Smart microgrids to improve reliability and resiliency of power supply in the Southeast

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Note from the Author: The exploration of the American power system is an exciting and challenging activity. While this report is focused on identifying key insights regarding potential reform of the Southeast power grid, some of its lessons on smart microgrid adoption are applicable to other regions with similar conditions.

This report intends to provide its readers with an interesting opportunity to understand the complexity behind the Southeast power grid from a technological and policy point of view, while providing elements to assess massive introduction of smart microgrids to improve the overall performance of the system.

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Executive Summary

The Southeast is no stranger to extreme weather events and their devastating impacts. For decades, this region has experienced powerful storms that have caused widespread damage to the power grid and have left millions of people without access to electricity for days and weeks. Despite investing billions in improvements over the years, electric utilities have not been able to fully mitigate some of the power grid's main vulnerabilities, which are directly linked to the centralized nature of the system.

Nonetheless, new decentralized smart microgrid technology could be an alternative to diminish the effects of extreme weather events, and an instrument to increase reliability and resiliency of power supply in the Southeast.

A microgrid is a group of interconnected loads and distributed energy resources (DERs) located within clearly defined electrical boundaries. Microgrids can coordinate with the main power grid but are managed by a different operator. Additionally, they add flexibility to the energy system because they can operate in a grid-connected or in island mode.

While smart microgrids have similar components, "no two microgrids are the same". Every microgrid is unique and requires a tailored approach to be designed, installed, and managed. Smart microgrids can improve reliability and resiliency of power supply up to 60%, however, their average costs tend to be very high, making most projects financially unfeasible. It is important to truly understand the real economic and social value that reliability and resiliency create in society to make a correct assessment for the utility of smart microgrids.

Despite DERs and smart microgrids being promoted by federal entities, the Southeast has not adopted them at the same rate as other regions. In the Southeast, the regulatory landscape follows a traditional vertically integrated utility model, which seems to have affected the rate of adoption of smart microgrids in this territory.

To take advantage of this technology and improve the overall well-being of people in the Southeast, stakeholders should work together to:

1. Establish clear and well-designed state level regulations that address rules regarding smart microgrids.

2. Require Electric Utilities to have clear standards and guidance for development and interconnection of smart microgrids to the grid.

3. Create federal, state, and local guidelines to determine economic benefits of resilient infrastructure, as well as pathways to access federal grants and funding for these projects.

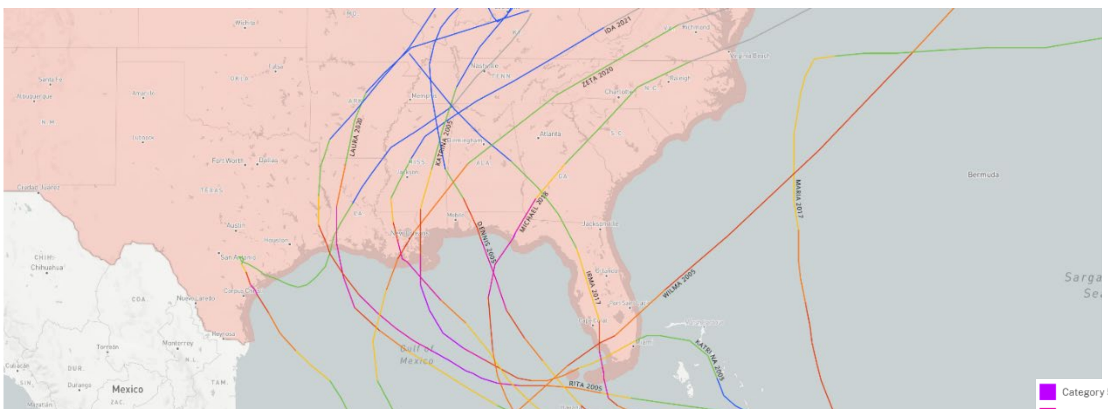
4. Assess the value of creating a Southeast ISO, which can replicate innovative and competitive practices in CA, TX, and NY.

Introduction

The Southeast is no stranger to extreme weather events and their devastating impacts. For decades, this region[1] has experienced powerful storms that have caused widespread damage to the power grid and have left millions of people without access to electricity for days and weeks. Despite investing billions in improvements over the years, electric utilities have not been able to fully mitigate some of the power grid's main vulnerabilities, which are directly linked to the centralized nature of the system. Nonetheless, new decentralized smart microgrid technology could be an alternative to diminish the effects of extreme weather events, and an instrument to increase reliability and resiliency[2] of power supply in the Southeast.

Extreme weather and power supply in the Southeast

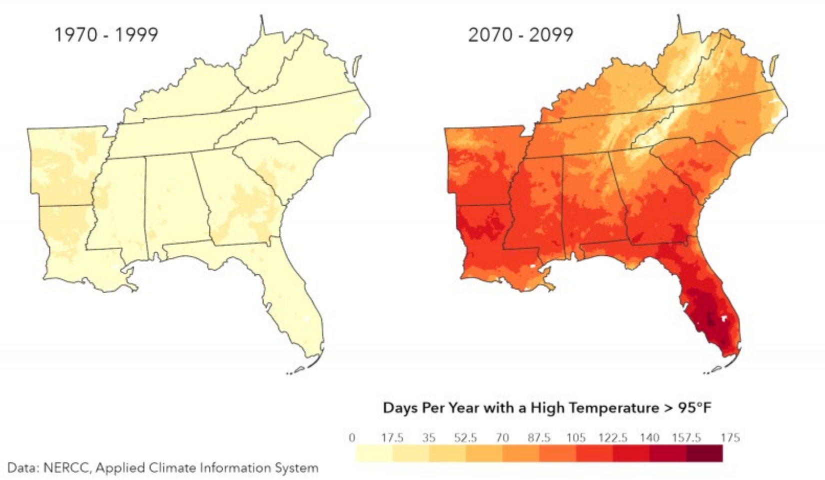
In September 2022, Hurricane Ian hit the western coast of Florida leaving approximately 2.7M homes and businesses in the state, or 24% of total customers, without electricity.[3] [4] One year before, Hurricane Ida severely damaged Louisiana's transmission grid causing an extensive power outage that affected over 1M users, that is, almost 50% of total customers in Louisiana.[5][6] The list goes on and on, with overwhelming consequences for the Southeast caused by Hurricanes Dorian (2019), Michael (2018), Irma (2017), Sandy (2012), Wilma (2005), Katrina (2005), and many others.



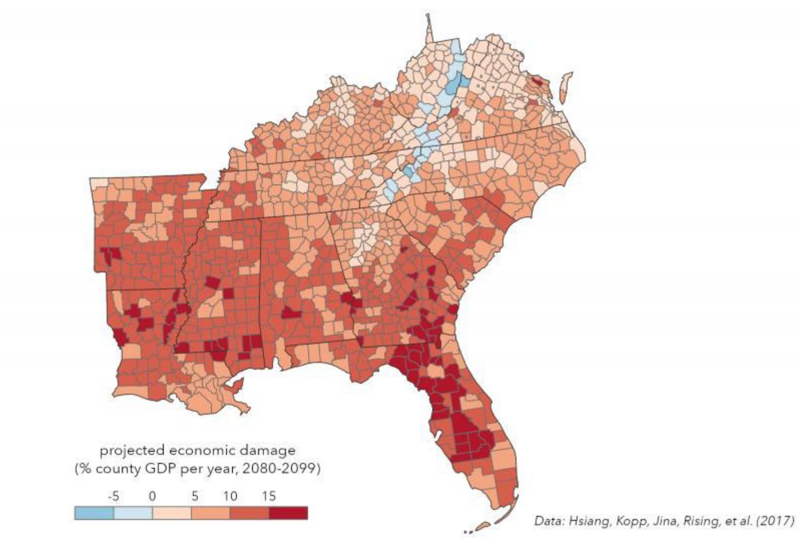
[*Map of Hurricanes Category 3+ Hurricanes impacting the US – last 20 year.*

[1] For purposes of this report, we will refer to the "Southeast" as the following coastal states located in the Southeast of the United States: North Carolina, South Carolina, Georgia, Florida, Alabama, Mississippi, and Louisiana.
[2] Reliability is defined as the ability of the electric system to deliver electricity as demanded by consumers. Resiliency is the ability for the electric system to withstand and recover from extreme and damaging conditions. Although sometimes used interchangeably, they are different concepts. Nonetheless, system resiliency will impact the reliability rates of the system.
[3] Tyko, Kelly, et al., "Florida power outages from Hurricane Ian continue for 1.6 million" Axios, Sep 2022, https://www.axios.com/2022/09/28/hurricane-ian-florida-power-outage
[4] Stevens, Joshua, "Power Outages after Hurricane Ian", NASA, Sep 2022, https://earthobservatory.nasa.gov/images/150431/power-outages-after-hurricane-ian
[5] Karlin, Sam, "Hurricanes Ian and Ida hammered two states' electric grids. The stories diverged from there", NOLA.com, Oct 2022, https://www.nola.com/news/hurricane/hurricanes-ian-and-ida-hammered-two-states-electric-grids-the-stories-diverged-from-there/article_1976b31e-4682-11ed-b5eb-379f2f974956.html
[6] Karlin, Sam, "Hurricane Ida brings 'havoc' to huge swath of Louisiana, but levees prevent mass casualties", NOLA.com, Aug 2021 https://www.nola.com/news/hurricane/article_a0a90bc2-09d2-11ec-a5fe-0b351e97fce1.html
[7] Coastal Management, "Historical Hurricane Tracks", National Oceanic and Atmospheric Administration, Apr 2023, https://coast.noaa.gov/hurricanes/#map=4/32/-80

The Southeast is also exposed to other extreme weather events that consistently impact the livelihood of its inhabitants[8], including fierce drought, intense rainfall, flooding, and excessive heat. These other natural disasters also have strong consequences on power supply. For instance, rainfall and flooding can directly damage the power infrastructure. On the other hand, excessive heat and drought create surges in demand for electricity (*i.e.*, cooling and irrigation), increasing the stress on the power system that can lead to blackouts or brownouts.[9]



[*Forecasted increase of temperature in the Southeast*][10]



[*Projected economic damages, as percentage of county GDP, per county, in the Southeast*]

[8] These natural disasters and interruptions to the power supply disproportionately affect poor and underserved communities in the Southeast.

[9] A blackout is a failure in the power system that leads to a complete interruption on the power supply, also known as a "power outage". On the other hand, brownouts are reductions of voltage in power supply when electric supply and demand cannot be met. The terms derive from the effects on lighting during such events.

[10] U.S. Climate Resilience Toolkit, "Southeast", Jun 2021, https://toolkit.climate.gov/regions/southeast

Extreme weather events[11] and electricity consumption in the Southeast have grown dramatically during the past decades, a situation that has exposed some serious vulnerabilities of the power system.[12] Experts have forecasted that natural disasters, population and power consumption will continue rise in the future as a result of further economic development, the transition to more renewable energy, and technology breakthroughs towards the "electrification of everything".[13]

Because electricity will become even more vital to our continuous development, the Southeast will need to double down on its efforts to embed higher resiliency into the system to maintain the stability of power supply.[14]

"Hardening" the grid has not been enough

In response these natural disasters and many power crises, utilities like Duke Energy and NextEra (Florida Power and Light or "FPL") invested billions of dollars in "grid hardening" efforts.[15] In a nutshell, the hardening process seeks to enhance electric grid's capabilities to reduce service disruptions.

