.[63]

In the period from 2014 to 2017, the price of lithium ion batteries increased 1.1% annually. This price growth was largely a result of increased demand for the batteries as well as increasing global lead prices. Lithium ion batteries essentially consist of two lead plates and plastic; these two inputs account for the majority of material prices, and materials account for over 57% of the cost of production. Hence, increasing lead prices generated upward pressure on the price of lithium ion batteries while, at the same time, decreasing plastic prices fought against this effect. Additionally, increased foreign competition further stunted the price growth of lithium ion batteries in the U.S. These trends are expected to continue in the period from 2017-2020, with a forecasted price growth of 1.9%. In general, the lithium ion battery market is still in an immature, growth stage characterized by this increasing demand and sales growth. The future of the market is also strongly dependent on potential future technological advances.

4.7 Power Inverters

All SMG's require some variant of a power inverter. Traditionally, this is a DC to AC inverter, which converts the DC electricity generated by the solar panels and stored in batteries into AC

[62] Beyond Four Hours_ESS Inc White Paper_12_2016_mr.pdf
[63] Solar Panel Installation [48646111] in the US procurement report.pdf

current, the electricity that typically flows through grids.[64] In 2016, the global power inverter market reached a value of US $60 billion dollars, and was forecasted to grow to $90 billion in 2022.[65] The demand for inverters from solar energy systems composed only a fraction of this market. In the period from 2014-2017, the price of inverters increased by 1.1%, fueled by increasing demand and stymied by falling production costs. This price growth was expected to continue at 0.8% until 2020 also as a result of increasing demand. The inverter market is mature with over 9,000 vendors and widespread product availability with intense, price-based competition between suppliers. With specific regard to SMGs, inverters are important because they add significant upfront and recurrent costs. Inverters required for solar energy projects are often heavy-duty and can cost between US $5,000 and $100,000. This inverter will be in continual operation converting solar power into AC current and will usually be exposed to the elements year-round. This necessitates frequent, at least annual maintenance and will add to the cost of any solar project.[66]

4.8 Racking

Panel racking, also referred to as mounting, is the last requisite component of an SMG that this paper considers. Although many variations of racking exist, all mounting systems are intended to support the solar panels so that they are well-positioned, oriented, and inclined to receive sunlight. In 2016, the most popular method of racking was ground-mounted, accounting for over 76.7% of the US $6.92 billion solar mounting market at this time, while roof-mounted composed the

[64] https://www.solarchoice.net.au/blog/ac-vs-dc-solar-battery-storage-explained
[65] https://globenewswire.com/news-release/2017/11/24/1205729/0/en/Global-Power-Inverter-Market-2017-2022-Market-Reached-a-Value-of-US-60-Billion-in-2016.html
[66] Power Adapters & Inverters [27812539] in the US procurement report.pdf

remaining 23.3%.[67] Depending on the chosen racking method, the cost of mounting will vary, but in general racking accounts for 5-10% of the cost of an installed solar energy system.[68] The racking market was forecasted to grow to $9 billion by 2024 as a result of increased solar energy demand with a largely fragmented supply side.[69] Although the overall market is characterized by having many vendors, individual segments show strong consolidation with four or five vendors controlling 80% of the segment. Hence, increased mergers and acquisition activity was expected for the period following 2017.[70] From an impact perspective, segments like racking and inverters may show less potential, but as the cost of solar modules and installation continues to decrease, these components become an evermore important consideration in the profitability of an SMG since their relative cost is rising.[71]

4.9 Microgrid Controllers & Other Components

In addition to the components already described, SMGs also can have a microgrid controller. This is a software-based device that controls the various operations of the SMG in order to best fulfill the needs of those receiving electricity from the SMG. These controllers can switch which resource a microgrid is using to generate energy at any given moment. For instance, the controller of a microgrid with solar panels and a diesel generator may only turn on the generators when the panels cannot produce sufficient electricity for the SMG's customers. Also, a controller

[67] https://globenewswire.com/news-release/2017/05/25/995994/0/en/Solar-PV-Mounting-Systems-Market-worth-9bn-by-2024-Global-Market-Insights-Inc.html
[68] https://www.greentechmedia.com/articles/read/3-things-you-should-know-about-the-us-solar-racking-market#gs.80XrC9Q
[69] https://globenewswire.com/news-release/2017/05/25/995994/0/en/Solar-PV-Mounting-Systems-Market-worth-9bn-by-2024-Global-Market-Insights-Inc.html; https://www.greentechmedia.com/articles/read/3-things-you-should-know-about-the-us-solar-racking-market#gs.80XrC9Q
[70] https://www.greentechmedia.com/articles/read/3-things-you-should-know-about-the-us-solar-racking-market#gs.80XrC9Q
[71] https://www.greentechmedia.com/articles/read/unirac#gs.2i==PvQ

of a grid-connected, battery-equipped SMG may continuously check wholesale electricity prices and buy power from the grid when wholesale energy prices fall, allowing the solar panels to charge the grid's batteries so that this energy can be used later, potentially when wholesale prices have increased. A controller is not a necessary component of an SMG, but it becomes essential when a microgrid is grid-connected or has multiple sources of energy to orchestrate.[72] However, to many in the microgrid industry, the best type of controller for a specific microgrid remains uncertain as of this writing.[73] According to Navigant Research, the top microgrid controller producers as of 2018 were Schweitzer Engineering Laboratories, Schneider Electric, Opus One Solutions, Encorp, and Siemens.

4.10 Maintenance

As already mentioned, SMGs require maintenance throughout their lifetime. For solar panels, this means cleaning the panels periodically to prevent dust, dirt, and even mold from building up on the panels.[74] This is thought to be the main maintenance requirement for panels, but the whole extent of their maintenance was not fully known as of 2018 since widespread solar panel installation was still a relatively new phenomenon. Furthermore, from both a financial and impact perspective, there is opportunity to improve the recycling process of panels. As of this writing, there were not enough defunct panels in the market to create economically viable, mass scale recycling centers for photovoltaic panels. As more panels enter the market, the need for

[72] https://microgridknowledge.com/microgrid-defined/
[73] https://microgridknowledge.com/microgrid-controllers-industry/
[74] Solar Panel Installation [48646111] in the US procurement report.pdf; https://www.technologyreview.com/s/429529/how-solar-based-microgrids-could-bring-power-to-millions/

such centers which can utilize economies of scale to drive prices downward will become more imperative.[75]

Besides panels, batteries must be replaced several times throughout a solar energy system's lifetime and the inverter must be routinely checked. The maintenance costs of SMGs are certainly not insurmountable, but they can become especially detrimental to a project when those operating the SMG do not know how to properly care for it. Specifically, SMG projects where the energy system is installed and then left to untrained or unknowledgeable proprietors to take care of alone are especially worrisome. Possible solutions include requiring the company that designs or installs the microgrid to clean and maintain the system.[76]

5. Profitability and Impact: Framework for Analysis

For a summary of our general framework for investment analysis, see Figure 25.

When evaluating a potential investment, one must look both to the potential profitability as well as a tangible social impact. We use several key analytical lenses to survey an investment in solar microgrids. We begin with identifying a market suitable for microgrids, comparing both the undeveloped and developed worlds. This is done by looking at energy demand in general, the reliability of the current energy infrastructure, and especially looking at markets with demand specifically for green energy; there is potential upside given through green government incentives. We also compare and contrast alternative green energy sources such as wind, biofuel, and hydropower. Finally, we survey the potential social impact metrics of employing solar

[75] Solar Panel Installation [48646111] in the US procurement report.pdf
[76] https://www.technologyreview.com/s/429529/how-solar-based-microgrids-could-bring-power-to-millions/

microgrids, whether it's CO_2 offset or driving further economic development in both the electrified and yet-to-be electrified world.

5.1 Market

5.1.1 Underdeveloped world

In the underdeveloped world, SMGs are a promising method to deliver energy to large groups of people in areas where electricity is being newly introduced. For one, they take away the need for large-scale capital projects and investments since they are much more localized. Forbes reports that the costs of solar and other renewable energy sources are also plummeting relative to their fossil fuel counterparts, with onshore wind and solar costs falling to between $.06-$.10 per KwH by 2020-2022 as compared to the general price range of fossil fuels being between $.05-$.17 per KwH, making solar power a very attractive investment.[77] Namely, a report by PV Tech, supported by the World Bank and Bloomberg New Energy Finance (BNEF), details the rise in demand for off-grid solar.[78] Namely, it claims that one in three households powered by off-grid sources will demand solar-powered energy sources by 2020.[79] We find an increasing demand for solar energy as the energy source of choice in off-grid energy users, with off-grid solar being very closely related to and easily improved by creating microgrids in these off-grid locations. This increase in demand is supported by falling costs of solar products relative to kerosene and other energy

[77] Dudley, Dominic. "Renewable Energy Will Be Consistently Cheaper Than Fossil Fuels By 2020, Report Claims." Forbes. January 13, 2018. Accessed May 06, 2018. https://www.forbes.com/sites/dominicdudley/2018/01/13/renewable-energy-cost-effective-fossil-fuels-2020/#58e64a94ff2e.

[78] Kenning, Tom. "One in Three Off-grid Households Will Use Solar Products by 2020." March 03, 2016. Accessed May 06, 2018. https://www.pv-tech.org/news/one-in-three-off-grid-households-will-use-solar-products-by-2020.

[79] Kenning, Tom. "One in Three Off-grid Households Will Use Solar Products by 2020." March 03, 2016. Accessed May 06, 2018. https://www.pv-tech.org/news/one-in-three-off-grid-households-will-use-solar-products-by-2020.

sources.[80] Moreover, the level of investment in off-grid solar in 2015 was 15 times as large than in 2012.[81] Based on these findings, off-grid solar companies pose the potential of being very successful investments due to an increase in market demand, an augmented flow of capital towards the space, and an increasing focus on fulfilling climate action goals.

Moreover, with over a billion people without electricity, SMGs are a highly promising way of capturing the energy needs and market demand in the developing world where grid infrastructure is largely absent.[82] There is substantial sunlight in many underdeveloped areas, such as Africa, along with very low costs of producing solar energy. Ninety-five percent of individuals without access to electricity reside in Sub-Saharan Africa and developing Asia, with eighty percent in rural areas.[83] Thus, there remains a huge need for energy resources in these areas, especially from sources like SMGs that can be islanded.

5.1.2 Developed world

In the developed world, the up-front capital costs of infrastructure installation have already been invested. There is, however, substantial costs in maintaining and in replacing the already existing distribution network. Specifically as the US energy infrastructure is aging and will require immense cost to update, microgrids are more promising than ever to bypass this cost as well as provide energy reliability in the case that energy infrastructure fails. Microgrids are a great concept for the US government to explore and invest in rather than in conventional energy distribution

[80] Kenning, Tom. "One in Three Off-grid Households Will Use Solar Products by 2020." March 03, 2016. Accessed May 06, 2018. https://www.pv-tech.org/news/one-in-three-off-grid-households-will-use-solar-products-by-2020.
[81] Kenning, Tom. "One in Three Off-grid Households Will Use Solar Products by 2020." March 03, 2016. Accessed May 06, 2018. https://www.pv-tech.org/news/one-in-three-off-grid-households-will-use-solar-products-by-2020.
[82] Young, Jacob R. *Smart Grid Technology in the Developing World*. Report. Seattle Pacific University. 2017.
[83] Allotrope Partners. "Microgrid Market Analysis & Investment Opportunities." http://sun-connect-news.org/fileadmin/DATEIEN/Dateien/New/MIA_Market_Report_2017.pdf.

networks. The market demand in the developed world comes from the energy cost of solar energy becoming lower than that of conventional fossil fuels. In addition, a key driver of demand is in green energy mandates, as several states and green-focused countries have mandated the investment and implementation of green energy sources, in ways such as offering tax incentives that further increase profitability. Microgrids can also serve as an essential backup for government facilities and prisons.

The reason microgrids have attractive impact investing qualities in the developed world and, more specifically, in the United States is that conventional energy infrastructure and transportation requires immense capital costs to build and maintain, as infrastructure spans and connects large areas.[84] It would cost $5 trillion to replace the current US infrastructure. These cost include high and low-voltage transmission lines and other costs associated with conventional energy provision.

Much of these infrastructure costs are not necessary when there is a better way to augment, secure, and protect developed energy supply through localized microgrids. Furthermore, Federal Energy Regulatory Commission's most recent Energy Infrastructure Update expects utility-scale solar would add 43.5 GW new capacity by 2020.[85]

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[84] Rhodes, Joshua D. "The Old, Dirty, Creaky US Electric Grid Would Cost $5 Trillion to Replace. Where Should Infrastructure Spending Go?" The Conversation. May 03, 2018. Accessed May 06, 2018. https://theconversation.com/the-old-dirty-creaky-us-electric-grid-would-cost-5-trillion-to-replace-where-should-infrastructure-spending-go-68290.

[85] Federal Energy Regulatory Commission. "Office of Energy Projects Energy Infrastructure Update for January 2018"

5.2 Timing

5.2.1 Positives

A growing push for "green energy" reform throughout the world, as illustrated by the Paris Climate Accords and increased acknowledgement of global warming, makes this a great time for clean energy investments.[86] There are currently tax incentives to offset the costs of solar investment in many countries globally, as well as green energy mandates that make the current time attractive for green investment. Renewable energy subsidies in the United States total $16 billion, makes solar energy much more competitive and attractive in the energy markets as compared to fossil fuels, which are subsidized less than a fifth of this amount, especially for individuals who want to become energy independent themselves.[87] In addition, solar energy is on the cusp of being price competitive with fossil fuels, this taking place by 2020 and has further potential to lower costs in the coming years even without the incentives in place.[88]

Microgrids may benefit from federal tax credits, such as the 30 percent investment tax credit now available for solar projects. Also, on the state and local level, many governors and mayors in the United States have called for an increased push towards clean energy, especially since the Trump administration's denouncement of the Paris Climate Accords. For example, Massachusetts aims

[86] Hirji, Zahra, Marianne Lavelle, Bob Berwyn, Dan Gearino, Georgina Gustin, Neela Banerjee, John H. Cushman Jr., James Bruggers, Meera Subramanian, Paul Horn, Nicholas Kusnetz, Phil McKenna, and Katherine Bagley. "More Americans than Ever Understand Climate Change-and Elected a Denier Anyway." InsideClimate News. January 24, 2017. Accessed October 04, 2018. https://insideclimatenews.org/news/24012017/global-warming-trump-us-knowledge.

[87] "Should the U.S. Shift More Energy Subsidies to Renewable Power?" Scientific American. Accessed May 06, 2018. https://www.scientificamerican.com/article/making-renewable-energies-competitive/.

[88] Dudley, Dominic. "Renewable Energy Will Be Consistently Cheaper Than Fossil Fuels By 2020, Report Claims." Forbes. January 13, 2018. Accessed May 06, 2018. https://www.forbes.com/sites/dominicdudley/2018/01/13/renewable-energy-cost-effective-fossil-fuels-2020/#58e64a94ff2e.

for 40 percent clean energy by 2030, and they are only half way to this goal.[89] In addition, New York has pledged 50 percent clean energy by 2030, and they are at 24 percent right now.[90]

5.2.2 Negatives

The drawbacks to investing now, however, stem from the current United States administration. Due to President Trump's enactment of tariffs on solar modules, solar investments and projects are more costly. Tariffs on solar modules would be as high as 30 percent, and also would phase out over time.[91] While this could serve as a boon for local solar manufacturing companies, solar projects that use more affordable foreign materials will take a hit, thus hurting the general outlook for solar energy installation. This is especially problematic since the tariffs don't affect wind generation and other forms of green energy in the same way as they do affect solar.[92] In essence, these tariffs create a competitive imbalance against new solar projects. The Solar Energy Industries Association, a group that represents installers and other businesses across the solar industry, opposed the effort to install protectionist policies on solar energy.[93] Furthermore, this organization estimates that the tariffs imposed by the Trump administration will cost 23,000 jobs this year and result in the delay or cancellation of billions of dollars in solar investments.[94]

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89 "Frequently Asked Questions: Mass Energy's Green Power Program." Mass Energy Consumer Alliance. Accessed May 06, 2018. https://www.massenergy.org/renewable-energy/faq.

90 Ailworth, Erin. "U.S. Imposes New Tariffs, Ramping Up 'America First' Trade Policy." The Wall Street Journal. January 23, 2018. Accessed May 06, 2018. https://www.wsj.com/articles/u-s-imposes-trade-tariffs-signaling-tougher-line-on-china-1516658821.

91 Ailworth. "U.S. Imposes Tariffs"

92 Ailworth. "U.S. Imposes Tariffs"

93 Ailworth. "U.S. Imposes Tariffs"

94 Ailworth. "U.S. Imposes Tariffs"

5.3 Competition

When we consider investment in SMGs, we must look at the competition surrounding solar energy as a whole. This includes every type of energy source--such as coal, oil, wind, biofuel, and hydrogen. Upon comparison, we find that solar energy has the greatest potential in terms of balancing profitability, scalability, and environmental efficacy.

5.3.1 Solar vs. Wind, Biofuels, and Hydropower

When it comes to renewables, wind and solar together will represent more than 80% of global renewable capacity growth in the next five years.[95] The major trade-off lies between these two energy sources. Wind turbines often produce energy at a cheaper rate than solar panels, but this gap is decreasing over time.[96] The advantage of solar projects, however, comes in their flexibility; it takes much less time for solar projects to be completed, as they can be installed on an individual residential level, whereas wind projects take much more planning and regulation to reach completion.[97] Wind projects also suffer from their efficacy of only being in particular, windy environments, and this technology suffers from opposition due to being large and unsightly, along with needing to be situated high above any obstacles that would block the wind, posing geographical challenges for installation.[98]

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[95] "Renewables 2017 : Key Findings." S: Global Carbon Dioxide Emissions, 1980-2016. Accessed May 06, 2018. https://www.iea.org/publications/renewables2017/.

[96] Aggarwal, Vikram. "Solar vs. Wind Energy: What's Better in 2018? | EnergySage." Solar News. September 28, 2018. Accessed October 04, 2018. https://news.energysage.com/solar-vs-wind-energy-right-home/.

[97] Aggarwal, Vikram. "Solar vs. Wind Energy: What's Better in 2018? | EnergySage." Solar News. September 28, 2018. Accessed October 04, 2018. https://news.energysage.com/solar-vs-wind-energy-right-home/.

[98] US Energy Information Administration. "Monthly Energy Review." April 2018. https://www.eia.gov/totalenergy/data/monthly/pdf/mer.pdf

In the United States, however, wind is actually more popular than solar: “In the United States, wind power is significantly more popular than solar. Out of all the renewable energy produced in the U.S. in 2017, 21% came from wind, while just 7% came from solar power. Utilities and large scale operations prefer heavily utilize wind energy while homeowners prefer solar energy.”[99] This suggests that some favoritism of wind power still exists.

In terms of biofuels, demand for this renewable energy source continues to be on the rise, potentially curtailing demand for solar. In fact, according to the International Energy Association, “biofuels are still expected to represent over 90 percent of total renewable energy consumption in road transport by 2022.”[100] Despite this domination of renewables in the transport industry, it is not as scalable as solar energy and has some greater emission trade-offs.

Hydropower, another renewable energy source gaining traction within the United States is another major competitor to solar power. The International Energy Agency reports that, “Hydropower will remain the largest source of renewable electricity generation in our forecast, by 2022 followed by wind, solar PV and bioenergy. In the next five years, growth in renewable generation will be twice as large as that of gas and coal combined.”[101] The main drawback to hydropower lies in that to successfully create a hydropower plant, significant areas of surface water are required, both of which can be extremely costly.[102]

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[99] EIA. “Monthly Energy Review.”

[100] "Renewables 2017: Analysis and Forecasts to 2022." 2017. https://www.iea.org/Textbase/npsum/renew2017MRSsum.pdf.

[101]"IEA: Global Renewable Electricity Generation Set to Grow More Than One-Third by 2022 | News | State of Green." Home. Accessed May 06, 2018. https://stateofgreen.com/en/profiles/state-of-green/news/iea-renewable-electricity-set-to-grow-40-globally-by-2022.

[102] Thill, Scott. "Why Is Corporate America Picking Wind Power over Solar?" The Guardian. December 21, 2016. Accessed October 04, 2018. https://www.theguardian.com/sustainable-business/2016/dec/21/solar-wind-energy-renewables-google-microsoft-amazon.

Ultimately, by surveying and comparing the different average energy costs in the US, we see that solar energy is competitive with different forms of renewable energy. Solar energy also seems to be the one with the least environmental impact, as well as greater scalability. Furthermore, over time these energy sources will grow stronger as technology improves (see Figure 14).[103]

5.3.2 Solar vs. Nonrenewable Sources

Moreover, in the competition against oil and coal, new renewable projects are actually more cost-effective than new oil and coal plants.[104] Renewables represented almost two-thirds of new net electricity capacity additions in 2016, with almost 165 gigawatts (GW) coming online, according to the IEA.[105] Therefore, with expanding energy needs due to increasing global growth and energy demand, solar energy is a promising way to meet the demand in a sustainable, environmentally-conscious, profitable way.[106]

As technology progresses very rapidly, the cost of solar energy is plummeting, and is more profitable than other forms of energy such as coal and nuclear energy. This is illustrated by the graph in Figure 15[107]. By 2030, solar energy will be the cheapest energy source besides onshore

[103]"Renewable Electricity Levelized Cost Of Energy Already Cheaper Than Fossil Fuels, And Prices Keep Plunging." Energy Innovation: Policy and Technology. February 05, 2018. Accessed October 04, 2018. http://energyinnovation.org/2018/01/22/renewable-energy-levelized-cost-of-energy-already-cheaper-than-fossil-fuels-and-prices-keep-plunging/.

[104] EIA. "Monthly Energy Review."

[105] "OECD - Electricity and Heat Generation from Renewables (Edition 2017/1)." *IEA Renewables Information Statistics*, 2017. doi:10.1787/22ad78a3-en.

[106] Jacobson, Mark Z., Mark A. Delucchi, Guillaume Bazouin, Zack A. F. Bauer, Christa C. Heavey, Emma Fisher, Sean B. Morris, Diniana J. Y. Piekutowski, Taylor A. Vencill, and Tim W. Yeskoo. "100% Clean and Renewable Wind, Water, and Sunlight (WWS) All-sector Energy Roadmaps for the 50 United States." *Energy & Environmental Science* 8, no. 7 (2015): 2093-117. doi:10.1039/c5ee01283j.

[107] "Renewable Electricity Levelized Cost Of Energy Already Cheaper Than Fossil Fuels, And Prices Keep Plunging." Energy Innovation: Policy and Technology. November 10, 2018. Accessed December 10, 2018. https://energyinnovation.org/2018/01/22/renewable-energy-levelized-cost-of-energy-already-cheaper-than-fossil-fuels-and-prices-keep-plunging/.

wind, naturally being the most profitable from those surveyed.[108] The competition for replacing fossil fuels does come from onshore wind, as it is cheaper. Nonetheless, since wind farms are larger projects, requiring hundreds of millions and even billions to be built, due to immense government regulation and planning needed,[109] they take more time and government supervision to take place. Thus, local SMG, which allow greater flexibility and pose lower upfront costs are more dynamic and more easily implemented.

5.4 Business Model

In the United States, the implementation of SMGs is most profitable in areas with the highest electricity costs. This coincides with the Northeast of the United States, where there are also many mandates to switch from fossil fuels into renewable energy types. As the Wall Street Journal states "the six-state region—where electricity costs are 56% above the national average—is heavily dependent on natural gas-fired power after years of losing older, uneconomic coal, oil and nuclear plants to retirement.[110] Gas is also in high demand for heating area homes."[111] In addition, there is also the advantage of a demand for more reliable energy to prevent outages in the case of extreme weather. Because SMGs can island itself from the main grid, they are a potential solution for this problem. Even without incorporating solar, energy controllers alone prove to be much more efficient. They can control load in response to sudden events, signals from the market, and even

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108 "Renewable Electricity Levelized Cost Of Energy Already Cheaper Than Fossil Fuels, And Prices Keep Plunging." Energy Innovation: Policy and Technology. November 10, 2018. Accessed December 10, 2018. https://energyinnovation.org/2018/01/22/renewable-energy-levelized-cost-of-energy-already-cheaper-than-fossil-fuels-and-prices-keep-plunging/.
109 Erin Ailworth. "Plans for U.S. Wind Farms Run Into Headwinds." The Wall Street Journal. July 09, 2017. Accessed September 04, 2018. https://www.wsj.com/articles/plans-for-u-s-wind-farms-run-into-headwinds-1499605200?mod=searchresults&page=1&pos=1.
110 Ailworth, Erin, and Jon Kamp. "New England Has a Power Problem." The Wall Street Journal. February 23, 2018. Accessed November 04, 2018. https://www.wsj.com/articles/new-england-has-a-power-problem-1519390800.
111 Ailworth, Erin, and Jon Kamp. "New England Has a Power Problem." The Wall Street Journal. February 23, 2018. Accessed November 04, 2018. https://www.wsj.com/articles/new-england-has-a-power-problem-1519390800.

forecasted prices. Since microgrids are a more localized type of energy distribution, the business model should be based on the creation of new microgrid projects on a very local level through partnerships with communities and utilities, utilizing federal solar tax credits and through incentives such as green initiatives/mandates.[112] (See Figure 16)

For rural projects, the model is much simpler. Given the advantage of not having to invest in infrastructure to connect these rural areas to a central grid, solar microgrids are an easier and more profitable method of electrifying these areas. Thus, a suitable model would be to simply find areas with an attractive solar profile (plentiful sunlight) and currently dependent on alternative forms of energy such as biomass or diesel, and work to create an independent solar microgrid.

5.5 Impact

SMGs tackle the UN's goals of universal access to affordable, reliable and modern energy and an increased renewable share in the global energy mix.[113] This can be achieved due to the increasing affordability and ease of implementation in countries with higher rates of rural living and no existing capital-intensive energy infrastructure.