Grid hardening[16] can include, among others:

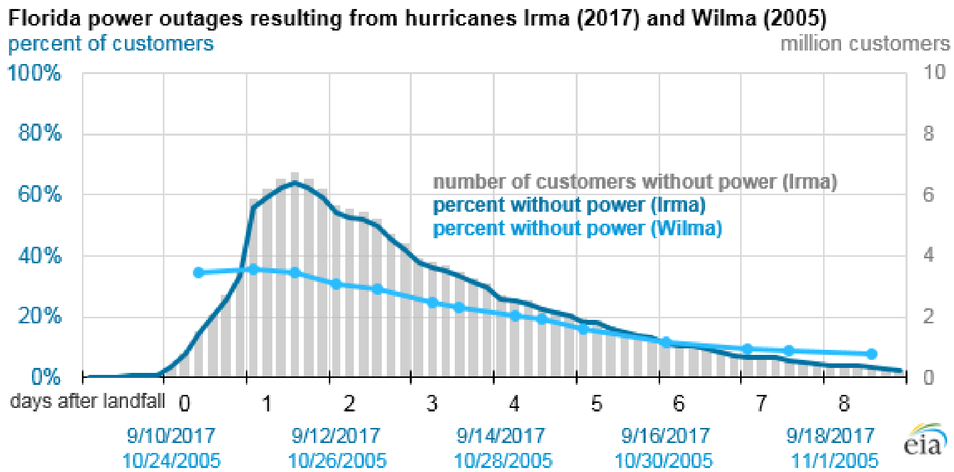
i. Strengthening poles and transmission infrastructure to endure extreme winds.
ii. Burying power lines to mitigate risk exposure.
iii. Elevating and fortifying substations against flooding and storm surge.
iv. Implementing thorough inspection and management systems using sensor and drone technology.[17]

In some cases, grid hardening has been very successful, as it has reduced the overall damage to the power system during severe storms, as well as reduced interruptions to power supply.

For example, in 2022, NextEra was able to restore service to 66% of all FPL customers affected by Hurricane Ian in less than 24 hours after the storm hit Florida. In a period of eight days, the company restored service to 99% of affected customers[18], making it the fastest service restoration time in the company's history. However, such a speedy recovery is expected to cost

[11] Environmental Protection Agency, "Climate Impacts in the Southeast", 2023, https://climatechange.chicago.gov/climate-impacts/climate-impacts-southeast#:~:text=Heavy%20downpours%20have%20also%20increased,and%20further%20increases%20are%20projected
[12] Population, industrial and commercial growth in the region have continued to rise at important rates in the Southeast coastal region. Louisiana is the state with the highest energy consumption per capita. Florida has become the second largest electricity producer in the US and the third most populous state in the US (only behind CA and TX). The region is expected to continue a consistent growth over the next decade.
[13] Myers Jaffe, Amy, "The Electrification of Everything: What You Need to Know", Wall Street Journal, May 2021, https://www.wsj.com/articles/electrification-of-everything-11620843173
[14] Department of Energy, "Southeast. Climate Change and the US Energy Sector: Regional Vulnerabilities and resilience solutions", 2023, https://www.energy.gov/sites/prod/files/2015/10/f27/Southeast.pdf
[15] Duke Energy, "Transmission Improvements. Enhancing power quality and reliability", 2023, https://www.duke-energy.com/our-company/future/transmission-improvements
[16] AIDash, "A guide to grid hardening: How to protect your utility grid", 2023, https://www.aidash.com/grid-hardening-guide/
[17] Fischbach, Amy, "FPL Hardens System Against Storm Outages", T&D World, Jun 2016, https://www.tdworld.com/grid-innovations/distribution/article/20966585/fpl-hardens-system-against-storm-outages
[18] Papaycik, Matt, "99% of Florida's power restored after Hurricane Ian, governor says", WPTV, Oct. 2022, https://www.wptv.com/weather/hurricane/gov-ron-desantis-hurricane-ian-10-7-22

customers more than $1.1B, in addition to billions of dollars previously invested in grid hardening[19].



In other cases, grid hardening has proved to be much less effective to improve resiliency and has only become a burden of billions of dollars to customers. For instance, despite investing over $6B between 2016 and 2021 in grid improvements[20] (including a $650M investment in a new gas plant for New Orleans), Entergy's[21] power service collapsed when hurricane Ida hit the gulf coast of Louisiana. It took Entergy 15 days to restore service to around 60% of affected customers, and many more months to achieve "full" restoration. Restoration efforts are expected to cost approximately $2.7B[22] on top of what was already invested, raising serious doubts on the effectiveness of grid hardening efforts by Entergy prior to the storm.[23] [24]

Despite varying degrees of success[25], grid hardening is extensive and costly. More importantly, grid hardening is unable to reduce vulnerabilities that are inherently related to the centralized nature of the power grid. Some of the grid's most important vulnerabilities derive from basic characteristics of the system[26], such as:

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[19] In general terms, utilities are subject to a regulated cost recoup process, although instruments to amortize such costs so may vary, some of these costs are ultimately transferred to costumers in fees on top of their electricity bills.

[20] Blau, Max, et al., "Entergy Resisted Upgrading New Orleans' Power Grid. Residents Paid The Price , NPR, Sep 2021, https://www.npr.org/2021/09/22/1039110522/entergy-resisted-upgrading-new-orleans-power-grid-residents-paid-the-price

[21] Entergy's is a Fortune 500 company headquartered in New Orleans, LA, and is Louisiana's largest electricity provider.

[22] Bennett, Abbie, "La. regulators approve Entergy storm cost recovery, $1B Hurricane Ida escrow", S&P Global, Feb 2022, https://www.spglobal.com/marketintelligence/en/news-insights/latest-news-headlines/la-regulators-approve-entergy-storm-cost-recovery-1b-hurricane-ida-escrow-69046834

[23] Stein, Michael Isaac, "Hurricane Ida revealed Entergy's misplaced investments, critics say, The Lens NOLA, Sep 2021, https://thelensnola.org/2021/09/21/hurricane-ida-revealed-entergys-misplaced-investments-critics-say/

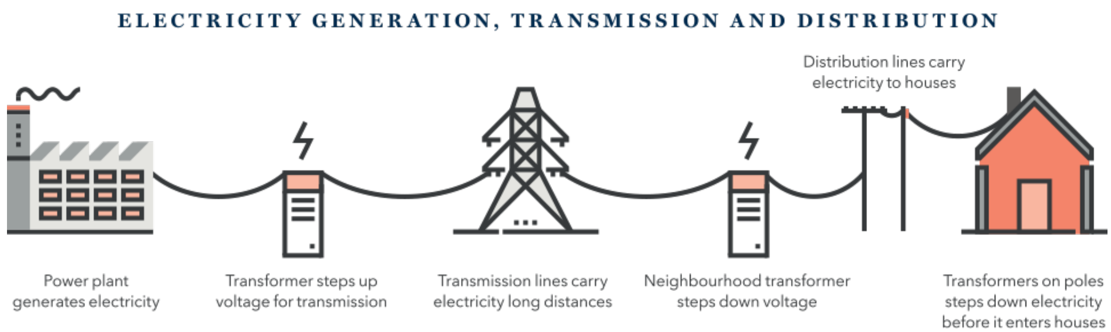
[24] WDSU Digital Team, "Entergy: Power restored to 90 percent of Louisiana 15 days after Hurricane Ida, WDSU, Sep 2021, https://www.wdsu.com/article/new-orleans-entergy-power-outages-ida/37592866#

[25] Miranda, Manny, "
OPINION
America deserves a better energy grid. FPL investments are helping customers prepare", Penascola Nes Journal, Jun 2022, https://www.pnj.com/story/opinion/2022/06/11/fpl-florida-power-and-light-investments-helping-customers-prepare-guestview/7554760001/

[26] McBride, James et al., "How does the U.S. Power Grid Work?", CFR, Jul 2022, https://www.cfr.org/backgrounder/how-does-us-power-grid-work

1. Centralization
2. Magnitude
3. Remoteness
4. Interconnectedness
5. Lack of redundancy

Under the current model, electricity is produced in large power plants, typically far away from urban areas where most consumption or "load" is located. Electricity is "stepped up", through a substation, to a higher voltage and is sent across long distances using transmission lines. Later, electricity is "stepped down", through a different substation[27], to a lower voltage and it is distributed to homes and businesses (the "load") through distribution lines.



[*Diagram of the power system*] [28]

Because of its size, the power grid is vulnerable at the generation, transformation, and transmission levels, making it extremely complex to implement one-size-fits-all solutions. Even assuming it is feasible to build redundancy and ensure generation and transformation in the system, transmission would remain highly vulnerable to hurricanes and other environmental and human factors given the length and exposure of transmission lines.[29]

However, new smart microgrid technology could provide a feasible and scalable alternative that could improve resiliency across the system.

In short, a microgrid is a self-sufficient energy system that serves a specific geographic point. A microgrid can power college campuses, hospital complexes, business centers or neighborhoods.[30] A "smart" microgrid is just an AI and remotely controlled version of a microgrid. Because smart microgrids rely on local power generation, storage, and distribution,

[27] There are different types of transformers that help step-up or step-down electricity between different voltages. A transformer is the heart of a substation, but individual transformers can be found in many other places to manage voltage in parts of the distribution system.
[28] Scott, Michael, "Making the Grid Smarter". Walter Scott, Dec 2022, https://www.walterscott.com/making-the-grid-smarter/
[29] Wood, Elisa, "How Many Hurricanes Must Slam the Grid Before We Get the Message? " Microgrid Knowledge, Sep 2021, https://www.microgridknowledge.com/editors-choice/article/11427757/how-many-hurricanes-must-slam-the-grid-before-we-get-the-message
[30] Wood, Elisa, "What is a microgrid?", Microgrid Knowledge, Mar 2020, https://www.microgridknowledge.com/about-microgrids/article/11429017/what-is-a-microgrid

they could provide the power grid with the flexibility required to enhance its reliability and resiliency.

Analyzing whether smart microgrids can provide the grid with the elements to build-in more resiliency into the power grid is of utmost importance for companies like Entergy, Duke Energy and NextEra, three of the largest electric utilities in the Southeast. Additionally, developing smart microgrids becomes even more important considering recent pledges from these companies to transition to net zero power generation by 2045 (NextEra)[31] and 2050 (Entergy and Duke Energy)[32] [33], given that microgrids could reduce the stress on the limited capacity of transmission lines.

While smart microgrids have gained national awareness among experts, media and policymakers, there are many challenges to smart microgrid adoption in the Southeast.[34] Some of these challenges include:

1. Lack of technological standardization
2. Policy and regulatory uncertainties
3. Diverse financial, social, security, and environmental factors.

Therefore, this paper will focus on examining whether *smart microgrids can be a feasible and scalable solution to improve reliability and resiliency of power supply in the Southeast consistently affected by extreme weather events.*

To answer this question, this report will (1) use some of the most relevant smart microgrid literature and case studies to evaluate main technological advantages and disadvantages of smart microgrids. (2) We will review the current policy and regulatory landscape to have a comprehensive understanding of regulatory and policy incentives or obstacles for the deployment of smart microgrids in the Southeast. (3) Finally, this report will briefly analyze other financial, social, security, and environmental factors related to the adoption of smart microgrids. All the foregoing, to identify key takeaways and provide policy recommendations regarding the effective use of smart microgrids as a tool to increase resiliency in the system and improve the lives of millions of people in the Southeast.