5.5.1 Environmental

The main environmental consideration to make in regards to solar microgrids is the substitution effect away from greenhouse gas emitting energy sources such as coal and gasoline into renewable and non-greenhouse emitting solar energy. It is a widely observed phenomenon that greenhouse gas emissions may be a key driver of global climate change and temperature rise. Global

[112] "How Microgrids Can Achieve Maximum Return on Investment (ROI)." *Microgrid Knowledge*, 2016. 2016. https://w3.usa.siemens.com/smartgrid/us/en/microgrid/documents/mgk guide to how microgrids achieve roi v5.pdf.
[113] "SDGs .:. Sustainable Development Knowledge Platform." United Nations. Accessed November 04, 2018. https://sustainabledevelopment.un.org/topics/sustainabledevelopmentgoals.

temperatures have increased by 1.62 degrees fahrenheit since the late 1800s. This has been attributed to greenhouse gas emissions such as carbon dioxide[114]. Five of the warmest years on record have taken place since 2010, and if current greenhouse gas emissions continue, the earth will cross a key climate threshold of 2 degrees of warming, which will begin to harm and change human civilization.[115] To avoid this level of warming, countries will have to suppress carbon dioxide levels below 450 ppm, with the atmosphere breaking 400 ppm for the first time in 2013.[116] The potential extent of carbon dioxide reduction due to solar microgrids is promising. As compared to using conventional fossil fuels, pilot studies that measure the environmental impact of switching to renewable micro-grid technologies exhibited a reduction of “31-92% in CO2 emissions.”[117] Looking at another case study of microgrid-carbon impact shows that 9 tons of CO2 emissions can be prevented in one year in a rural Japanese area of 32 households relying on agriculture.[118] To provide context, greenhouse gas emissions in the US totaled 6,870 million tons for the year 2014.[119] If this savings could be theoretically expanded to the approximately 125 million households in the US, the US would see a 35 million ton decrease in emissions. There is consideration to be made for this decrease (of about half a percent) not comprising a large fraction of our current emissions, and may shift the focus from renewable microgrids being a way to impact

[114] CMB.Contact@noaa.gov. "Global Climate Change Indicators." National Climatic Data Center. Accessed October 04, 2018. https://www.ncdc.noaa.gov/monitoring-references/faq/indicators.php.
[115] Mann, Michael E. "Earth Will Cross the Climate Danger Threshold by 2036." Scientific American. April 01, 2014. Accessed November 04, 2018. https://www.scientificamerican.com/article/earth-will-cross-the-climate-danger-threshold-by-2036/.
[116] Mann, Michael E. "Earth Will Cross the Climate Danger Threshold by 2036." Scientific American. April 01, 2014. Accessed November 04, 2018. https://www.scientificamerican.com/article/earth-will-cross-the-climate-danger-threshold-by-2036/.
[117] Youli, Su. "Economic and Environmental Impact Assessment of Micro Grid." *Proceedings of the International MultiConference of Engineers and Computer Scientists* 2 (March 18, 2015). Accessed November 4, 2018. https://pdfs.semanticscholar.org/994a/69fe68f6f83c99d821a80462fce820b06eaa.pdf.
[118] Youli, Su. "Economic and Environmental Impact Assessment of Micro Grid." *Proceedings of the International MultiConference of Engineers and Computer Scientists* 2 (March 18, 2015). Accessed November 4, 2018. https://pdfs.semanticscholar.org/994a/69fe68f6f83c99d821a80462fce820b06eaa.pdf.
[119] "Climate Change Indicators: U.S. Greenhouse Gas Emissions." EPA. December 17, 2016. Accessed November 04, 2018. https://www.epa.gov/climate-indicators/climate-change-indicators-us-greenhouse-gas-emissions.

climate change on existing energy infrastructure, to being a profitable investment and possible way to provide access to the electric-less world.

Another empirically more impactful environmental consideration of utilizing solar over current energy sources is the dependence of the developing world on biomass as a form of energy. As of 2005, about 2.4 billion people in rural areas predominantly in Asia and Africa depended on biomass such as firewood, charcoal, or dung. These energy sources are used for cooking and heating, and emit harmful air pollutants. Around 35%, and in some areas 90%, of energy comes in the form of biomass, and is usually burned with low efficiencies of "10 to 15%".[120] Deaths from biomass and coal-linked air pollutants cause 1.6 million deaths annually according to the World Health Organization.[121] Current environmentally-linked health issues are another area of potential impact from the substitution away from current energy sources into solar microgrids, especially in developing areas. Solar microgrids are especially attractive for these rural areas due to their reliability in the form of islanding, as well as lower infrastructure costs in connecting these areas to a main grid.

5.5.2 Access

Expanding access to electricity to those living without it promises an extreme acceleration in economic growth and therefore in quality of life. In a study done by social enterprise Mlinda, it was found that economic growth was at 10.6% in Indian villages installed with microgrids versus

[120] Holm, Dieter, and Jennifer Mcintosh. "Renewable Energy – the Future for the Developing World." *Renewable Energy Focus* 9, no. 1 (2008): 56-61. doi:10.1016/s1471-0846(08)70027-1.
[121] Holm, Dieter, and Jennifer Mcintosh. "Renewable Energy – the Future for the Developing World." *Renewable Energy Focus* 9, no. 1 (2008): 56-61. doi:10.1016/s1471-0846(08)70027-1.

4.6% in villages without the microgrids through 13 months[122]. Increased economic growth at a larger scale could prove to be very promising for global affairs and global poverty in the short and long run. At the moment, we only have a worldwide electrification rate of about 85 percent.[123] That means 1.3 billion people currently lack access to an electrical grid, relying on high impact alternatives such as diesel generators or kerosene.[124] Large scale electric grids require a lot of time and capital to be put into place. $19.1 billion per year would be required for universal access by 2030.[125] Bringing access to green electricity to over a billion people could bring immense global growth, as well as prevent the environmental impact that would come with doing so in a non-green way.

5.5.3 Reliability

Natural disasters affect a total of 217 million people every year.[126] There has been an increase in the amount of natural disasters, especially those that are climate related. There have been three times as many disasters in the first decade of 2000 versus 1980-1989. With an increase in the prevalence of natural disaster, it would be wise for investment to take place to create more resilient energy systems. Microgrids prove a worthwhile energy distribution system to look into due to its increased reliability, as detailed in the Technology section. We'll look at the recent case of Puerto Rico to see the market for increased energy reliability as it relates to natural disasters.

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[122] "Mini-grids Could Be a Boon to Poor People in Africa and Asia." The Economist. July 12, 2018. Accessed October 04, 2018. https://www.economist.com/finance-and-economics/2018/07/12/mini-grids-could-be-a-boon-to-poor-people-in-africa-and-asia.

[123] "Access to Electricity (% of Population)." Access to Electricity (% of Population) | Data. Accessed November 04, 2018. https://data.worldbank.org/indicator/EG.ELC.ACCS.ZS.

[124]

[125] Frost and Sullivan

[126] "New York, NY." Steady Increase in Climate Related Natural Disasters. Accessed October 04, 2018. https://www.accuweather.com/en/weather-blogs/climatechange/steady-increase-in-climate-rel/19974069.

Four months after Hurricane Maria, about 450,000 of 1.5 million electricity customers in Puerto Rico are still left without electricity.[127] Blackouts regularly occur for hours at a time. This affects local business and commerce. Local Firefighter Ronald Vega said "I'm paying at least $15 a day for the fuel of my generator during the week" causing a substantial burden to be placed upon a recovering populace. The storm damaged 80 percent of the electrical grid on the island.[128] The largest facilities were operational within weeks but couldn't export their power to the grid until the network was repaired. It would cost about $17.6 to holistically update and strengthen Puerto Rico's electrical grid. To stormproof NYC it would cost $60 billion.[129]

Table 3-7 shows the cost of incorporating microgrid infrastructure at a series of important sites. Deploying SMGs at residential homes would save a total of $315 million in energy costs. (See Figure 19)

5.6 Case Studies

In 2014, Nairobi-based microgrid company SteamaCo invested in a SMG in the town of Entasopia, a town that originally was 30 miles away from the central grid and relied on diesel generators. Solar has proven to be cheaper, as well as more reliable than the diesel in this area.

The 5.6 kilowatt microgrid had a $75000 installation cost and is accompanied with battery storage that lasts up to 24 hours which has proven to be sufficient for the village when peak use is at night

[127]Villamizar, Monica. "Here's Why Restoring Power in Puerto Rico Is Taking so Long." PBS. January 25, 2018. Accessed September 04, 2018. https://www.pbs.org/newshour/show/heres-why-restoring-power-in-puerto-rico-is-taking-so-long.

[128]Gallucci, Maria. "Rebuilding Puerto Rico's Power Grid: The Inside Story." IEEE Spectrum: Technology, Engineering, and Science News. March 12, 2018. Accessed October 04, 2018. https://spectrum.ieee.org/energy/policy/rebuilding-puerto-ricos-power-grid-the-inside-story.

[129] "Build Back Better: Reimagining and Strengthening the Power Grid of Puerto Rico." December 2017. Accessed October 4, 2018. https://www.governor.ny.gov/sites/governor.ny.gov/files/atoms/files/PRERWG_Report_PR_Grid_Resiliency_Report.pdf.

due to electrical use such as lights and televisions. In three years, the investment has already recouped initial costs and is starting to make a profit. Although the population is poor, there is still money to be made, as the revenue generated from this microgrid in the small village of Entasopia is above $10000 a year. "SteamaCo and the microgrid partners that increasingly license its platform to charge between two and four dollars a kilowatt-hour. But that's still cheaper than kerosene for lanterns and diesel-fueled generators. And eliminating the use of both fuels cuts the town's greenhouse gas emissions by 485 tons of CO2 a year."[130] Solar microgrids have allowed the Kenyan village reliability, affordability, profitability, and emission-reduction as compared to previous energy sources.

In a case study conducted by the Microgrid Investment Accelerator on India, Indonesia, and Tanzania, the costs of different energy sources are illustrated in Figure 20.[131] An extremely important benefit to SMGs is that rural SMGs produce cleaner, safer, and more reliable energy than the present diesel use in remote areas. In addition, kerosene and diesel costs increase in proportion to remoteness, due to transportation costs, whereas a SMG is localized, where costs will remain stable and reasonable.

For an example of how reliability can be a big upside to SMGs, we can look to the National Interagency Biodefense Campus in Maryland. Since beginning operation in 2008, there has not been a single interruption in electrical services. In the event of an interruption, the electrical systems can island for 88 hours without fuel resupply. This facility shows the efficacy of

[130] "New Smart Solar Microgrids Speed Up Rural Electrification in Kenya." AIChE. September 02, 2016. Accessed October 04, 2018. https://www.aiche.org/chenected/2016/02/new-smart-solar-microgrids-speed-rural-electrification-kenya.
[131] "Microgrid Market Analysis & Investment Opportunities In India, Indonesia, and Tanzania." *Microgrid Investment Accelerator*. Accessed November 4, 2018. https://sun-connect-news.org/fileadmin/DATEIEN/Dateien/New/MIA_Market_Report_2017.pdf.

microgrids for high-value government installations, especially with this technology being dated to almost 10 years ago.[132]

Currently, there is still not a substantial amount of case studies regarding solar microgrids, though the ones available do point to their promise. Investment in solar microgrids is indeed a new idea, and our paper is one step to expanding knowledge and potential investment regarding this subject.

6. Microgrids for Rural, Underdeveloped Areas

6.1 Overview of SMG Application for Rural, Underdeveloped Areas

In many developing countries around the globe, access to electricity is still a distant prospect, but one that may be rapidly approaching reality in the near future. While total global electrification is the seventh of the United Nations' sustainable development goals (SDGs), progress towards universal global access to energy by 2030 currently "falls short of what is needed to achieve energy access for all and to meet targets for renewable energy and energy efficiency."[133]

The link from energy access to poverty reduction is straightforward: With access to energy, there arise changes in enterprise propagating further changes in productivity, quality, cost of production, prices, volumes of products, operating hours, employment, creation of new products or services, and the creation of new enterprises.[134] The initial benefits to energy access are great as new and existing enterprises directly benefit from power sources, with diminishing marginal return as higher access to energy is provided. Thus, the initial benefit achieved from providing energy is

[132] "Advanced Energy Microgrid National Interagency Biodefense Campus, Maryland." 2017. Accessed August 4, 2018.

[133] "Goal 7 .:. Sustainable Development Knowledge Platform." Accessed April 22, 2018. https://sustainabledevelopment.un.org/sdg7.

[134] Attigah, B. and Mayer-Tasch, L. (2013): The Impact of Electricity Access on Economic Development - A Literature Review. In: Mayer-Tasch, L. and Mukherjee, M. and Reiche, K. (eds.), Productive Use of Energy (PRODUSE): Measuring Impacts of Electrification on Micro-Enterprises in Sub-Saharan Africa. Eschborn.

very high, with a huge potential return on investment. As demonstrated in Figure 5, the correlation between the amount of electricity provided to the amount of development achieved resembles a logarithmic function. Initially, there is a large ROI of development for the amount of energy provided, which eventually levels off as more is provided. The provision of less than 500 kWh per capita is enough energy to achieve the description of "medium human development" and about 3,000 kWh per capita required to achieve "high human development" as gauged by the Human Development Index.[135] This correlation underlines the value of initial provision of any energy for attaining highest human level of development.

Despite the numerous and clear benefits of electrification, there are currently 1.06 billion people globally without access to energy, a number which has not significantly changed in the past few decades.[136] The United Nations' 2017 report on the world's 47 Least Developed Countries(LDCs) stated that achieving global universal access to energy by 2030 would require "a 350% increase in their annual rate of electrification."[137] 82% of those in LDC's without access to power live in rural areas, for which microgrids and other renewable energy sources present both the most viable and most sustainable prospect for development.[138] For investors striving to maximize their social impact, investing in the creation of SMG's in developing countries offers an unmatched potential for increasing human welfare.

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135 Attigah, B. and Mayer-Tasch, *The Impact of Electricity Access on Economic Development - A Literature Review*, (Eschborn, Deutsche Gesellschaft für Internationale Zusammenarbeit, 2013).

136 Stephanie Hirmer and Peter Guthrie, "The Benefits of Energy Appliances in the Off-grid Energy Sector Based on Seven Off-grid Initiatives in Rural Uganda," *Renewable and Sustainable Energy Reviews* 79 (November 2017): 924-934, doi:10.1016/j.rser.2017.05.152.

137 "With Access to Clean, Modern Energy, Poorer Countries Look to Power Ahead through Innovation – UN Report | UN News," United Nations News, November 22, 2017, accessed April 29, 2018, https://news.un.org/en/story/2017/11/636982-access-clean-modern-energy-poorer-countries-look-power-ahead-through-innovation.

138 "With access to clean, modern energy, poorer countries look to power ...." UN News.