[31] NextEra Energy, "NextEra Energy sets industry-leading Real Zero™ goal to eliminate carbon emissions from its operations, leverage low-cost renewables to drive energy affordability for customers", 2023, https://newsroom.nexteraenergy.com/2022-06-14-NextEra-Energy-sets-industry-leading-Real-Zero-TM-goal-to-eliminate-carbon-emissions-from-its-operations,-leverage-low-cost-renewables-to-drive-energy-affordability-for-customers

[32] Entergy, "Entergy's path to net-zero emissions and climate resilience, Nov 2022, https://www.entergy.com/userfiles/content/environment/docs/2022-Climate.pdf

[33] Duke Energy, "Duke Energy outlines progress on clean energy transition" Oct 2022, https://news.duke-energy.com/releases/duke-energy-outlines-progress-on-clean-energy-transition#:~:text=Duke%20Energy%20is%20executing%20an,zero%20carbon%20emissions%20by%202050

[34] D'Acosta, Luis, "Overcoming The Barriers To Widespread Microgrid Adoption And Sustainable Buildings:, Forbes, Jun 2022, https://www.forbes.com/sites/forbestechcouncil/2022/06/24/overcoming-the-barriers-to-widespread-microgrid-adoption-and-sustainable-buildings/?sh=78606940c2ae

From Grid to Microgrid: elements of power supply

To understand if smart microgrids are a potentially beneficial alternative for the Southeast, we must first review the basic notions behind existing centralized power systems (status quo). We will proceed to contrast these notions against the advantages and disadvantages of different smart microgrid technologies (decentralized power systems).

After such conceptual review, we will analyze different case studies to assess the effects and value of smart microgrids on reliability and resiliency of power supply.

Principles of the (centralized) power grid

The power grid is the world's largest machine.[35] While the history of electricity dates back to 600 B.C., the light bulb and the power grid were invented less than 150 years ago. It was during the 1880's that the UK and the US inaugurated their first hydro[36] and coal-fired[37] power plants, respectively. Soon after that[38], hundreds of nations around the globe started electrifying and expanding their power systems.[39]

Although the power system is a sophisticated network, its design is focused on a relatively simple principle: interconnecting and balancing power generation and consumption, at all times, in the most efficient way.[40] The need to quickly deliver the cheapest available electricity to homes and businesses derived in a centralized system design[41], based on building large power plants and long transmission lines because of the following reasons:

i. **Economies of Scale**. In general terms, large power plants can generate electricity more efficiently than smaller power plants because it can reduce the per unit cost of electricity generated, as both capital and operating expenses per MWh tend to be lower.[42]

ii. **Generation Mix**. Larger power plants can use a variety of fuel sources, including coal, natural gas, biomass, nuclear, wind, solar, among others. Not only can large power plants be hybrid, but they can also be co-located with other power plants or even battery storage

[35] Aggarwal, Sonia, "Greasing the Electric Grid, the World's Largest Machine (Op-Ed)", LiveScience, Nov 2014, https://www.livescience.com/48893-improving-efficiency-on-the-electric-grid.html
[36] https://www.bbc.co.uk/news/uk-england-tyne-21586177
[37] BBC, "Hydro-electricity restored to historic Northumberland home", Feb 2013, https://ethw.org/Milestones:Pearl_Street_Station,_1882#:~:text=On%204%20September%201882%2C%20Edison's,all%20central%20electric%20generating%20stations
[38] The real process of grid centralization started after the "War of the Currents", which ended up in defining the supremacy of Alternating Current (AC) as the primary technology the transport electricity (long distance from large power plants to cities). For more information, please visit: https://www.historyextra.com/period/victorian/edison-westinghouse-tesla-real-history-behind-the-current-war-film/
[39] Twinkl, "What is the History of Electricity?", 2023, https://www.twinkl.com/teaching-wiki/the-history-of-electricity#:~:text=Benjamin%20Franklin%20is%20credited%20for,has%20changed%20because%20of%20electricity
[40] https://justenergy.com/blog/power-grid-what-is-it-and-how-does-it-work/
[41] Please consider that a centralized grid design in this context refers only to the characteristics of the technology. Under this assumption, power is generated in large power plants and transmitted through long transmission lines to load/consumption centers. In opposition to this concept, decentralized technologies are those referred to as distributed energy resources (DERs), where electricity is generated in close proximity to the load.
[42] Just Energy, "Power Grid: What Is It and How Does It Work?", 2023, https://www.e-education.psu.edu/eme801/node/530

units. This diversity and flexibility allow plant operators to increase efficiencies, reliability and, in some cases, reduce costs.[43] [44]

iii. **Transmission Efficiency**. Higher voltage transmission lines deliver power more efficiently, reduce energy losses, and allow the grid operator to transport electricity from areas with excess capacity to areas with high demand.[45] [46]

iv. **Cost Savings**. Larger infrastructure can reduce operational and maintenance costs linked to multiple smaller infrastructure.

Under this paradigm, nations were able to enter a new phase of industrialization and increase productivity rates to levels never seen before. For more than a century, some of the most important living standards improved in countries, showing an important correlation between electricity access and well-being (*e.g.*, food, shelter, health, education, etc.)[47].

However, the power system was designed under paradigms and constraints of the 20th century. Its high degree of centralization has intrinsic vulnerabilities that could be mitigated using new technologies developed during the last decade, including new renewable energy, power storage and AI-controlled components. Perhaps these inventions of the 21st century will grant us the opportunity to reimagine and rebuild a more local, flexible, and resilient power grid.

What are "smart" (decentralized) microgrids?

A microgrid is a group of interconnected loads and distributed energy resources (DERs)[48] located within clearly defined electrical boundaries. In simple terms, microgrids are "mini" versions of the grid[49] that are independently controlled. Microgrids can coordinate with the main power grid but are managed by a different operator. Additionally, they add flexibility to the energy system because they can operate in a grid-connected or in island mode.[50]

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[43] Farnoosh, Arash, Power Generation from Coal, Oil, Gas, and Biofuels", The Palgrave Handbook of International Energy Economics, May 2022, https://link.springer.com/chapter/10.1007/978-3-030-86884-0_6

[44] Berkeley Lab, "Hybrid Power Plants: Status of Operating and Proposed Plants", 2023, https://emp.lbl.gov/hybrid

[45] Smith, Brett, "How Electricity can Travel Long Distances with Minimal Power Loss", AZO Materials, Jul 2019, https://www.azom.com/article.aspx?ArticleID=18258

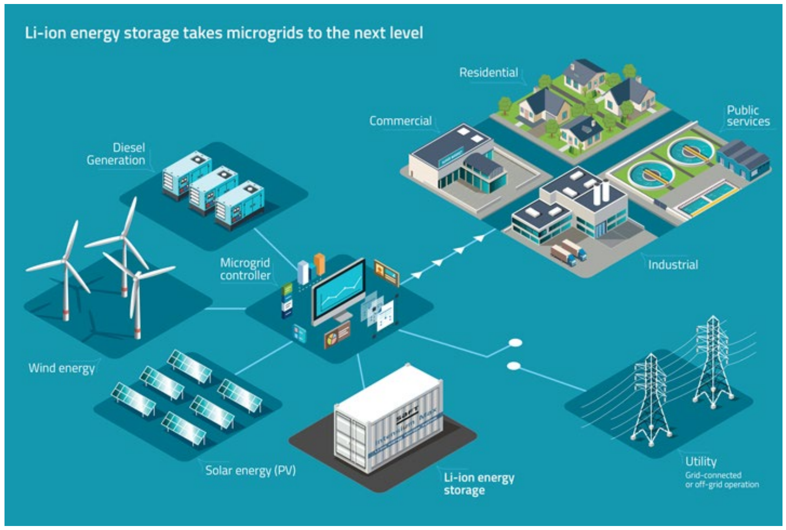
[46] ATC, "Higher voltage transmission lines deliver power more efficiently, reduce carbon emissions", Jun 2017, http://www.atcllc.com/wp-content/uploads/2017/06/Line-Losses-2017.pdf

[47] Ahmad, Shail, et al., "Household electricity access, availability and human well-being: Evidence from India ", Energy Policy, Volume 69, Jun 2014, https://www.sciencedirect.com/science/article/abs/pii/S0301421514000913

[48] DERs are power generation and battery storage assets closely located to consumption centers or "loads". While DERs are typically identified with renewable power sources like solar panels, DERs can be any power resources scattered closely to the load, including diesel generators and small windmills. Depending on the regulation, DERs can be owned and operated by the electric utilities, businesses, or individuals.

[49] Tsui, Jenna, "How Smart Microgrids Will Change the Way We Consume Energy", Altenergy Magazine, Jun 2020, https://www.altenergymag.com/article/2020/06/how-smart-microgrids-will-change-the-way-we-consume-energy/33212

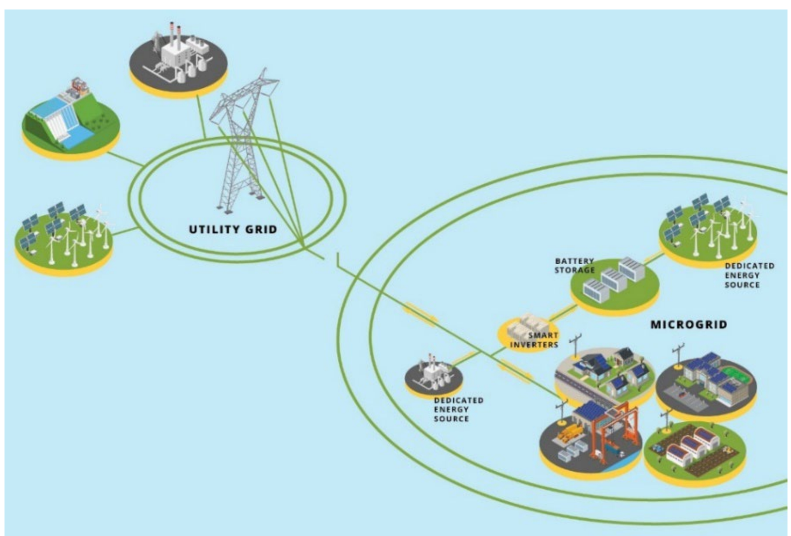
[50] DOE, "The US Department of Energy's Microgrid Initiative, https://www.energy.gov/sites/prod/files/2016/06/f32/The%20US%20Department%20of%20Energy%27s%20Microgrid%20Initiative.pdf



[*Diagram of a grid-connected microgrid]* [51]

In some cases, microgrids are used as an off-the-grid solution when the grid is not available or is unreliable. In other cases, microgrids are used to create redundancy in the network that leads to higher resiliency in power supply.[52]

The "smart" title comes from the fact that the microgrids are controlled, operated, and monitored using software, AI and/or digital sensors. Given the variability of technology used in microgrids, we will assume that any microgrid in the US is, to a certain extent, a smart microgrid.



[*Diagram of a smart microgrid*][53]

[51] McDowall, Jim, "Taking Microgrids to the Next Level With Li-ion Energy Storage" Alterngy Magazine, Jun 2018, https://www.altenergymag.com/article/2018/03/taking-microgrids-to-the-next-level-with-li-ion-energy-storage/28049
[52] Imagine you are flying an airplane with one engine. If this engine fails, then the plane will stop working. Now imagine you install a second engine to your plane. Even if one of the engines fails, the plane can continue flying. Installing a second engine creates redundancy in the airplane, which leads to resiliency, or the ability to withstanding and adapt to disruptions in the system.
[53] Schneider, Jude, "The Microgrid Solution", Edison International, Jan 2020, https://energized.edison.com/stories/the-microgrid-solution

Types of microgrids

While there are many microgrids classifications, most systems can be categorized into the three following: [54] [55]

Remote Microgrid.

Also known as "off-grid" microgrids, remote microgrids are physically isolated from the utility grid or macro-grid, and always operate in island mode. It is common to find them in areas where transmission and distribution are unavailable, unaffordable and/or unreliable.

For example, remote microgrids are typically used to power up islands, such is the case of Tesla's Ta'u microgrid in American Samoa[56]. Also, remote microgrids are deployed to provide energy access in remote areas (*i.e.*, in countries where electrification rates are still relatively low), such as microgrids operated by Devergy in Tanzania.[57]

These remote microgrids are powered by *in situ* generators[58], including those fueled by hydrocarbons, renewable energy, or hybrid power. Additionally, many off-grid microgrids have energy storage systems paired up with renewable energy generators to maintain stability of power supply.[59]

[*Diagram of an off-grid microgrid*][60]

[54] Solar Tech, "What Are The Different Types of Microgrids, And How Do They Work?", 2023, https://solartechonline.com/blog/what-are-microgrids/
[55] Duke Energy One, "3 Types of Microgrids Transforming the Industry", Duke Energy, Apr 2021, https://sustainablesolutions.duke-energy.com/resources/three-types-of-microgrids/
[56] Lin, Daniel, "How a Pacific Island Changed From Diesel to 100% Solar Power, National Geographic, Feb 2017, https://www.nationalgeographic.com/science/article/tau-american-samoa-solar-power-microgrid-tesla-solarcity?loggedin=true&rnd=1682393226943
[57] USAID, "Adaptive Solar PV Mini-Grids in Tanzania", https://www.usaid.gov/energy/mini-grids/case-studies/tanzania-smart-solar
[58] This is a very nice way to say that they are in proximity to the customers. Also known as "local" generation.
[59] Unlike a diesel generator that can be turned at any moment if you have diesel, solar energy is only produced when sunlight strikes the solar panels and when the wind turns the wind turbines. To avoid this intermittency, many remote microgrids include battery storage units that can be activated when the sun is not shinning and the wind is not blowing.
[60] Madathil, Sreenath Chalil, " Modeling and Analysis of Remote, Off-grid Microgrids", Semantic Scholar, 2017, https://www.semanticscholar.org/paper/Modeling-and-Analysis-of-Remote%2C-Off-grid-Madathil/b6128176d8a98d1c24e825c9c818ff943378ff37

Grid-connected Microgrid.

Grid-connected microgrids have a physical connection to the utility grid via a switching mechanism. These microgrids can disconnect and reconnect to the utility grid as needed.

For example, microgrids can disconnect from the main utility grid in case of a power outage and continue to operate independently. On the contrary, when connected to the grid, microgrids can provide ancillary services (*e.g.*, frequency and voltage regulation, real and reactive power support, demand response, black start, etc.) to help address potential capacity, power quality, reliability, and voltage issues on the utility grid.[61]

Grid-connected microgrids have demonstrated economic viability for small geographic areas, especially to build resiliency in critical and non-critical infrastructure, such as:

i. Military bases
ii. Medical complexes
iii. Homeland security and public safety facilities
iv. Telecom infrastructure
v. Educational campuses
vi. Agricultural farms
vii. Industrial facilities

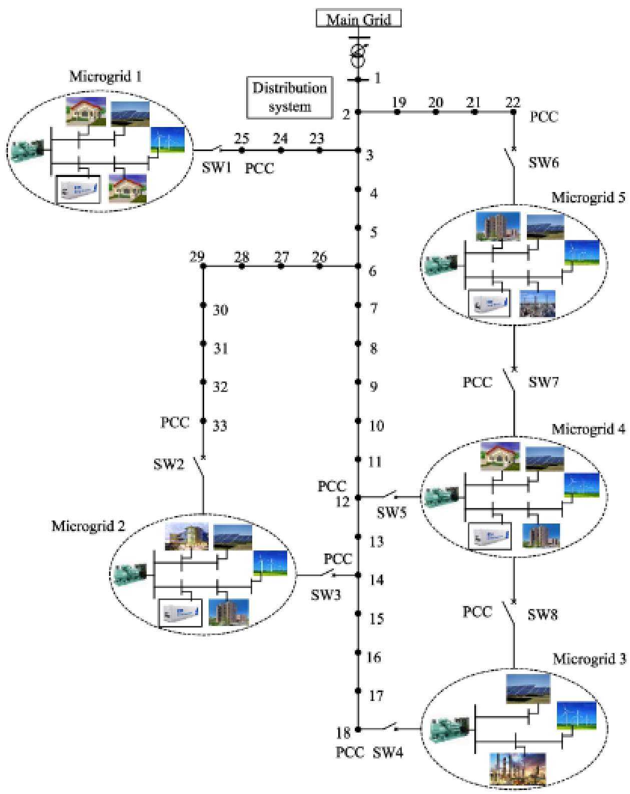
[*Diagram of critical infrastructure microgrids*][62]

[61] These are all vital activities to maintain stability of power supply. Typically, the electric utility is responsible for handling all variables to keep the wheel spinning. Although most people never realize it, the system is constantly being balanced by the best professionals that need to face all types of unforeseen events every 24/7.
[62] Siemens, "How microgrids future-proof your energy system", 2017, https://new.siemens.com/us/en/products/energy/energy-automation-and-smart-grid/microgrid.html

Examples of grid-connected microgrids: Borrego Springs, CA, University of Texas in Austin, Texas, or Fort Sill, OK.[63]

Nested Microgrid.

Nested or "networked" microgrids (NMGs) are "clusters of microgrids that are physically connected and functionally interoperable"[64]. In other words, an NMG is a microgrid of microgrids. Nested microgrids are typically managed and optimized by a supervisory control system to operate and coordinate at different tiers of hierarchy along the utility grid circuit segment.[65]



[*Diagram of a nested microgrid*] [66]

Example: Oncor's microgrid in Lancaster, Texas and (proposed) nodular microgrid project in New Paltz, NY.

[63]Clean Coalition, "Microgrids Across the United States", 2023, https://clean-coalition.org/community-microgrids/microgrids-across-the-united-states/
[64] Bo, Chen, et al., "Networked Microgrids for Grid Resilience, Robustness, and Efficiency: A Review", OSTI, 2020, https://www.osti.gov/servlets/purl/1776742#:~:text=%EF%80%A0,physically%20connected%20and%20functionally%20interoperable
[65] This is what I like to call a "gated community" of microgrids. There is just one entrance (utility grid circuit segment), on a normal basis, homeowners interact with each other as a community (interconnected microgrids), but if something bad happens, you they can always isolate from the other (microgrids in island mode).
[66] Alam, M. et al., "Networked Microgrids: State-of-the-Art and Future Perspectives", Semantic Scholar Mar 2019, https://www.semanticscholar.org/paper/Networked-Microgrids%3A-State-of-the-Art-and-Future-Alam-Chakrabarti/7231b063bddf813a4f357ea3b611a91b512389a7

While smart microgrids have similar components[67], "no two microgrids are the same".[68] Every microgrid is unique and requires a tailored approach to be designed, installed, and managed. Microgrids are customized to meet the specific needs of homeowners, businesses, utilities, and communities. Therefore, smart microgrids can vary considerably in terms of size, generation capacity, energy storage, distribution infrastructure, sensors, and software.[69]

Each microgrid must be designed and engineered based on its specific load requirements, available energy sources, and local environmental and regulatory conditions. For example, a microgrid in a remote, off-grid location with limited access to fuel may rely on solar panels and energy storage systems to meet its energy needs (*i.e.*, microgrid used for energy access purposes). On the other hand, a microgrid in an urban area may use a combination of renewable and non-renewable energy sources and may be connected to the utility grid to supplement its energy supply (*i.e.*, microgrid used for resiliency purposes).

Moreover, the management and operation of microgrids can also vary depending on their purpose and characteristics. As described above, some smart microgrids may be designed to operate in parallel with the centralized grid, while others may function independently and require more sophisticated control systems and management strategies. In other cases, regulations might not be clear regarding ownership rights, financing schemes, tariffs, among others.

Advantages and disadvantages of smart microgrids

Smart microgrids are gaining popularity in the world given their potential to increase energy efficiency, enhance grid resiliency, and improve sustainability in the electricity system.

While the deployment of smart microgrids can provide many advantages, there are also several disadvantages associated with their implementation, especially when thinking about potential large-scale adoption in the future. The following include the most important advantages and disadvantages of smart microgrid deployment[70] [71] [72]:

Advantages

1. **Energy Efficiency**. Smart microgrids can reduce energy waste and optimize energy consumption by balancing supply and demand in real-time. Smart microgrids can identify peaks in demand and automatically divert from using energy from the grid to energy from DERs or vice versa.

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[67] For more information on basic components, please visit: https://www.energy.gov/sites/default/files/2020/10/f80/1_Reillly-Microgrids.pdf
[68] Yuksel, Aytek, "Types of Microgrids, with examples", Cummins, Sep 2021, https://www.cummins.com/news/2021/09/23/types-microgrids-examples
[69] A similar analogy with smartphones. They are not all created equal. They are not the same brand, don't have the same quality, specifications, capacity, or size.
[70] RF Wireless World, "Advantages of Smart Grid | Disadvantages of Smart Grid", 2023, https://www.rfwireless-world.com/Terminology/Advantages-and-Disadvantages-of-Smart-Grid.html
[71] Prasad, Abhishek, "Smart Microgrids and some of its benefits", BBN Times, Jun 2016, https://www.bbntimes.com/technology/smart-microgrids-and-some-of-its-benefits
[72] Krueger, Morgan, "The Pros and Cons of Microgrids", Pacific Data Integrators, 2023, https://www.pacificdataintegrators.com/insights/microgrid-pros-and-cons

2. **Resilience**. New technology can add flexibility to the centralized grid, guaranteeing steady power supply to businesses, homes and/or critical infrastructure during blackouts or brownouts, reducing the impact of power outages in determined geographic locations.

3. **Sustainability**. Smart microgrids can be used as a pathway to incorporate more renewable energy sources to the power generation mix without increasing the strain on the (already congested) transmission grid, leading to a reduction of carbon emissions.

4. **Energy Security**. As mentioned above, the centralized power grid is susceptible to natural disasters and human acts in three different levels (generation, transformation, and transmission/distribution). By adding smart microgrids, population centers could effectively protect themselves against failures of large infrastructure and avoid being dragged down.

5. **Grid Flexibility**. Smart microgrids can adapt to changes in energy demand and supply, allowing for more efficient use of existing infrastructure and reducing the need for the construction of more power generation capacity (*e.g.*, by providing ancillary services like frequency control support, voltage control support, congestion management, reduction of grid losses, and improvement of power quality).[73]

6. **Faster Construction**. While smart microgrids have many technical complexities, they are faster to build because of their size, pre-built components, and environmental and social impact, when compared to large power plants, transmission lines and other large electric infrastructure.

Disadvantages

1. **High Deployment Costs**. Despite an important reduction in the price of certain DER components over the last decade, building smart microgrids is expensive. More importantly, given that smart microgrids are intended to improve the quality and consistency of power supply, there is no clear definition or way to calculate real costs or benefits of resiliency in the system.

2. **Regulatory Barriers**. The regulatory environment for microgrids can be complex and slow-moving, making it difficult to obtain necessary permits and approvals.

3. **Technical Complexity**. Smart microgrids require sophisticated monitoring and control systems, which can be challenging to operate and maintain. Also, these systems require continuous network communications and must synchronize with the electric utility to match voltage, frequency, and power limits at all times.

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[73] Martinez-Ramos, Jose L., et al., "Provision of Ancillary Services by a Smart Microgrid: An OPF Approach", IEEE, 2018, https://www.3dmicrogrid.com/papers/Provision%20of%20Ancillary%20Services%20by%20a%20Smart%20Microgrid%20An%20OPF%20Approach.pdf

4. **Lack of Standardization**. There is currently no standard approach to designing or implementing microgrids, leading to inconsistencies and potential compatibility issues. Some giants in the industry, like Schneider Electric, Siemens, ABB, or Tesla, use different types of components and software, which need to be compatible with existing power infrastructure.