A review of the literature on the link between access to electricity and economic empowerment concludes that energy access allows the poor in developing countries to "engage in improved or new income generating activities." This creates opportunities for productive, rather than consumptive, use of energy, improving the standards of living as a result. Furthermore, the review found that according to the United Nations Development Program's Multidimensional Poverty Index, "exclusion from modern energy might be a direct indicator of poverty based on definitions which refer to living standards."[139] Thus, ensuring access to energy is supremely important for reaching millennium development goals, as well as spurring economic development in developing countries.

Figure 23 depicts the three components of any successful implementation of renewable energy. [140] Establishing the sufficient conditions for implementation are especially imperative for rural electrification, as the internal infrastructure is necessary for the successful creation of long-term reliable electricity access. These initial conditions consist of both the requisite policy regulation as well as a source of funding for projects, two factors which are difficult to attain in developing countries. The electricity supply is where microgrid and solar delivery companies come into play, streamlining the actual access and provision of electricity. The demand is largely a given in developing areas where there is no such access to electricity in the status quo.

[139] Attigah, B. and Mayer-Tasch, "The Impact of Electricity Access... A Literature Review".
[140] Muther, Kyle. "Smart Power for Rural Development Creating a Sustainable Market Solution to Energy Poverty." Accessed April 29, 2018. http://www.sun-connect-news.org/fileadmin/DATEIEN/Dateien/New/Smart_Power_Case_Final.pdf.

6.2 Case Studies: Microgrid Use in Developing Countries

6.2.1 Prospects for Africa

Similar to the case of phone access, many analysts predict that many developing countries can utilize the same process to provide access to sustainable and cheap energy. As the World Economic Forum states: “African countries can skip an outdated era of power delivered solely through large-scale generation and transmission lines run by monopoly utilities.”[141] This development is not unique to Africa, with developing countries around the world now embracing new technologies. Unburdened by prior infrastructure and energy investment spending, they can develop novel, decentralized energy.

According to the Global Tracking Framework, electricity access in Africa increased from 31% to 38% over the period from 2007 to 2014.[142] Yet, half of the 1.06 billion people globally without access to energy live in sub-Saharan Africa.[143] Furthermore, as illustrated in Figure 6, solar cells are predicted to be cheaper than the traditional energy grid in 85% of the African continent by the year 2020,[144] presenting a sustainable option as a highly economically viable alternative to traditional energy sources in the near future.

As a result of the unreliable energy grid in Africa today, “Businesses experience an average of 8 power outages per month, each lasting almost 5 hours” which causes them to “lose more than 7% of annual sales as a direct result.” This in turn leads to almost half of businesses being “forced to

[141] Tilleard, Matt. "Why Africa Needs an Investment Fund to Back Solar Energy." World Economic Forum. June 19, 2015. Accessed April 29, 2018. https://www.weforum.org/agenda/2015/06/why-africa-needs-an-investment-fund-to-back-solar-energy/.
[142] "Time." Global Tracking Framework. Accessed April 29, 2018. http://gtf.esmap.org/time.
[143] "Progress of Goal 7 in 2017." Sustainable Development Knowledge Platform. Accessed April 29, 2018. https://sustainabledevelopment.un.org/sdg7.
[144] "Tilleard, Why Africa needs an investment fund to back solar energy | World ....".

rely on expensive, and dirty, diesel power to supplement their grid supply," furthering reliance on unsustainable energy sources.[145] This is not to say that Africa should never develop or rely on an energy grid. As the World Economic Forum states, "competition from distributed solar power means that the supply of electricity is no longer a natural government monopoly. African countries can skip the outdated era of power delivered solely through large-scale generation and transmission lines run by monopoly utilities," creating a more robust market for energy, increasing accessibility and affordability. A flexible system which combines "providing mass, base load power to major population and commercial centers" and "private provision of distributed generation," is the most effective and efficient system for providing power to Sub-Saharan Africa.[146]

A research report presented at the Power Engineering Society Inaugural Conference and Exposition in Africa advocates for "a top down and bottom up (holistic approach) to regional cooperation and integration being contemplated by the various African power pools" and goes on to emphasize the importance of the "bottom-up approach through an evaluation of autonomous or non-autonomous microgrids used to provide electricity to local residents and which serve as basic building blocks for future system expansion."[147] The flexibility of beginning with a bottom-up approach is imperative to the success of future grid expansion in Africa.

6.2.2 Prospects for India

As of 2014, close to 80% of India's population had access to energy.[148] According to a report released by researchers from the University of Michigan examining consumer responses in Uttar

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[145] Ibid.
[146] Ibid.
[147] B.k. Blyden and Wei-Jen Lee, "Holistic Approach for Grid Interconnection in Africa," *Proceedings of the Inaugural IEEE PES 2005 Conference and Exposition in Africa*, April 3, 2006, , doi:10.1109/pesafr.2005.1611813.
[148] "Access to electricity (% of population) | Data - World Bank Open Data." https://data.worldbank.org/indicator/EG.ELC.ACCS.ZS?locations=IN. Accessed 10 Apr. 2018.

Pradesh district, rural customers are more satisfied with microgrid systems than centralized grid systems. The report finds that, "consumer preference for electricity is based most significantly on (in order of strength of preference) power, reliability, and price... despite 9.4 hours of electricity supply per day from the main grid, as compared to an average of only 7.2 hours from microgrids, the respondents exposed to both systems were almost twice as satisfied with the SMGs reliability."[149] Thus, microgrids are largely favored by individuals in rural areas due to the increased reliability of an island system, as compared to the unreliable nature of a central grid system. For example, Recently, a report published in the IEEE Electrification Magazine, "a 2,500-year-old monastery in the Ladhak region in the Himalayas was illuminated using solar PV by the Global Himalayan expedition team to cater to the needs of roughly 150 monks who live there." For India, where only a small fraction of total villages remain unconnected to the grid, the major challenge of electrification lies in the difficulty of connecting households to the grid system from which they derive their power, known as "last mile" infrastructure. These costs are the same whether households service their power from the traditional grid or from a microgrid, and are currently the largest barrier to providing power to rural households in India.[150] A report from the Brookings Institute stresses that "fixed costs of wiring and connectivity are very high for low levels of consumption," perhaps pointing to standalone power systems as a cheaper alternative to traditional grid solutions for remote areas. In most of these regions it would be exorbitantly expensive to connect to a grid, for a very low level of power consumption.[151]

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[149] "Solar microgrids in rural India - Deep Blue - University of Michigan." https://deepblue.lib.umich.edu/bitstream/handle/2027.42/136234/Graber_Narayanan_Practicum.pdf?sequence=1&isAllowed=y. Accessed 10 Apr. 2018.

[150] Tongia, Rahul (2018). "Microgrids in India: Myths, Misunderstandings, and the Need for Proper Accounting", Brookings India IMPACT Series No. 022018. February 2018.

[151] Ibid.

6.3 Funders

A report released by Allotrope Partners, a Microgrid Investment Accelerator, explains that despite the market being described as "nascent and characterized by high variability," lower capital costs and changing government policies are allowing the market to become more accessible and a more viable investment opportunity.[152] The report emphasizes that "Overall market immaturity is a barrier to private and commercial investment in the microgrid segment" and stresses the importance of various funding sources for microgrid projects, since investors may hesitate to invest in early stages of the market.[153] Lack of capital is a major obstruction for microgrid progress, as microgrid energy service companies report that "low-cost, long-term project capital, preferably as project equity or debt" is highly desirable for implementing projects.[154] Currently, financing sources for microgrid development projects stem from two main channels: private market initiatives, and government investment, sometimes with the assistance of partner organizations. Each of these areas is discussed in further detail below.

6.3.1 Private Market Initiatives

Private market based initiatives for SMGs are a great area for potential investment opportunities. Currently, the largest players in the industry include ABB, General Electric, Hitachi, Lockheed Martin, Schneider Electric, and Siemens.[155] A 2016 report from GTM Research, an electricity research firm, found that microgrid spending can potentially yield annual growth rate of over 20

[152] *Microgrid Market Analysis & Investment Opportunities IN INDIA, INDONESIA, AND TANZANIA*. Allotrope Partners. Sun Connect News. 2017. Accessed May 6, 2018. http://sun-connect-news.org/fileadmin/DATEIEN/Dateien/New/MIA_Market_Report_2017.pdf.
[153] *Microgrid Market Analysis & Investment Opportunities „"*. Allotrope Partners. Sun Connect News. 2017.
[154] Ibid.
[155] Mukherjee, Jagoron, Joe Van Den Berg, and Owen Ward. *Powering Up the Neighborhood Grid & A Strategic Entry Plan for the Microgrid Business*. PWC. Strategy And. 2016. Accessed May 6, 2018. https://www.strategyand.pwc.com/media/file/Powering-up-the-neighborhood-grid.pdf.

percent as investors and firms move to the new market.[156] This is a large potential area for investment, estimated to be $20-40 million in 2017, projected to grow to over $100 million by 2020, with potential investments providing "favorable project finance terms in the range of 4-9% interest rate for 7-12 years."[157] Common to the success of the private market initiatives surveyed is a business model which places customers and users at the forefront of the distribution and consumption model. Such a setup ensures that companies are responsive to the needs and concerns of the consumers and are working to increase ease of access and use.

6.3.2 OMC Power

One such successful private-market initiative that has seen great success is OMC Power, a renewable energy services company that aims to provide affordable and reliable renewable energy to rural areas in India. The model of OMC power is to provide electricity from solar mini-grids that produce approximately 25-100 kW of power to rural businesses which can "increase output and productivity with a reliable source of power" to robustly improve the health of local economies.[158] By offering electricity for the same amount that is spent on diesel, kerosene, or other fuels today, and by providing a distribution mechanism contingent on demand, OMC power is working to cater to the needs of developing rural economies. OMC power recently partnered with the Rockefeller Foundation, which financed the creation of 100 mini-grids in India, reaching

[156] Saadeh, Omar. "Research Note - U.S. Microgrid Market Update: Q2 2016." Gtmresearch. May 2016. Accessed May 06, 2018. https://www.greentechmedia.com/research/report/gtm-research-note-us-microgrid-market-update-q2-2016#gs.S9A8g2k.
[157] *Microgrid Market Analysis & Investment Opportunities ,, "*. Allotrope Partners. Sun Connect News. 2017.

[158] Muther, Kyle. "Smart Power for Rural Development Creating a Sustainable Market Solution to Energy Poverty." Accessed April 29, 2018. http://www.sun-connect-news.org/fileadmin/DATEIEN/Dateien/New/Smart_Power_Case_Final.pdf.

1,000 villages.[159] OMC finances microgrid creation through partnerships such as this one, but the core tenet of its business model lies in empowering community entrepreneurs who can establish microgrids (oftentimes with support and backing from financial institutions), and sells power to their community, which benefits from increased productivity and economic growth.[160] Through the provision of energy in this form, microgrids could become catalysts for rural economic development. The fundamentals of this system are illustrated in Figure 24.

6.3.3 Husk Power

A second successful private-market initiative is Husk Power, based in India, but looking to expand to Africa and Tanzania. Husk is similar to OMC in that it designs, builds, owns, and operates the distribution of microgrids. It offers a slightly different product as the system combines solar, biomass, and batteries to provide highly reliable power, through a pay-as-you-go mechanism.[161] Husk has also caught the eye of investors, as it received $20 million in investments to scale its operations in January 2018. This investment will help expand Husk's services to reach 100,000 customers.

6.3.4 Governments

Government-directed initiatives for implementation of microgrids possess a large potential for success, due to attributes inherent and unique to a government-based approach. Government-based

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[159] Kumar, Anup. "The Rockefeller Foundation and OMC Power Reach a US$4.5 Million Deal to Finance 100 Mini-grids in Rural India." The Rockefeller Foundation. March 8, 2016. Accessed May 06, 2018. https://www.rockefellerfoundation.org/about-us/news-media/the-rockefeller-foundation-and-omc-power-reach-a-us4-5-m-deal-to-finance-100-mini-grids-in-rural-india/.

[160] OMC. "The Micropower Ecosystem & Process." OMC Ecosystem. Accessed May 06, 2018. http://www.omcpower.com/communities/ecosystem.

[161] *Husk Power Systems*. IFC. Husk Power. September 2011. Accessed May 6, 2018. https://www.ifc.org/wps/wcm/connect/1b7be8004d332ecb8976cdf81ee631cc/Husk Power.pdf?MOD=AJPERES.

initiatives possess the advantages of having policy backing, large amounts of funding as well as project follow-through and implementation. A large, and often overlooked benefit of government-based initiatives to provide for access to global and renewable energy is the accountability inherent to publicized programs and projects, which is not necessarily a component of private-market based initiatives. Furthermore, government support is “needed to scale private sector investment in microgrids” by reducing risk associated with investing in the markets.[162]

Partner organizations offer a valuable opportunity to subsidize or streamline the implementation of SMGs within developing countries, as provision of energy is one of the United Nations Sustainable Development Goals, and the importance of energy access is widely recognized. The United Nations, The World Bank, and the International Development Association are a few of the organizations which have provided funding for SMG projects in areas around the globe to complement government initiatives.

6.3.5 Bangladeshi Government-Directed Initiative

Bangladesh was able to create the government-owned Idcol to satisfy the energy needs of its population without the uncertainty and unreliability inherent in private-market efforts. Bangladesh is one developing nation where companies have already begun to embrace the investment prospects for the potential of renewable energy power to reshape access to energy.