5. **Cybersecurity**. Like any interconnected asset, smart microgrids are vulnerable to cyber-attacks, which can disrupt power supply or compromise sensitive data even from a distance.

6. **Integrity of Assets**. Additionally, given the distributed nature of its components, it is more difficult to safeguard DERs from theft and other human misbehaviors.

As with any other innovations, smart microgrids are subject to the interests, resources and constraints of those entities sponsoring the projects. Given the multiplicity of potential stakeholders, the benefits, and challenges of smart microgrids are better reflected by summarizing the main attributes of fully deployed projects.

Case Studies

While assessing the relative impacts of smart microgrid deployment, the Department of Energy (DOE) and the National Renewable Energy Laboratory (NREL) have determined that microgrids can improve grid reliability and resiliency up to 50% – 60%[74], energy efficiency by at least 15%[75], and help reduce almost all carbon emissions if completely paired with renewable power.[76]

Nonetheless, the following case studies can serve as a proxy to understand the different benefits that can be achieved[77]:

Case Study #1: UCSD Microgrid

Projects Elements	Description
Project Name	UC San Diego Microgrid (CA)
Sponsor	University of California, San Diego (UCSD) – San Diego Gas and Electric (SDG&E)
Ownership	Mixed: UCSD and SDG&E
Financing	Mixed: PPA, Renewable Energy Bonds and Grants

[74] DOE, "2014 Smart Microgrid System Report", 2014, https://www.energy.gov/oe/articles/2014-smart-grid-system-report-august-2014
[75] DOE, "DOE OE 2021 Strategy White Papers on Microgrids", Apr 2021, https://www.energy.gov/sites/default/files/2022-09/1-Program%20Vision%2C%20Objectives%2C%20and%20R%26D%20Targets%20in%205%20and%2010%20years.pdf
[76] https://www.energy.gov/sites/default/files/2022-12/Topic2%20Report.pdf
[77] Clamp, Alice, "Microgrids with Energy Storage: benefits, challenges of two microgrid case studies", Kodiak Electric, Sep 2020, https://kodiakelectric.com/wp-content/uploads/2020/10/Surveillance-CEATI-Rpt-Microgrids-and-ES-Pt2-September-2020-002.pdf

Drivers	Campus-wide initiative to reach net-zero, as well as creating a more energy-efficient cost-saving alternative to a standard power grid.
Project Characteristics	- Two 13.5 MW high efficiency gas turbines - 3 MW steam turbine - 2.8 MW fuel cell (running on waste methane) - 2.4 MW solar PV - 2.5 MW battery storage system and 4-million-gallon thermal energy storage
Costs	$27M - $33M
Benefits	- Produces 92% of campus energy needs. - $8M – $10M annually in savings (3.5 years for repayment of system) - UCSD is the largest demand response customer for SDG&E and provides a vital backup to the main grid in emergencies. - Key to R&D efforts at UCSD and California.
Challenges	- Further renewable integration. - Safety and hazard regarding battery storage fires. - Cybersecurity risks.

Case Study #2: Kodiak Island Microgrid

Projects Elements	Description
Project Name	Kodiak Island Microgrid (AK)
Sponsor	Kodiak Electric Association (KEA), ABB
Ownership	Full Ownership: KEA
Financing	Mixed: Public-private partnerships, state and federal grants, and Renewable Energy Bonds.
Drivers	Integration of renewable energy into existing microgrid, as well as expansion due to upgrade in port infrastructure.
Project Characteristics	- Two 4.5 MW wind turbines - Two 1 MW PowerStore grid stabilization generators* - Two 1.5 MW battery storage systems - MGC600 decentralized microgrid control system* - Three 11.25 MW hydro power plants
Costs	$4M (for upgrades*)
Benefits	Net zero electricity, better air quality and environmental protection.

	- Increased efficiency for port and price reduction for customers.
Challenges	- KEA faces additional and ongoing operational challenges because of Kodiak's wet and windy climate, which can cause excess water to collect inside the turbine hubs.

Case Study #3: Inland Empire Utilities Agency

Projects Elements	Description
Project Name	Inland Empire Utilities Agency Microgrid (CA)
Sponsor	Inland Empire Utilities Agency, Advanced Microgrid Solutions, Southern California Edison (SCE)
Ownership	Mixed: Inland Empire Utilities Agency and other services providers
Financing	Installed under an Energy Management Services Agreement with no up-front
Drivers	Transition to renewable energy power generation, improve resiliency, reliability and energy savings.
Project Characteristics	- 3.5 MW solar PV (including 0.99 MW at RP-5) - 1 MW wind turbine - 2.8 MW fuel cell - 3.65 MW Li-ion batteries (including 0.5 MW at RP-5), - 2.5 MW of back-up diesel generators (including undisclosed capacity at RP-5) - Load control and demand response software, AMS Armada platform
Costs	Under the 10-year Energy Management Services Agreement, the IEUA will pay AMS fixed monthly equipment fees ($65/kW per year) and performance-based incentive awards (50/50 split on upside).
Benefits	- Estimated savings could reach a threshold of $230,000 per year. - Replacing nuclear and natural gas peaking capacity in the region.
Challenges	- Changing regulatory status of facilities. - Coordinating different vendors and services providers to single agreements.

	- BESS added technical and regulatory challenges to utility-driven requirements for interconnection.

Case Study #4: NYU Microgrid[78]

Projects Elements	Description
Project Name	NYU Microgrid
Sponsor	New York University (NYU), SourceOne and others.
Ownership	Full Ownership: NYU
Financing	- $126 million of Series 2007A tax-exempt revenue bonds arranged through the Dormitory Authority of the State of New York (DASNY) and NYU tuition and fees helped provide low-cost financing sources. - $1 million in System Benefit Charge (SBC) cost-sharing grant from NYSERDA
Drivers	Transition towards modern natural gas fired heat and power facility, increase reliability and energy savings.
Project Characteristics	- Seven 850 kW diesel generators (backup) - Seven 895 kW Caterpillar D399 dual fuel generators - 2.4 MW steam turbine - Two 5.5 MW gas turbines - Total capacity: 13.4 MW - Three 65 MMBtu/hr high temperature hot water boilers - 114 MMBtu/hr high-pressure steam boiler - 3 electric centrifugal chillers - 3 absorption chillers - 20 MMBtu/hr waste heat from duct fire burners - Two heat recovery steam generators - One absorption chiller
Costs	- Capital costs: $126M - Fuel cost: $5M annually
Benefits	- Energy cost savings: $9Mto $11.6M annually - Fuel savings: $7.5M annually

[78] NYS SmartGrid Consortium, "New York University Microgrid", 2023, http://nyssmartgrid.com/projects/new-york-university-microgrid/

	- Reliability benefits: $1.9M - Avoided emissions: $329,530 annually
Challenges	- Changing regulatory status of facilities. - Coordinating different vendors and services providers to single agreements. - BESS added technical and regulatory challenges to utility-driven requirements for interconnection.

Case Study #5: Borrego Springs Microgrid[79]

Projects Elements	Description
Project Name	Borrego Springs Microgrid (CA)
Sponsor	San Diego Gas & Electric (SDG&E), NREL, California Energy Commission (CEC)
Ownership	Full Utility Ownership: San Diego Gas & Electric
Financing	- $17M from ratepayers - $13M grants from the DOE and the CEC
Drivers	Backup renewable energy microgrid for emergencies and planned outages. Blackstart services to the grid.
Project Characteristics	- 26 MW PV - Two 1.8 MW Diesel generators - Control Room - 4.5 MWh batteries - 250 kW ultracapacitor - Substation
Costs	$30M
Benefits	- Improved resiliency in cases of power outages, especially due to fire. - Provides all Borrego Springs community, over 2,800 people, with power during planned outages.
Challenges	- High cost, especially because of mixed technologies. - Complexity during the interconnection process. - Overcoming regulatory burden.

[79] Nikolewski, Rob, "$4.5 million federal grant looks to upgrade Borrego Springs microgrid to 100% renewable energy", San Diego Tribune, Aug 2020, https://www.sandiegouniontribune.com/business/story/2020-08-03/4-5-million-federal-grant-looks-to-upgrade-borrego-springs-microgrid-to-100-renewable-energy#:~:text=To%20date%2C%20the%20cost%20of,and%20the%20California%20Energy%20Commission.

Case Study #6: Hot Springs Microgrid[80]

Projects Elements	Description
Project Name	Hot Springs (NC)
Sponsor	Duke Energy
Ownership	Full Utility Ownership: Duke Energy
Financing	- 100% Ratepayers
Drivers	Provide energy security and cost-effective power to Hot Springs town, reducing environmental footprint
Project Characteristics	- 2MW (AC) PV - 4.4MWh battery storage
Costs	10M (approx)
Benefits	- Backup power supply in case of power outage.
Challenges	- Located in a remote mountainous area. - First of its kind; supposedly, top of the line smart grid technology.

Case Study #7: Shaw Airforce Base[81]

Projects Elements	Description
Project Name	Shaw Airforce Base Microgrid (SC)
Sponsor	US Airforce, Duke Energy
Ownership	Full Ownership Utility: Duke Energy
Financing	Non; fixed monthly cost.
Drivers	Improve energy security and resiliency of system that provides Shaw Air Force Base, home to 80 F-16 jets and 11,000 family members.
Project Characteristics	15MW generators (fuel)
Costs	NA
Benefits	- Generates nearly 70% of power needs. - Allows most of the wing to maintain power indefinitely if local power infrastructure is damaged. - At least 50% of associated costs offset through efficiency programs
Challenges	- Finding a cost-effective way to increase resiliency in facilities that had existing backup generation.

[80] Duke Energy, "North Carolina regulators approve Duke Energy's innovative microgrid project in Madison County " May 2019, https://news.duke-energy.com/releases/north-carolina-regulators-approve-duke-energys-innovative-microgrid-project-in-madison-county
[81] Duke Energy, "Shaw Airforce Base*", 2023, https://sustainablesolutions.duke-energy.com/resources/shaw-air-force-base/

As mentioned, smart microgrids are closely related to critical infrastructure. That is because critical infrastructure must always maintain full operational capacity, regardless of unforeseen disturbances in power supply. In some cases, both resilience and energy savings are possible, resulting in a positive net present value for the projects.

While the costs of microgrids vary according to their size, in 2018, the California Energy Commission and the National Renewable Energy Laboratory (NREL) calculated that the average per unit cost of a microgrid would be around $4M/MW.[82] This means that most smart microgrids will not make financial sense, as not all locations are ideal for maximizing gains from DERs or have opportunity costs that can offset the sticker price of microgrids.

Nevertheless, we will need to focus our efforts in trying to understand (and quantify) the real economic value of microgrids for communities, and conduct other type of assessments (*e.g.*, cost-benefit analysis using Interruption Cost Estimate (ICE) calculator).[83]

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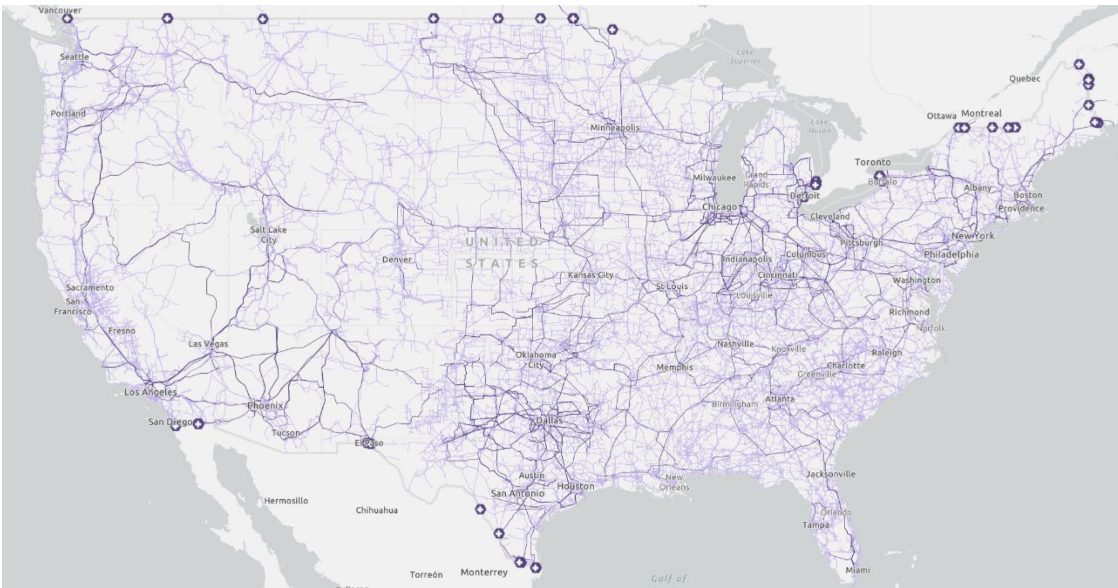
[82] California Energy Commission, "Microgrid Analysis and Case Studies Report", Aug 2018, https://www.energy.ca.gov/sites/default/files/2021-06/CEC-500-2018-022.pdf
[83] NREL, "Microgrids for Resiliency", Nov 2020, https://www.nrel.gov/docs/fy21osti/75909.pdf

Regulatory and Policy Landscape: How Grid and Microgrids interact

The US power grid expanded rapidly between 1882 and 1930 to keep up with industrial activity, as well as with massive population and economic growth. These phenomena led to the creation of one of the most impressive energy systems in the world.



[*Map of US transmission infrastructure*][84]

Nonetheless, differences in economic, social, and political conditions among regions, especially in the Southeast, affected the power grid design, leading to a multi-tiered system that coordinates municipal, state, and national regulatory structures.

Therefore, despite evident technological advantages of smart microgrids, it is important to understand how the current regulatory and policy landscape incentivizes or hinders the deployment of smart microgrids in the Southeast.

Evolution of the US Power System

Understanding how the US power system works can be an overwhelming endeavor, especially given heavy policy and regulatory burden, as well as differences across activities in the industry's value chain. Nevertheless, there are some basic notions that can help untangle the complexity of the system, especially if we intend to complement macro-grids with smart microgrids.[85]

[84] EIA, "Energy Infrastructure Atlas", 2023, https://atlas.eia.gov/apps/895faaf79d744f2ab3b72f8bd5778e68/explore
[85] Macro-grids = utility grids (centralized power systems and status quo).

The US power system is not centrally regulated, nor has ever been.[86] Chronologically speaking, the industry went from deregulation to regulation.[87] It was first regulated by municipalities, then states, and finally the federal government. It is not a perfect system, but rather one that was created in response to the needs of different times.

Electricity was originally serviced by private companies.[88] Just like what happened in other intense capital industries in the early 20th century, private companies went through a consolidation phase and formed large monopolies.[89] There were two obvious problems with this: 1) few players had a lot of power in a crucial commodity, and 2) many parts of the country that were not as profitable to service as the main population centers were not electrified.

In an attempt to fix this, some municipal governments started their own not-for-profit municipal utilities (also known as "Munis") to service people within their political boundaries. On the other hand, State Public Utilities were formed to regulate private utilities (also known as "Investor-Owned Utilities" or "IOUs") in each state.

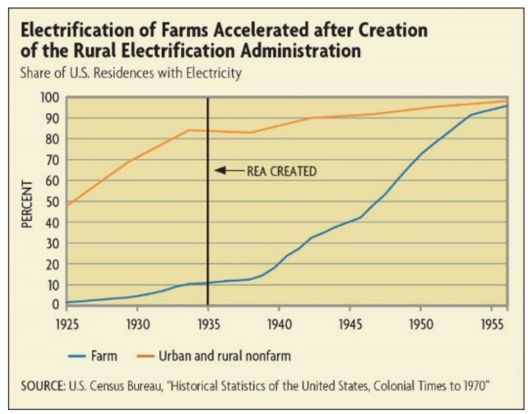
In the 1930's, the federal government also reacted and created the Tennessee Valley Authority (TVA, 1933), the first of several federally owned utilities focused on providing affordable electricity to underserved populations.

At the same time, Congress[90]:

i. Amended the Federal Power Act (PUA, 1935) to create the Federal Power Commission (FPC)[91] to regulate electricity interstate commerce and transmission.

ii. Enacted the Public Utility Holding Company Act (PUHCA, 1935) to limit private utility operations to a single geographic area.

iii. Enacted the Rural Electrification Administration (REA, 1936), which promoted the creation of rural electric cooperatives (also known as "Co-Ops) under a not-for-profit member-owned utility model.



[86] Unlike places like the United Kingdom (National Grid), France (Electricity Transmission Network or "RTE"), Mexico (Federal Electricity Commission or "CFE") and China (State Grid Corporation of China), the United States did not undergo a government backed up full-scale consolidation process in the industry.
[87] People who refer to regions where generation, transmission, distribution, and commercialization (retail and/or wholesale) of energy is unbundled as "deregulated" markets fall under a conceptual mistake. These should be called "competitive markets" vs "vertically integrated" markets or semi vertically integrated markets. But they are both regulated.
[88] This is no different to what happened with telephone, cable and other service and infrastructure industries.
[89] A similar effect happened in the oil, steel, tobacco, sugar, telecom, cement, among others.
[90] This marked the end of the era of American oligarchs, conglomerates, and massive holding companies, as they were blamed for causing the Great Depression. Companies General Electric's Bond and Share Company (EBASCO) were eventually forced to split by federal mandate.
[91] Reorganized in the 70's as the Federal Energy Regulatory Commission (FERC) with broader powers.

The outcome of these reforms was very positive from the consumer point of view, as electricity prices were cut, on average, more than 50%, poverty was substantially reduced, and electricity access reached almost 100% in less than 20 years.[92]

Nevertheless, the number of players, regulations and ramifications grew exponentially, making it extremely difficult to coordinate, as well as implement swift and substantial changes in the future.[93]

Up to this point, most of the power industry in the United States operated under the vertically integrated model. Under this "traditional" model, an electric utility operates as a regional monopoly that owns all assets and performs all activities in the value chain, including generation, transmission, distribution, and retail/wholesale.

Grid Policy and Regulatory Landscape: US and the Southeast

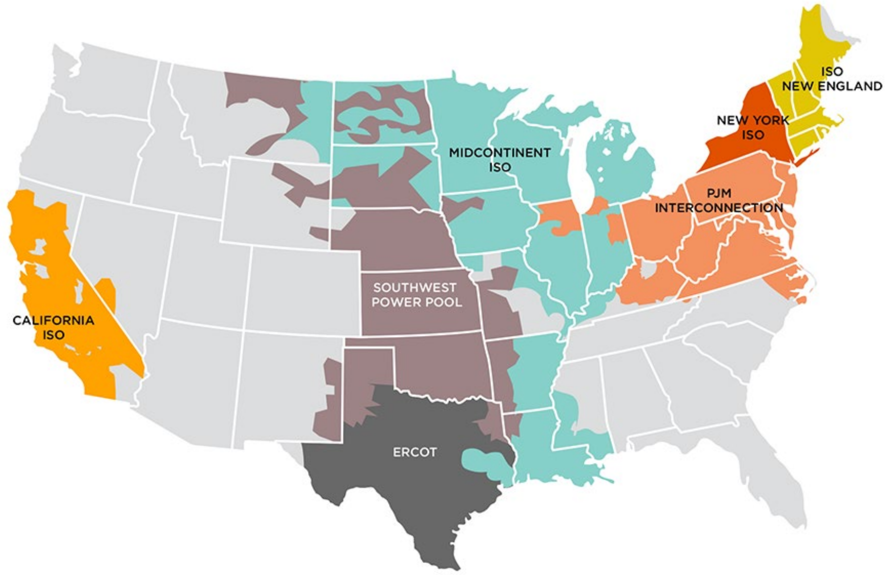
With time, many other aspects of the regulatory landscape changed, but the most significant ones were introduced by the federal government. To promote innovation and competition[94], the federal government effectively expanded its influence on the industry through the Public Utility Regulatory Policies Act (PURPA, 1978) and the Energy Policy Act (EPAct, 1992 and 2005).

These reforms created the system that we effectively know today. New independent entities were created, and further competition was allowed in power generation and retail activities. Despite remaining as sole owners of transmission and distribution infrastructure, private utilities now must coexist with independent transmission operators, power producers and retailers in select markets.[95]

As a result, today the US energy system[96] is mainly structured as follows:

- **Federal Level**. The Federal Energy Regulatory Commission (FERC) is responsible for regulating interstate electricity transmission, regional transmission planning and wholesale markets. The FERC works with Independent System Operators (ISOs) and Regional Transmission Organizations (RTOs) to coordinate competitive wholesale markets and operate the grid in the following seven regions:[97]

[92] To learn more about the early history of the industry, please visit: https://americanhistory.si.edu/powering/past/h1main.htm
[93] Never forget that today is the legacy of yesterday. Regulatory changes happen in phases, but it takes time. The electricity industry, as a highly regulated and complex industry, requires tremendous coordination to change.
[94] Substantial changes in the industry happened after the OPEC oil embargo (1973), political and economic movements towards deregulation and decentralization (80's and 90's), as well as innovation, competition, and environmental protection (90's and 00's).
[95] DOE, "Electric System Overview", https://www.energy.gov/sites/prod/files/2017/02/f34/Appendix--Electricity%20System%20Overview.pdf
[96] For more information on the industry structure, please visit: https://www.raponline.org/wp-content/uploads/2016/05/rap-lazar-electricityregulationintheus-guide-2011-03.pdf
[97] Regions of the US have integrated into competitive wholesale markets where different parts of the power value chain are unbundled to promote competition. Depending on the specific regulations of each market, generation, transmission, distribution, and retail sales can be performed by companies different than an electric utility.



Furthermore, the FERC works with the North American Electric Reliability Corporation (NERC) to establish standards for the reliability and security of the power grid. [98]

The Department of Energy (DOE) also plays a critical role in developing and implementing energy policies and programs. The DOE conducts research and development on energy technologies and works with state and local governments to promote the innovation and development of renewable energy sources.[99]

Additionally, it is possible to find five federally owned vertically integrated utilities (e.g., TVA), which are regulated by the federal government.

- **State Level**. Public Utility Commissions (PUCs)[100] are responsible for regulating the retail sale of electricity within their state, including planning and siting and construction of transmission, generation, and distribution infrastructure, setting prices, determining clean energy targets, budgets, incentives, and funding.[101] They oversee investor-owned utilities and may also regulate some aspects of other types of utilities, such as publicly owned utilities (mostly municipal) and rural electric cooperatives. The degree of regulatory burden will depend on each city and state.

- **Municipal Level**. Municipal bodies and codes oversee most of the operations of municipal utilities. However, "Munis" can also be subject to state regulations. The degree of regulatory burden will depend on each city and state.