[162] Muther, Kyle. "Smart Power for Rural Development Creating a Sustainable Market Solution to Energy Poverty." Accessed April 29, 2018. http://www.sun-connect-news.org/fileadmin/DATEIEN/Dateien/New/Smart_Power_Case_Final.pdf

The Infrastructure Development Company Limited (Idcol), a “government-backed Bangladeshi energy and infrastructure group” currently controls more than 90 percent of the country’s booming home solar market.[163]

The Center for Public Impact emphasizes the government-based nature of this intervention, stating that “the Bangladeshi government considered off-grid renewable energy technology to be one of the best options for bringing electricity to rural areas, where more than 70 percent of the population lives.”[164] Since the Bangladeshi government subsequently declared its goal to provide all citizens with power by 2020, Idcol has provided energy to 18 million people through installing close to four million solar panels, supplying directly over 12% of the country’s population. Bangladesh has become one of the world’s largest markets for home solar systems as a result of this large-scale government initiative.[165]

6.4 Microgrid Implementation Models for Developing Economies

Electrification is not the end goal for providing access to energy. Rather, the overarching motive is to create sustainable and productive uses for energy that improves standards of living around the globe. Dr. Kituyi, Secretary General of the United Nations Conference on Trade and Development, stated that “The productive use of energy is what turns access into economic development, and what ensures that investments in electricity infrastructure are economically

[163] Yee, Amy. "Opinion | In Rural Bangladesh, Solar Power Dents Poverty." The New York Times. October 4, 2016. Accessed May 06, 2018. https://www.nytimes.com/2016/10/04/opinion/in-rural-bangladesh-solar-power-dents-poverty.html.
[164]"The Solar Home Systems Initiative in Bangladesh." Centre for Public Impact (CPI). October 20, 2017. Accessed May 06, 2018. https://www.centreforpublicimpact.org/case-study/solar-home-systems-bangladesh/.
[165]Yee, Amy. "Opinion | In Rural Bangladesh, Solar Power Dents Poverty." The New York Times. October 4, 2016. Accessed May 06, 2018. https://www.nytimes.com/2016/10/04/opinion/in-rural-bangladesh-solar-power-dents-poverty.html.

viable. But that means looking beyond satisfying households basic needs to achieving transformational energy access – satisfying producers' needs for adequate, reliable and affordable energy."[166] The link between electricity provision and economic development is indisputably clear, especially so for developing countries.

6.4.1 Combination Investments

As microgrids are inherently more flexible than traditional electricity grids, the utilization of their flexibility is key when devising strategies for implementation. Combining multiple services may prove to be immensely profitable for companies wishing to enter these marginalized markets. As microgrids stand to benefit rural or otherwise underdeveloped communities, energy is likely not the sole challenge that these areas face. As the Beam reports, "Electrification can easily be coupled with other technology investments to provide all kinds of services, such as entertainment, cold storage, local transportation, or water pumping and irrigation."[167] One service area in particular which could help increase access to global markets within these marginalized populations is creating access to internet through a similar mechanism. A cyber café could connect to the grid, creating novel employment opportunities through simultaneously offering a sustainable energy source along with access to the internet, the global information economy, and jobs outsourced by large companies.[168]

[166]Chavez, Dominic. "With Access to Clean, Modern Energy, Poorer Countries Look to Power Ahead through Innovation – UN Report | UN News." United Nations. November 22, 2017. Accessed May 06, 2018. https://news.un.org/en/story/2017/11/636982-access-clean-modern-energy-poorer-countries-look-power-ahead-through-innovation.

[167]Beam, The. "In Africa, Microgrids Are Changing People's Lives – TheBeamMagazine – Medium." Medium. August 18, 2017. Accessed May 06, 2018. https://medium.com/thebeammagazine/microgrids-are-building-a-better-future-for-populations-in-remote-areas-46d06b0c9966.

[168]Ibid.

6.4.2 Market-Based Incentives for Sustainability

A service-based approach to providing energy not only provides incentives for investment in this sector, but also incentivizes sustainable energy use in the long-term. If the microgrid operator sells a service along with energy, and is also providing the appliances used to deliver it, “she also has an incentive to use efficient appliances.” Combining with initiatives such as HerPower or other community-based retail positions where individuals in the community are responsible for developing the infrastructure that will be used in the future, can help to ensure that these power hubs remain sustainable in the long term. Through providing an ingrained market mechanism which values cost and energy-efficiency, microgrid creation seems to be a promising vehicle for avoiding the energy crises and inefficiencies that have plagued traditional grid-based systems of delivery which rely on limited or unsustainable energy sources.

6.4.3 End-User Education/Contracts

Key to the continued success of energy initiatives in developing communities is the shift in “holistic energy approach that includes cultural shifts regarding energy appliances.” Researchers Stephanie Himer and Peter Guthrie state that “the sustainability of energy projects can be linked to the availability of after-sales services and the beneficiaries’ acceptance of a development initiative.” They also stress the role in communicating “the benefits that sustainable energy initiatives can bring to their community” in order to improve acceptance and maintenance within communities.[169]

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[169]Hirmer, Stephanie, and Peter Guthrie. "The Benefits of Energy Appliances in the Off-grid Energy Sector Based on Seven Off-grid Initiatives in Rural Uganda." *Renewable and Sustainable Energy Reviews*79 (November 2017): 924-34. doi:10.1016/j.rser.2017.05.152.

7. Solar Microgrids in Developed Cities

7.1 Overview of SMG Application for Developed Cities

While grids are powered by a factory or other outside source that supplies energy to the entire community, they remain vulnerable to mass power outages in the event of a catastrophe or natural disaster. Taking down a single power line could shut off critical services in an entire part of town. Often, these disasters disproportionately endanger people in the outskirts of well developed cities. If outdated electric grids are dependent on an indestructible infrastructure, then they rely on the impossible. Microgrids, however, eliminate all risk by depending on the inevitably reliable. Whether through the power of the sun or some other renewable source, microgrids can power critical resources like hospitals and gas stations in times of crisis while separating, or "islanding," themselves from the main grid. The microgrid can store its own energy as well. All energy generation is processed by a microgrid controller that manipulates inputs and outputs for the grid. When connected, it can funnel that energy to the larger grid as needed to maintain balance.[170] Both states, therefore, offer a reliable and environmentally friendly way to power cities.

The microgrid has the tremendously important ability to become an island during a crisis, but it also lends itself to renewable energy sources. Microgrids can be seen as a tool to move away from fossil fuels towards an efficient system supporting distributed clean energy, from the solar panel to the storage unit to the electric vehicle.[171] Microgrids have that transformative quality because cities must first change their systems of allocation before changing the actual source. Moving to a microgrid is moving towards a future where energy is efficient and abundant. As we arrive at that

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[170] Gies, Erica. "Microgrids Keep These Cities Running When the Power Goes Out." InsideClimate News. December 05, 2017. Accessed April 22, 2018. https://insideclimatenews.org/news/04122017/microgrid-emergency-power-backup-renewable-energy-cities-electric-grid.
[171] Ibid.

future and rely more on a variety of sources, microgrids also make the utility's job easier. Instead of working with hundreds of sources of energy, they now only interact with one entity that aggregates them. It is, then, cheaper for the utility. More short-term, microgrids can funnel back excess energy during peak demand and lift the burden from power plants. Their storage capabilities can regulate somewhat unsteady energy production for renewable sources, like solar, at a much larger scale than a home-by-home basis. Therefore, they cut on dirty energy and manipulate clean energy better.

7.2 Case Studies: Microgrids Used in Developed Cities

Connecticut, New York, and Massachusetts have all recognized these advantages and have introduced microgrid incentives accordingly. Thanks to these policies, Princeton, NYU, and Co-op City were able to keep power throughout Superstorm Sandy in 2012. Co-op City, in particular, has an impressive heat-and-power microgrid for 50,000 residents in its housing developments. In California, the energy commission requested $45 million for new proposals from advanced microgrids looking to transition to clean energy. In conclusion, states across the country are recognizing the power and potential of microgrids in their cities. As it will be seen in the following cases, most microgrids will be solar powered but the purpose of this section was to show that the microgrid itself has tremendous societal value. Energy needs a reorganization. With this technology available, it is short-sighted to maintain the same single producers and delicate infrastructure. The sources have to be varied. The consumer has to be connected. Microgrids is what will facilitate these transactions.

7.2.1 Fairfield

Fairfield is another example of the state fronting the capital for a massive project. The state of Connecticut gave Fairfield a $1.1 million grant and, along with $130,000 from the city, Schneider Electric built Fairfield a 350kW microgrid.[172] Schneider also built a 47 kW solar photovoltaic system and a 300kW natural gas generator for the system, both of which demonstrate the system's ability to integrate different sources. The on-grid and island mode ensure residents have power, bringing peace-of-mind to the neighborhood.

7.2.2 Brooklyn

In New York, the Brooklyn microgrid project is signing up community members to a virtual trading platform where they can buy and sell energy through their phones. So far, the project has 50 participants, but it hopes to serve as a decentralized renewable model for the rest of the world. The Brooklyn Microgrid is a collection of solar-powered homes and businesses. As a producer-consumer, or prosumer, they have the ability to make peer-to-peer trades with each other depending on their energy demands. The currency is in renewable-energy credits: numbered certificates that are used to track electricity exported from the renewable microgrid to the larger electric grid. Both the utilities and customers can buy these credits to claim green energy use and, in the process, buy the energy others produce or sell their own excess. Such a system bypasses the electric company altogether, giving new literal and figurative power to the consumer. It also is the most effective way to meet demand. Rather than unnecessary energy taking up space in a battery, it is distributed as needed throughout the community. Energy is shared as opposed to partitioned.

[172] Runyon, Jennifer. "Municipal Solar And Microgrids: A PV Outlook." Renewable Energy World. May 18, 2016. Accessed April 22, 2016. https://www.renewableenergyworld.com/articles/2016/05/municipal-solar-and-microgrids-a-pv-market-outlook.html

While legislation is yet to catch up to define this particular market beyond pricing, Governor Cuomo's Reforming The Energy Vision encourages the development of microgrids for a more flexible, resilient, and effective economy. New York envisions clusters of microgrids supplemented by larger power plants. The only issue is that these generation and storage networks function independent from the utilities, perhaps cutting them from the market.[173]

Brooklyn has two sides and, after showcasing the more gentrified part, it is important to see microgrids in low income areas such as the Marcus Garvey Apartments. In a $190 million refinancing project, 21 rooftops of the 36 buildings now have solar panels that offset 160 metric tons of carbon dioxide.[174] Surprisingly enough, funding for the microgrid comes from the ConEd Brooklyn-Queens Neighborhood Program, a utility program to avert construction of a $1 billion substation with less expensive distributed energy.[175] So while utilities in the Brooklyn microgrid are arguably cut, utilities for the Marcus Garvey Apartment are the investors. Perhaps utilities can maintain their position through investment, of both capital and equipment.

7.2.3 Buffalo

Buffalo, New York is subject to the same statewide initiatives that offer certain incentives to companies that set up a proper renewable network. Opus One, a solar company, and National Grid, the utility for Buffalo, turned the massive 120-acre Buffalo Niagara Medical Center campus to a

[173] Kilpatrick, Ryan Ho, "This Startup Lets You Collect and Trade Solar Power, Bypassing the Grid." *Fortune*, fortune.com/2017/03/14/brooklyn-microgrid-solar-energy-blockchain-startup/.
[174] Wood, Elissa, "Marcus Garvey Microgrid Begins Operating as a First for NYC Affordable Housing." *Microgrid Knowledge*, 21 June 2017, microgridknowledge.com/marcus-garvey-microgrid/.
[175]Conedison, "The Neighborhood Program - For Residents." *Residential Neighborhood Program | Con Edison*, www.coned.com/en/save-money/rebates-incentives-tax-credits/rebates-incentives-tax-credits-for-residential-customers/residential-neighborhood-program.

clean energy producer for the area with readily transparent pricing for the energy they will sell. [176] National Grid also requested that Opus, even with their limited information, take their real-time power flows and create a model for the market. So while Brooklyn Microgrid struggles to wrestle definite concepts of energy credits, Opus uses computer modeling to alleviate some of those issues. The hospital will still have to rely on diesel energy for a backup but they can now strengthen the existing grid with reliable alternative energy.

7.3 The Future of Urban Microgrids

Puerto Rico is a unique case in that the previous examples all have existing microgrid structures while currently investors and companies are only considering the reorganization of energy post-Maria devastation. Hurricane Maria destroyed a majority of the power lines and infrastructure, giving Puerto Rico perhaps the opportunity to follow suit with microgrid technology. Puerto Rico had one of the largest public owner authorities.

7.4 Potential Funders

Schneider Electric, the company working in Fairfield, is also working to make microgrids more attractive for green cities.[177]They believe that the push for microgrid technology should not just come from state grants and incentives. A possible model for development in the future would match their equipment and expertise with a partner willing to finance and own the assets. Because the municipality would receive the microgrid as a service, the city would no longer have to pay.

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[176]Kaufman, Leslie. "How New York Is Building the Power Grid of the Future." *InsideClimate News*, 26 May 2017, insideclimatenews.org/news/24052017/new-york-renewable-energy-electrical-grid-solar-wind-energy-coal-natural-gas.

[177] Runyon, Jennifer. "Municipal Solar And Microgrids: A PV Outlook." Renewable Energy World. May 18, 2016. Accessed April 22, 2016. https://www.renewableenergyworld.com/articles/2016/05/municipal-solar-and-microgrids-a-pv-market-outlook.html

Furthermore, utility companies could be prime investors for Schneider projects given their ability to own and operate assets. There is then the possibility for microgrids to exist alongside well-established utilities, working in fact for them.

LO3 Energy's approach is so decentralized it could eliminated the need for a grid at all. LO3, the company responsible for the Brooklyn Microgrid, builds digital networks that, again, give consumers the power. From an app, project participants can purchase and sell electricity while managing settings for future transactions.[178] Consumers do not want to day trade energy. Instead, they can set certain parameters for their consumption needs that would carry out transactions automatically. At the moment, these are all conducted over PayPal to test the system; electricity has no market status until lawmakers write in regulations. While consumers still pay the utility for infrastructure fees and services, the system is self-sufficient and user-friendly.

7.5 Microgrid Implementation Models for Developed Economies

In the cases above, microgrids were implemented through a combination of state and private investments that built infrastructure, connected the grid, and implemented the appropriate software. Initiative can come from either party, but generally, government policy aligned the commercial and social interests. Commercially, energy is cheaper for the consumer and abundant for the producer. Socially, SMGs are a clean option and attract environmentally-conscious urbanites. While the exact finances are still undefined for the exchange between grids, grid owners, and consumers, it follows from all our knowledge of microgrids that the grid will become more efficient, the grid owner will amass users, and users spend less on electricity. The

[178] Cardwell, Diane. "Solar Experiment Lets Neighbors Trade Energy Among Themselves." *The New York Times*, The New York Times, 13 Mar. 2017, www.nytimes.com/2017/03/13/business/energy-environment/brooklyn-solar-grid-energy-trading.html.

efficient system is the profitable system. Furthermore, the efficient system gets attention. Utilities are buying into diversified energy generation, as seen with Con Edison and the Marcus Garvey apartments, and storm-prone cities are making leaps towards energy sustainability. Cities are moving towards a new vision of energy. This vision is more decentralized but more stable, more expensive but more sustainable.

8. Conclusion

Ultimately, our four months of intensive research, interviews, and data collection support the case for a high probability of success for impact investments in solar microgrids (SMGs). Specifically, both market indicators and environmental/SDG metrics suggest a large potential for both profitability and impact within this space.

Specifically, we find potential in investing in companies that manage, install, and/or develop SMGs and their technology. These include companies like OMC Power and Husk Power that work actively to bring energy access to rural, underdeveloped areas as well as companies like LO3 that work to refine current energy systems in urban, developed areas. In terms of upstream potential, we find the highest probability of profitability and impact in putting capital towards solar panel producers, installers, and technologists. There is also a huge capacity for impact in refining the silicon extraction process for these panels, but currently environmental harms counteract much of the positive impacts of creating SMGs.

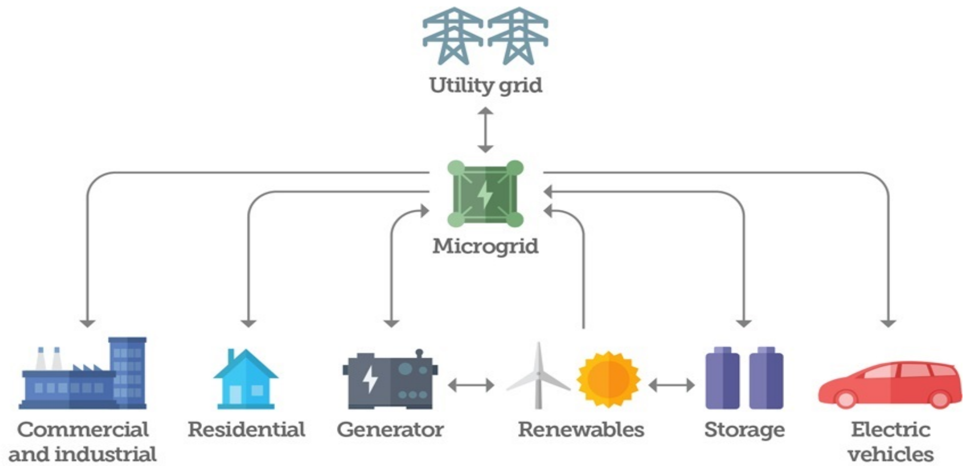
Our recommended framework for analysis entails an equal weighting between impact and profit. We find profitability to be directly linked to sustainability and, thus, a huge consideration of quality in an investment. Conventional metrics of profitability--such as price-to-earnings ratio, free cash flow, etc.--should be used with a long-term, instead of a quarterly, focus. Societal impact and value are vested over long periods of time, so investors must have a long time horizon in the way they approach these investments. Moreover, in terms of impact, investors should look at three key indicators: percent reliability, percent increase in access to energy, and net reduction in the social cost of carbon over time. In areas where old energy infrastructures already exist, the second of these three metrics might not apply, but--overall--these areas of focus provide a useful framework for quantifying impact both before and after an investment is made.

Overall, investments in SMGs should also take a systems-wide approach. By putting money into everything from the technology that backs these microgrids to the companies that actually manage their operation, the potential for success of these investments increases dramatically based on the spillover benefits from each upstream component to the rest of the system.

In a world where the search for alternative energy sources is gaining more and more urgency and support, rethinking the fundamentals of our energy infrastructure is imperative. SMGs facilitate reliable access to clean energy for those who do not have any pre-existing access as well as for those who are losing off of the pre-existing, centralized inefficiencies of the current urban energy infrastructure.

9. Appendix

Figure 1



Source: LG CNS

Figure 2

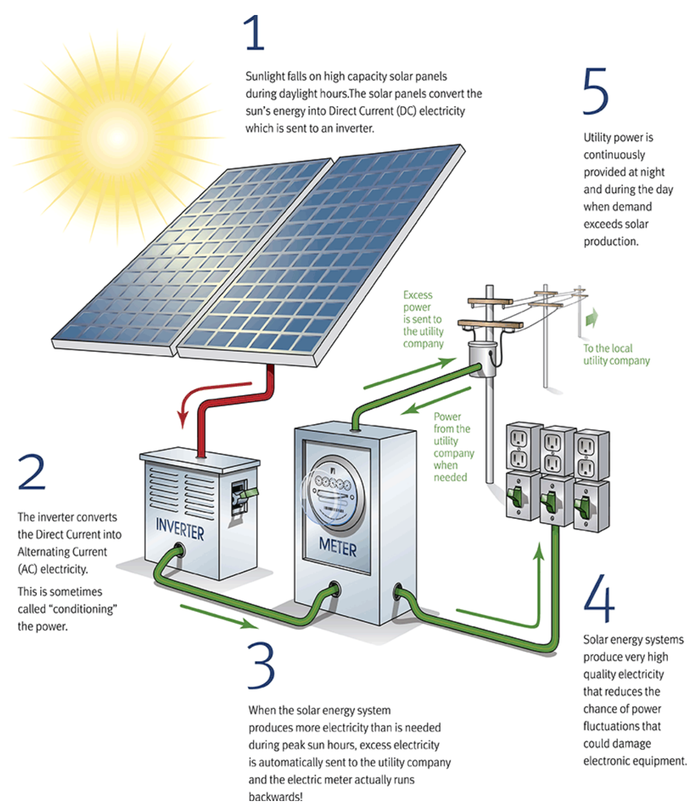


Figure 3

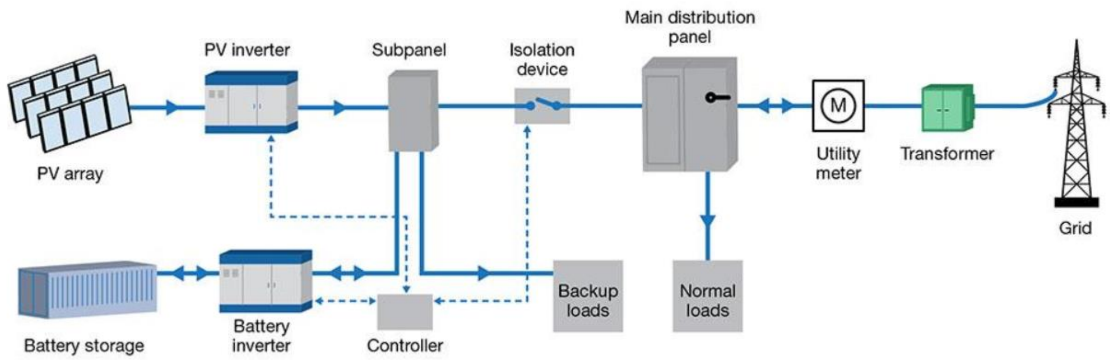


Figure 3 This figure shows a schematic diagram for an ac-coupled solar microgrid in which the PV and energy storage systems connect to separate inverters that share a connection to a common ac bus.

Figure 4

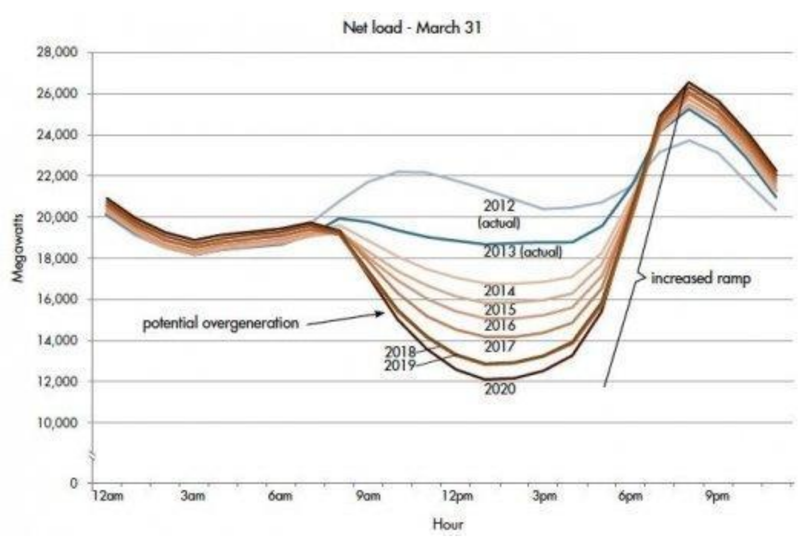
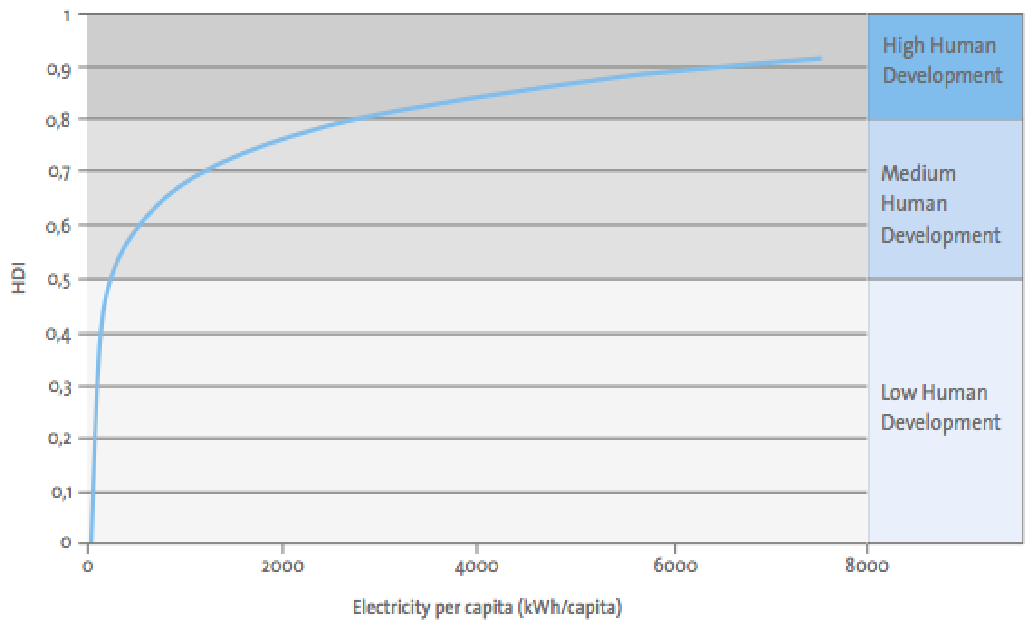