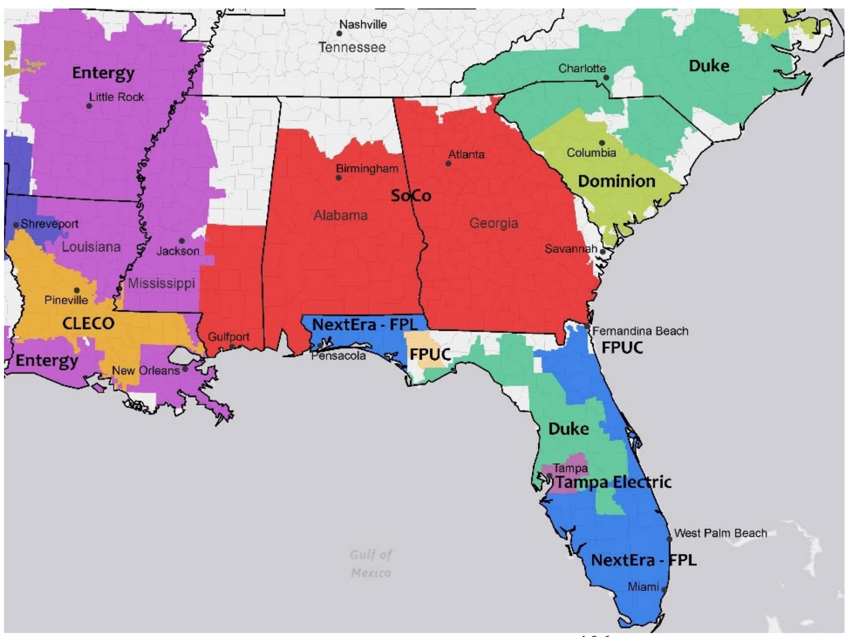
[98] For example, NERC's Reliability Standard CIP-014-2 requires transmission companies to identify critical facilities and implement security measures to protect them from physical and cyber threats.
[99] For example, DOE's Grid Modernization Initiative aims to modernize the power grid by developing new technologies and policies that improve its resilience, reliability, and security.
[100] Sundback, Mark, et al., "Electricity regulation in the United States: overview", Thomson Reuters, Jul 2020, https://content.next.westlaw.com/practical-law/document/Ieb49d7b91cb511e38578f7ccc38dcbee/Electricity-regulation-in-the-United-States-overview?viewType=FullText&transitionType=Default&contextData=(sc.Default)&firstPage=true
[101] EPA, "An Overview of PUC s for State Environment and Energy Officials" May 2010, https://www.epa.gov/sites/default/files/2016-03/documents/background_paper.pdf

- **Rural Level**. As self-governing democratic entities[102], "Co-ops" are only partially regulated by some state and federal regulations, including the Rural Utilities Service.[103] The degree of regulation will depend on each state.[104]

Nevertheless, the Southeast was a late bloomer in the electrification process given a lower population density, scattered settlements, and a predominantly rural society during the early 20th century. While a lot has changed, many aspects of the Southeast power regulatory landscape are a legacy of its history.

Containing some of the most traditionally regulated markets, the Southeast is dominated by vertically integrated utilities such as NextEra, Duke Energy, Entergy, Southern Company (Georgia, Alabama, and Mississippi Power) and Dominion Energy.

This does not mean that utilities are not subject to federal or state oversight, but it does mean that they are not subject to some of the most innovative and competitive rules that we can see in other power markets (*e.g.*, FERC Order 2222 – enables DER participation in wholesale markets).[105] In the Southeast, regulations and policies will vary from state to state and from utility to utility.



[Utilities in the Southeast][106]

[102] Slepyan, Anya, "Rural Electric Cooperatives on a Bumpy Road to Renewable Energy", Daily Yonder, Oct 2020, https://dailyyonder.com/rural-electric-cooperatives-on-a-bumpy-road-to-renewable-energy/2020/10/30/
[103] Heinemann, Richard et al., "Municipal Utility Governance:
Options and Responsibilities", LWM, Oct 2019, https://www.lwm-info.org/DocumentCenter/View/3824/Public-Utilities-356-Municipal-Utilities-Governance-Options-and-Responsibilities
[104] Knisley, Bri, et al., "Power to the People: Organizing Rural Electric Cooperatives", The Forge, Oct 2020, https://forgeorganizing.org/article/power-people-organizing-rural-electric-cooperatives
[105] In simple terms, the FERC created general rules for DERs (FERC Orders 745, 755, 784 and 2000) to sell power and other services to the grid. This effectively grants clarity to investors as it builds more revenue streams for projects.
[106] Southeastern Electric Exchange, "About SEE", 2023, https://www.theexchange.org/aboutus.html

The power system policy and regulatory[107] landscapes show us two very valuable lessons towards smart microgrid adoption in the Southeast:

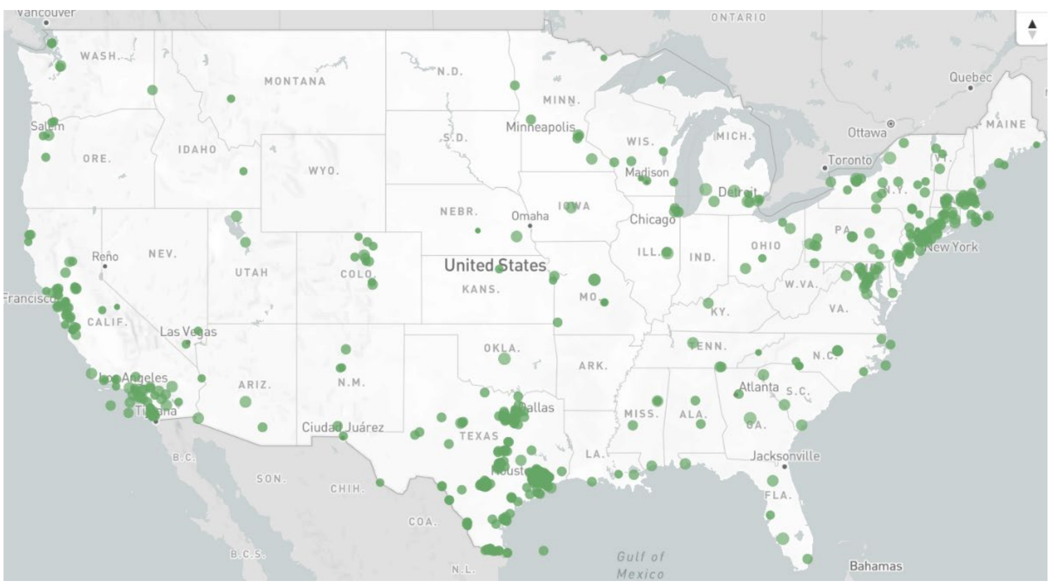
- Lesson #1: As sole owners and transmission and distribution assets (and electricity suppliers to over 75% of customers in the country), private utilities are essential for any grid technology deployment.[108] [109]

- Lesson #2: In the US, it is highly unlikely that a policy or regulatory change in a single level will shake the whole system (or even a whole region).[110]

Microgrid Policy and Regulatory Landscape: US and the Southeast

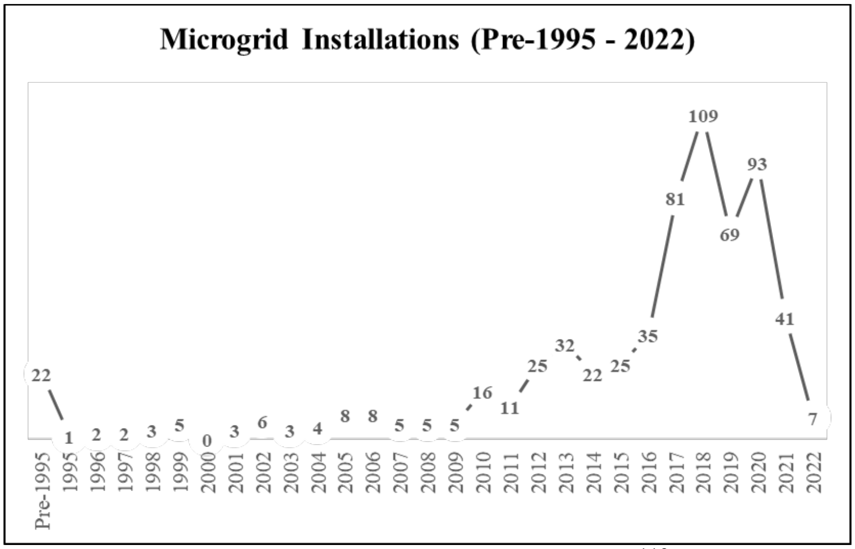
Formally speaking, the first "microgrid" in the US was set up by Thomas Edison in Pearl Street Station in 1882. However, it was not until 1955 when the first modern microgrid was developed at the Whitling Refinery in Indiana.[111]

According to the U.S. Department of Energy, as of December 31, 2022, there were a total of 687 installed microgrids in the U.S., which combined represent a total installed capacity of 4,357 MW.



[Map of all microgrids in continental US][112]

[107] Whenever faced with the daunting question of "how the US power system works?", the correct answer always is: "it is difficult to explain".
[108] The remaining 28% are served by publicly owned utilities (16%) and rural electric cooperatives (12%).
[109] This is an important observation for those people demonizing electric utilities.
[110] This is another important observation for those people proposing one-size-fits-all and simplistic solutions to DER and smart microgrid adoption.
[111] Asmus, Peter, et al., "Microgrids: Islanded Power Grids and Distributed Generation for Community, Commercial, and Institutional Applications", Pike Research, 2009, https://www.missioncriticalmagazine.com/ext/resources/MC/Home/Files/PDFs/WP-MICROPike_Research-ExecutiveSummary.pdf
[112] DOE, "U.S. Department of Energy Combined Heat and Power and Microgrid Installation Databases", 2023, https://doe.icfwebservices.com/microgrid

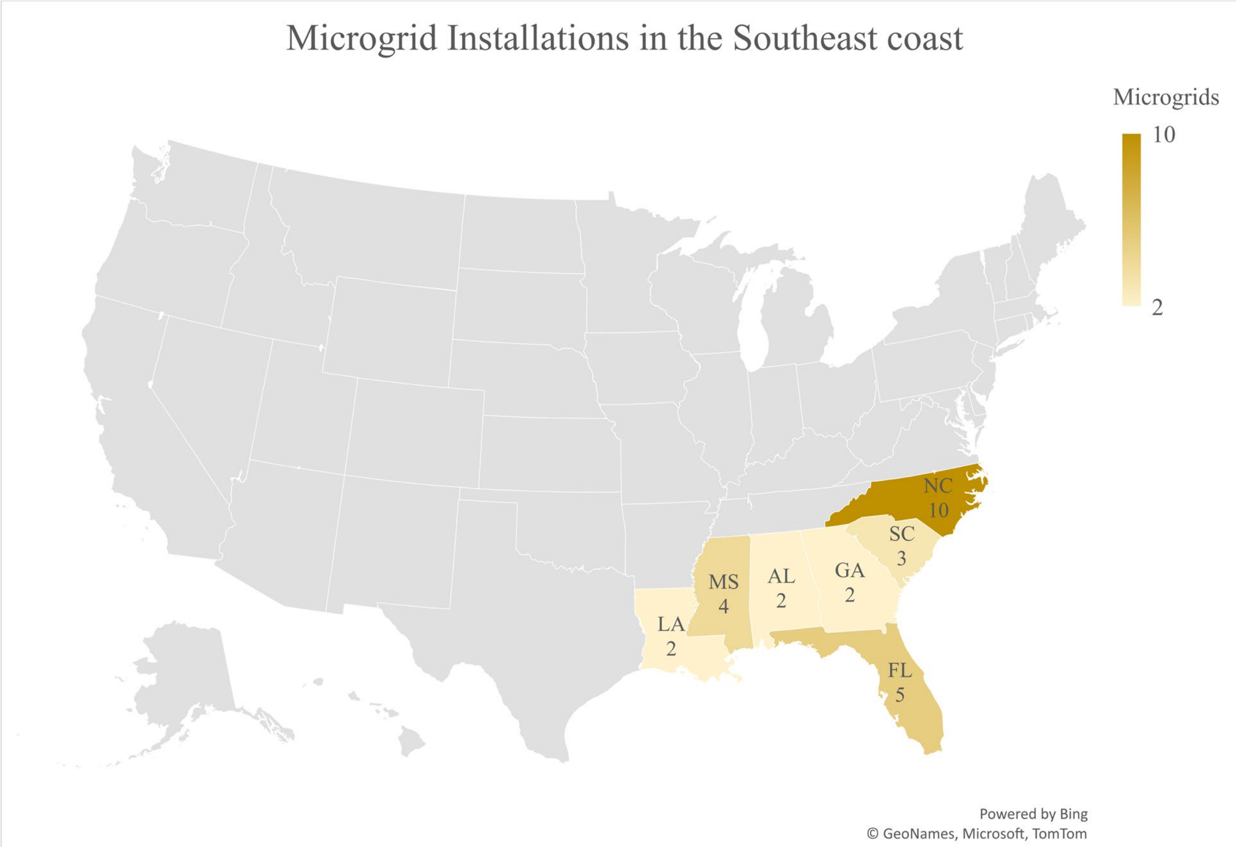


[Microgrid Installations in the US][113]