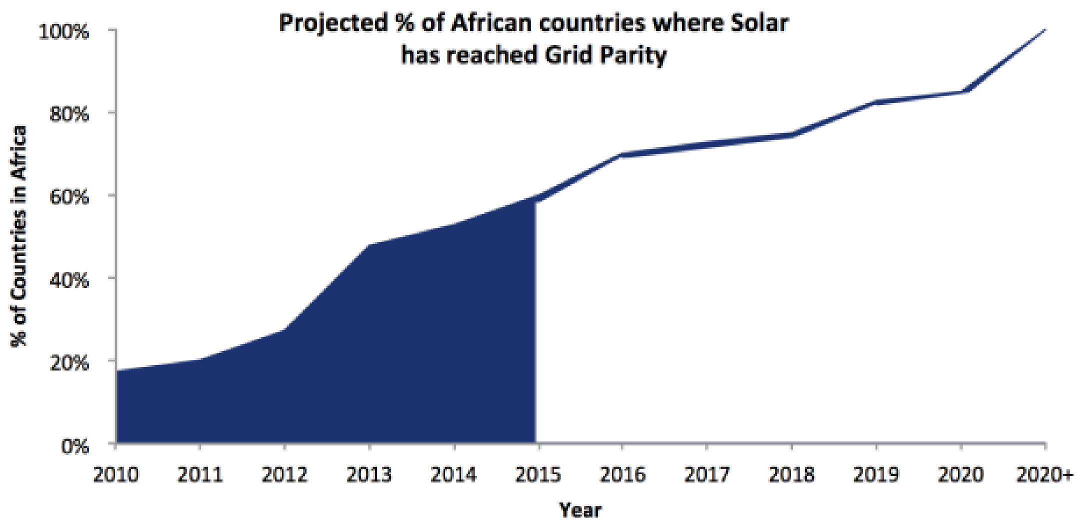
Figure 5

Figure 2: Macro-Level Correlation Between Electricity and Human Development



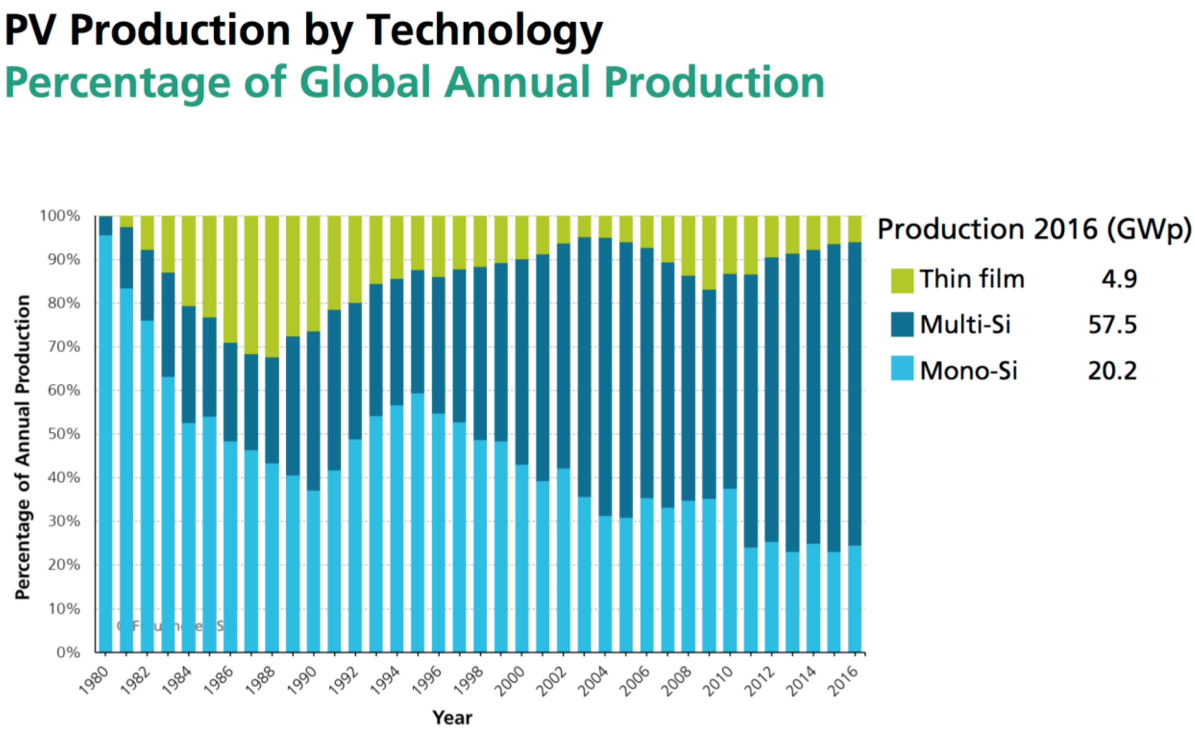
Source: White (2002)

Figure 6



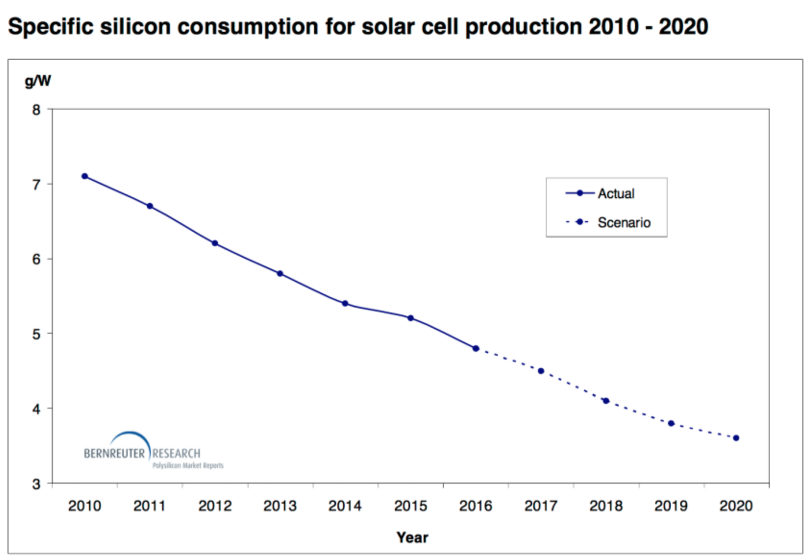
Projected % of African countries where Solar has reached Grid Parity
100%
80%
60%
40%
20%
0%
% of Countries in Africa
2010
2011
2012
2013
2014
2015
2016
2017
2018
2019
2020
2020+
Year

Figure 7



Source: https://www.ise.fraunhofer.de/content/dam/ise/de/documents/publications/studies/Photovoltaics-Report.pdf

Figure 8



The specific silicon consumption of the solar industry will halve between 2010 and 2020.

Source:http://www.bernreuter.com/fileadmin/user_upload/polysilicon-report/Bernreuter-Research-Polysilicon-Consumption-for-Solar-Cells.pdf

Figure 9

Table: Top Solar Panel Manufacturers in 2018 – Global ranking by shipment volume

2017 RANK	COMPANY	HEADQUARTERS
1	JinkoSolar	China
2	Trina Solar	China
3	Canadian Solar	Canada
4	JA Solar	China
5	Hanwha Q CELLS	South Korea
6	GCL-SI	Hong Kong
7	LONGi Solar	China
8	Risen Energy	China
9	Shunfeng	China
10	Yingli Green	China

https://news.energysage.com/best-solar-panel-manufacturers-usa/

Figure 10

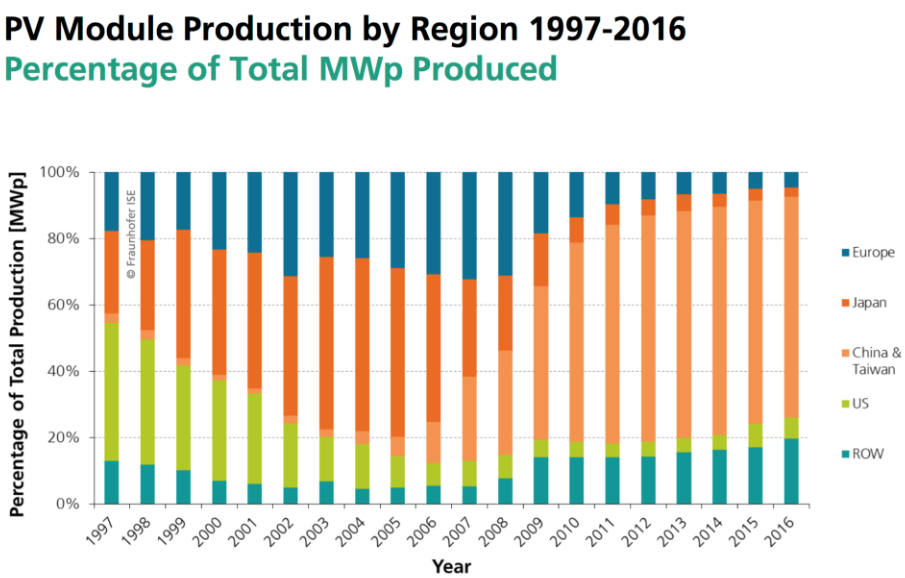


Figure 11

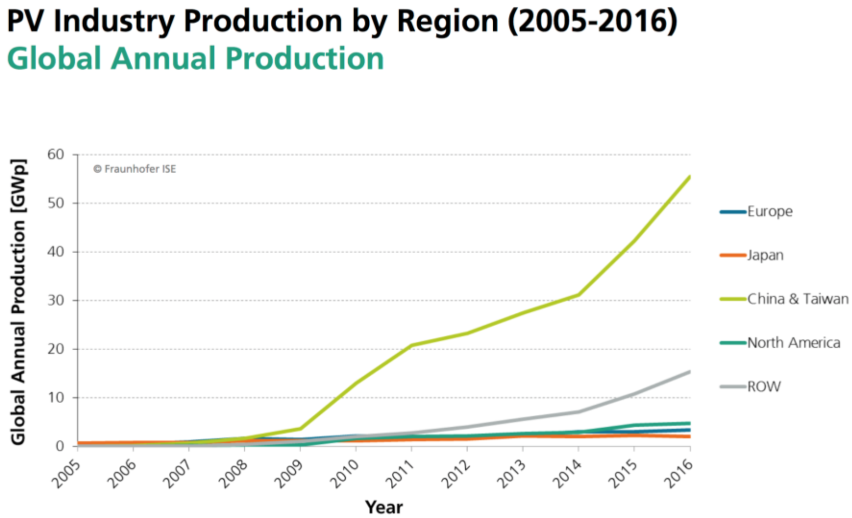


Figure 12

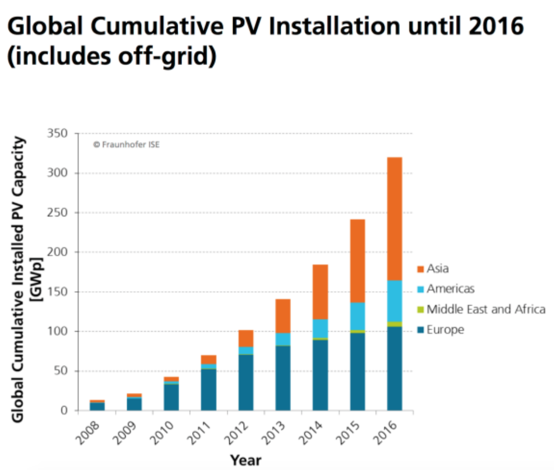
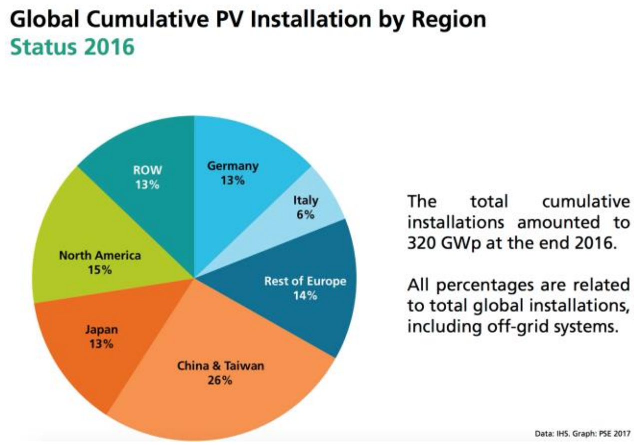


Figure 13



Source: https://www.ise.fraunhofer.de/content/dam/ise/de/documents/publications/studies/Photovoltaics-Report.pdf

Figure 14

Table 5 Approximate fully annualized, unsubsidized 2013 and 2050 U.S.-averaged costs of delivered electricity, including generation, short- and long-distance transmission, distribution, and storage, but not including external costs, for conventional fuels and WWS power (2013 U.S. $ per kWh-delivered)[a]

	Technology year 2013			Technology year 2050		
Technology	LCHB	HCLB	Average	LCHB	HCLB	Average
Advanced pulverized coal	0.083	0.113	0.098	0.079	0.107	0.093
Advanced pulverized coal w/CC	0.116	0.179	0.148	0.101	0.151	0.126
IGCC coal	0.094	0.132	0.113	0.084	0.115	0.100
IGCC coal w/CC	0.144	0.249	0.197	0.098	0.146	0.122
Diesel generator (for steam turb.)	0.187	0.255	0.221	0.250	0.389	0.319
Gas combustion turbine	0.191	0.429	0.310	0.193	0.404	0.299
Combined cycle conventional	0.082	0.097	0.090	0.105	0.137	0.121
Combined cycle advanced	n.a.	n.a.	n.a.	0.096	0.119	0.108
Combined cycle advanced w/CC	n.a.	n.a.	n.a.	0.112	0.143	0.128
Fuel cell (using natural gas)	0.122	0.200	0.161	0.133	0.206	0.170
Microturbine (using natural gas)	0.123	0.149	0.136	0.152	0.194	0.173
Nuclear, APWR	0.082	0.143	0.112	0.073	0.121	0.097
Nuclear, SMR	0.095	0.141	0.118	0.080	0.114	0.097
Distributed gen. (using natural gas)	n.a.	n.a.	n.a.	0.254	0.424	0.339
Municipal solid waste	0.204	0.280	0.242	0.180	0.228	0.204
Biomass direct	0.132	0.181	0.156	0.105	0.133	0.119
Geothermal	0.087	0.139	0.113	0.081	0.131	0.106
Hydropower	0.063	0.096	0.080	0.055	0.093	0.074
On-shore wind	0.076	0.108	0.092	0.064	0.101	0.082
Off-shore wind	0.111	0.216	0.164	0.093	0.185	0.139
CSP no storage	0.131	0.225	0.178	0.091	0.174	0.132
CSP with storage	0.081	0.131	0.106	0.061	0.111	0.086
PV utility crystalline tracking	0.073	0.107	0.090	0.061	0.091	0.076
PV utility crystalline fixed	0.078	0.118	0.098	0.063	0.098	0.080
PV utility thin-film tracking	0.073	0.104	0.089	0.061	0.090	0.075
PV utility thin-film fixed	0.077	0.118	0.098	0.062	0.098	0.080
PV commercial rooftop	0.098	0.164	0.131	0.072	0.122	0.097
PV residential rooftop	0.130	0.225	0.177	0.080	0.146	0.113
Wave power	0.276	0.661	0.468	0.156	0.407	0.282
Tidal power	0.147	0.335	0.241	0.084	0.200	0.142
Solar thermal for heat ($ per kWh-th)	0.057	0.070	0.064	0.051	0.074	0.063

[a] LCHB = low cost, high benefits case; HCLB = high cost, low benefits case. The methodology for determining costs is given in the ESI. For the year 2050 100% WWS scenario, costs are shown for WWS technologies; for the year 2050 BAU case, costs of WWS are slightly different. The costs assume $0.0115 (0.11–0.12) per kWh for standard (but not extra-long-distance) transmission for all technologies except rooftop solar PV (to which no transmission cost is assigned) and $0.0257 (0.025–0.0264) per kWh for distribution for all technologies. Transmission and distribution losses are accounted for. CC = carbon capture; IGCC = integrated gasification combined cycle; AWPR = advanced pressurized-water reactor; SMR = small modular reactor; PV = photovoltaics. CSP w/storage assumes a maximum charge to discharge rate (storage size to generator size ratio) of 2.62 : 1. Solar thermal for heat assumes $3600–$4000 per 3.716 m^2 collector and 0.7 kW-th per m^2 maximum power.[2]

Figure 15

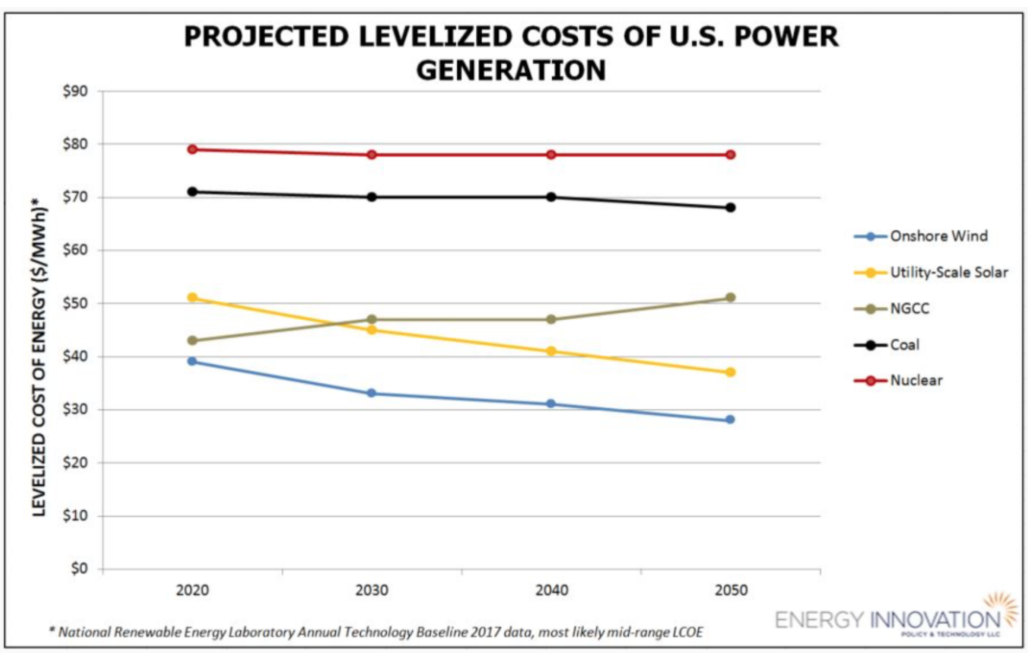


Figure 16

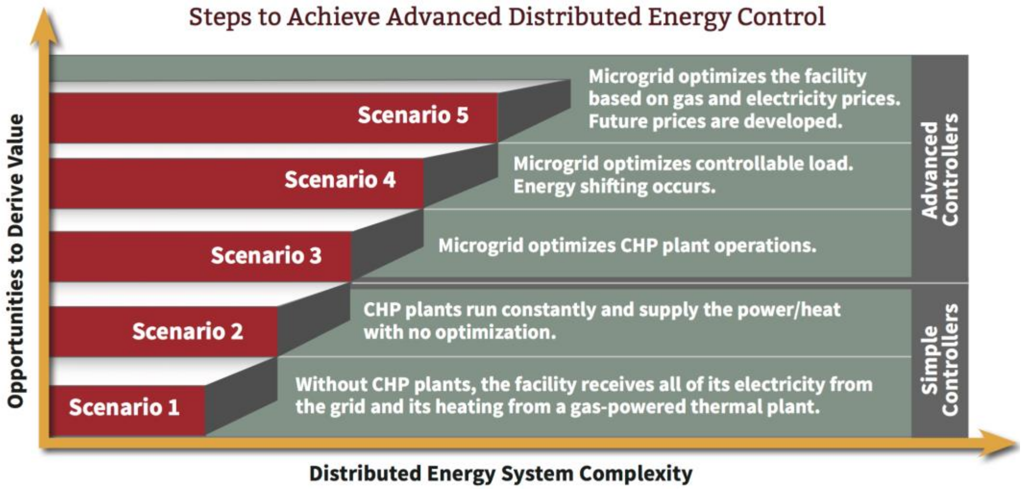


Figure 19

TABLE 3-7. MICROGRID COST ESTIMATES

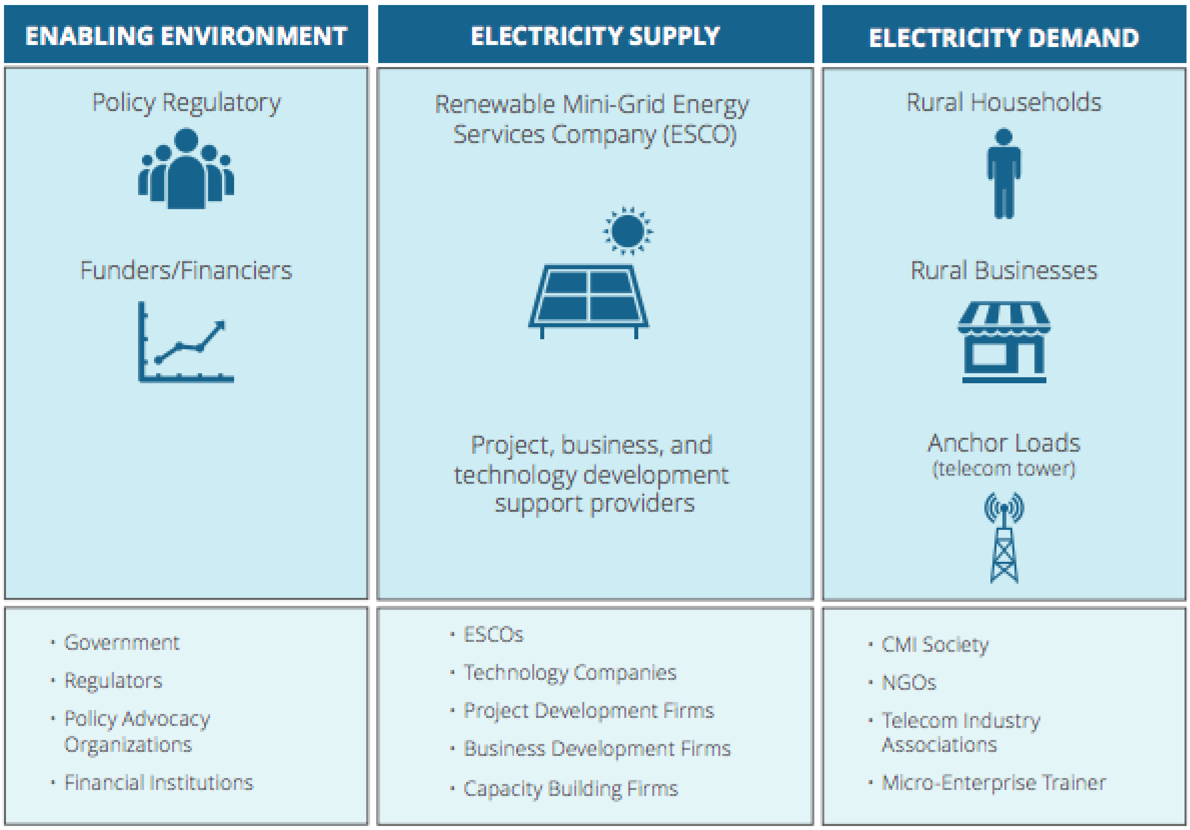
Facility Type		Number of Sites in Puerto Rico	Technology Required	Estimated Cost per Site	Targeted Microgrid Deployments	Total CAPEX ($ Millions)
Critical Infrastructure	Hospitals	58	PV, BESS, CHP, RICE	$19 million	26	$496
	Police Stations	Approx. 100	PV, BESS, RICE	$240,000	20	$5
	Fire Stations	84	PV, BESS, RICE	$240,000	20	$5
	Emergency Shelters	452	PV, BESS, RICE	$4.6 million	75	$345
	Wastewater Treatment Facilities	50	PV, BESS, RICE	$3.6 million	5	$18
	Drinking Water Treatment Facilities	Approx. 100	PV, BESS, RICE	$2.4 million	10	$24
Remote Communities		Multiple	PV, BESS, RICE	$38.1 million	3	$114
TOTAL					159	$1,007

Figure 20

Comparative Energy Costs

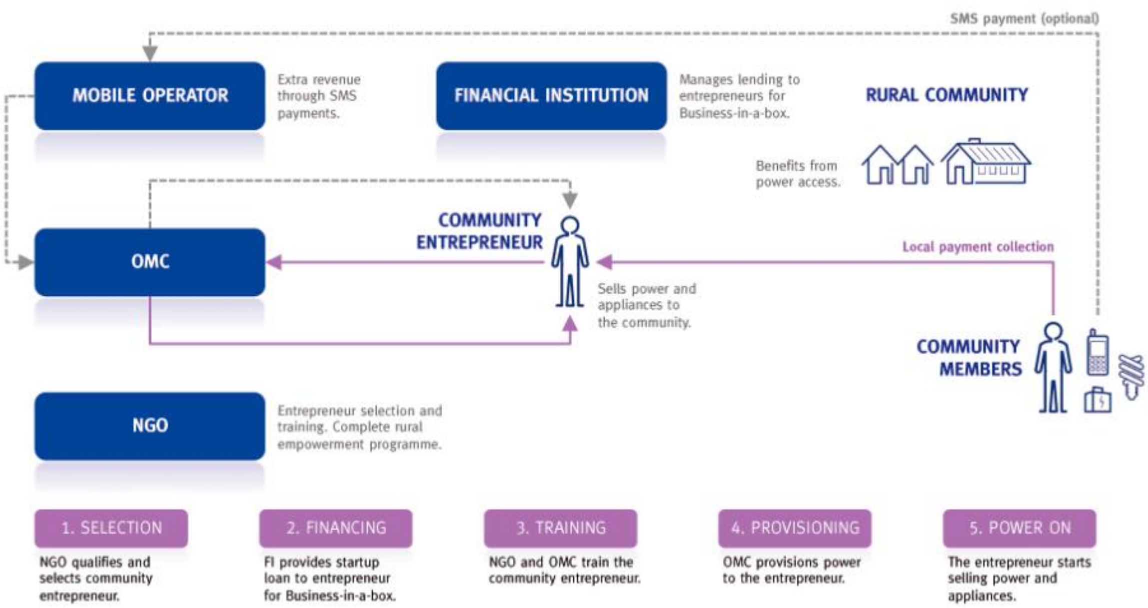
	India	Indonesia	Tanzania
Microgrid tariff	$2-4/month	$5-$25/month	$3-$15/month
Microgrid LCOE	$.25-$.70/KWH*	--	$.35/KWH****
Public Utility	$.054/KWH**	$.08/KWH***	$.16/KWH
Diesel Fuel*****	$.26/KWH ($.91/liter)	$.18/KWH ($.62/ liter)	$.34/KWH ($1.20/ liter)

Figure 21



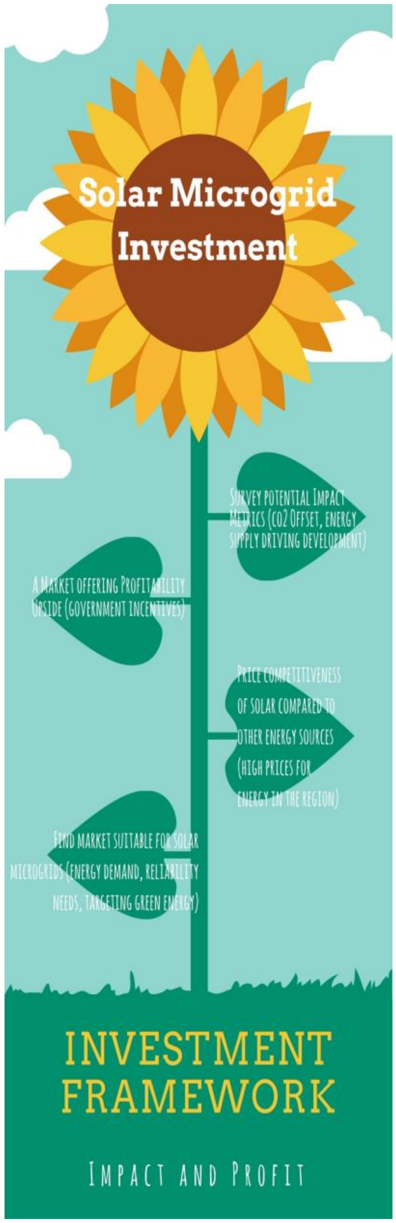
ENABLING ENVIRONMENT
ELECTRICITY SUPPLY
ELECTRICITY DEMAND
Policy Regulatory
Funders/Financiers
Renewable Mini-Grid Energy Services Company (ESCO)
Project, business, and technology development support providers
Rural Households
Rural Businesses
Anchor Loads
(telecom tower)
• Government
• Regulators
• Policy Advocacy Organizations
• Financial Institutions
• ESCOs
• Technology Companies
• Project Development Firms
• Business Development Firms
• Capacity Building Firms
• Civil Society
• NGOs
• Telecom Industry Associations
• Micro-Enterprise Trainer

Figure 24



http://www.omcpower.com/communities/ecosystem

Figure 25


Solar Microgrid Investment
Survey potential Impact Metrics (co2 Offset, energy supply driving development)
A Market offering Profitability Upside (government incentives)
Price competitiveness of solar compared to other energy sources (high prices for energy in the region)
Find market suitable for Solar microgrids (energy demand, reliability needs, targeting green energy)
INVESTMENT FRAMEWORK
Impact and Profit

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