Despite the importance of microgrids for energy resiliency, not a single state in the Southeast figures among the Top 10 states with most microgrids installed. Actually, as of the end of 2022, there were only 28 installed projects in the Southeast, representing only 4% by number of microgrids and 9.7% (422.78 MW) by installed capacity in the United States.

Ranking	State	Sites	Capacity (MW)
1	TX	257	645.6
2	CA	91	442.5
3	NY	68	662.5
4	MA	27	274.0
5	CT	20	132.2
6	AK	19	219.2
7	NJ	16	76.8
8	HI	15	100.3
9	MD	15	157.4
10	PA	13	92.5
11	CO	10	45.8
12	NC	10	27.3
13	MI	9	358.5
14	MN	6	44.1
15	OR	6	12.6
16	WI	6	4.7
17	FL	5	132.2
18	IL	5	109.9
19	MO	5	133.3
20	WA	5	23.1

[113] *Idem*



Compared to the top three states in the list, that is, Texas (257 sites, 645.6 MW) California (91 sites, 442.5MW) and New York (68 sites, 662.5MW), the Southeast barely has any projects.

What is happening? While there is not one single reason, there are several correlations that we can deduct from the data.

The first correlation is drawn from the number of outages in the last 20 years, population size and energy consumption across states.[114] In most cases, we can see a high correlation between these factors and the amount of microgrids deployed in their territories.

If we factor in these assumptions, as well as electrical downtime for more recent periods (2015 – 2019 and (2022 – 2023)[115], Louisiana, Florida, Georgia, North and South Carolina – in that order – should be contenders to the top 15 in the ranking.[116]

Also, there is a higher observed correlation between microgrid deployment and competitive power markets and/or markets that have integrated microgrid provisions into their regulations.

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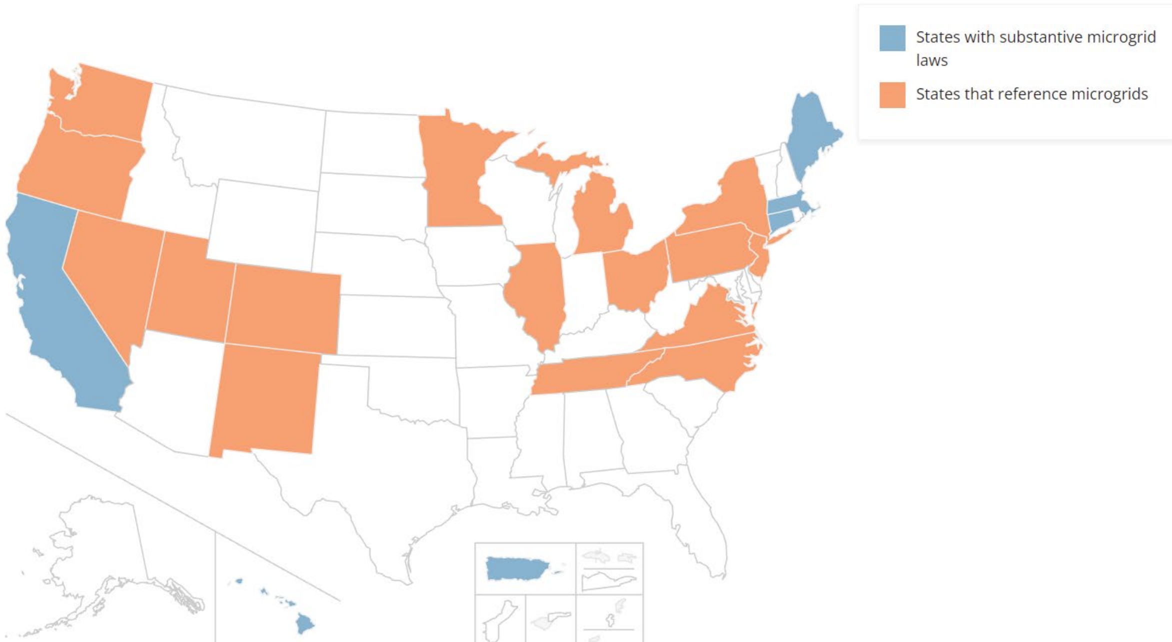
[114] Payless Power, "The Most At-Risk States for Power Outages", 2023, https://paylesspower.com/blog/the-most-at-risk-states-for-power-outages/

[115] Kaminski, Joe, "The most & least power outages by state", MRO, Mar 2021, https://www.mroelectric.com/blog/most-least-power-outages/

[116] World Population Review, "Power Outages by State 2023", 2023, https://worldpopulationreview.com/state-rankings/power-outages-by-state

The following map shows states[117] that have included references to microgrids (*e.g.*, revenue sources, ownership, interconnection, etc.) in their state laws:



[*State Microgrid Laws*][118]

For instance, California, Connecticut, Hawaii, Maine and Puerto Rico have defined microgrids in statute as part of larger policies. By defining a microgrid in statute, states can determine the types of systems that qualify under a variety of state programs and enumerate the goal of a specific policy or program.[119]

In 2018, California enacted legislation requiring the California Public Utilities Commission to establish microgrid services tariffs, along with the:

- Microgrid service standards regarding compliance with state and local permitting.

- Methods to reduce barriers for microgrid deployment without shifting costs between ratepayers.

- Guidelines for interconnection, including what impact studies will be required of microgrid developers.

[117] Texas is not included because, well, it's Texas. After their winter storm of 2021, they proposed S.B. No. 1606 to commence an assessment on potential resilience and microgrid additions to their grid, but it was never approved. Also, they are the leading state in microgrids and, perhaps, the most competitive US wholesale market, so they might not even need it at this point.
[118] Shea, Daniel, "Microgrids: State Policies To Bolster Energy Resilience", National Conference of State Legislatures, Jun 2022, https://www.ncsl.org/energy/microgrids-state-policies-to-bolster-energy-resilience
[119] Connecticut has funded a Microgrid Grant and Loan Program in response to Superstorm Sandy, funding more $45 million in projects. Oregon HB 2021 established a $50 million grant program to support community energy resilience projects. California enacted SB 1339 to establish microgrid services tariffs and standards for interconnection.

- Separate large utility rates and tariffs necessary to support microgrids.

Some states have established programs to help microgrid developers overcome regulatory and early financing obstacles, as well as funded pilot projects with critical infrastructure.[120]

Additional programs and policies at the federal level include:

- DOE's Office of Electricity (OE) Microgrid Program Strategy, where it conducts R&D regarding smart microgrid adoption. The OE provides technical assistance and guidance to utilities and other stakeholders on smart grid issues, including microgrid development and deployment.[121]

- NREL's R&D and technical support on microgrid technologies, including renewable energy integration, energy storage, and control systems.

- The DOE also provides funding and support for smart microgrid projects through various programs and initiatives, including the Grid Modernization Initiative, the Solar Energy Technologies Office, and the Advanced Research Projects Agency-Energy (ARPA-E).

- Inflation Reduction Act (IRA) establishes tax credits[122] ranging between 10% – 70% through 2032 for DER technology used in microgrids. Additionally, smart microgrid projects could potentially access funding through the $27B Greenhouse Gas Reduction, $3 billion for Environmental Justice Block Grants, $37M to reduce air pollution in schools, and $235M for tribal climate resilience.[123]

Several factors, including the IRA, the declining costs of DERs, a more important structural focus on energy resilience and transition to renewable energy, among others, will push microgrid development forward in the Southeast, regardless of any changes in the regulatory environment.

Nevertheless, evidence shows that smart microgrids tend to thrive in highly competitive power markets, such as California, New York, and Texas, especially in those where PUCs have specific regulations addressing microgrids. This is because more stakeholders can be involved in the microgrid development process, project risks are reduced (*e.g.*, revenue streams, net metering, interconnection requirements, quality, and operation standards), there is better access to financing and, overall, utilities are better prepared and more engaged in smart microgrid deployment.

[120] For more information on state backed-up programs to promote microgrid deployment, please visit: https://www.naseo.org/Data/Sites/1/v2_naseo_microgrid.pdf

[121] DOE, "Request for comment from the public on its Microgrid Program Strategy", Federal Register, Nov 2022, https://www.federalregister.gov/documents/2022/10/25/2022-23183/microgrid-program-strategy

[122] https://www.ameresco.com/incentives-and-implementation-how-policy-informs-the-clean-energy-transition/

[123] Overall, the most important aspect of the IRA is that it will directly lower the cost of developing smart microgrids (for sophisticated developers). Unfortunately, tax credits can only be used against tax liabilities (it acts as a discount to your taxes, but you can sell it), and the legislation does not allow for a rebate (get direct refunding from the IRS). Nevertheless, there are many grants inside the IRA that can also be used for this type of projects.

Other Considerations and Policy Recommendations

Smart microgrids are a fascinating piece of technology, but their integration with the existing power system is highly complex from a technical and a regulatory point of view. If not well implemented, DER systems can end up negatively impacting efficiency, stability, reliability, and resilience of the distribution grid.[124] Therefore, any solution to be implemented will need to be created in coordination with electric utilities, as they are the protectors of the power system in the Southeast.

Nevertheless, there are other benefits that are worth considering and that might transcend obstacles that need to be overcome to effectively deploy smart microgrid solutions[125]:

Energy Independence and Geopolitical Strategy. Smart microgrids can help increase energy independence by improving energy efficiency and promoting the use of local renewable energy resources. By reducing energy waste and using *in situ* generation, smart microgrids can help the Southeast become less reliant on imported fuels and be less exposed to price variabilities.

Overall, both the Southeast and the country would benefit from smart microgrids in this aspect, as it will enhance the US bargaining position for future energy imports, excluding those from countries hostile to American interests and human rights violators.[126]

Equity and Environmental Justice. Smart microgrids have the potential to address equity and environmental justice matters in the Southeast by:

- Increasing access to reliable and affordable electricity for rural and low-income communities, including community-owned microgrids.

- Lowering DER costs would, in the long term, reduce the financial burden on vulnerable households.

- Improving resilience during natural disasters and avoiding power outages, which disproportionately affect underserved and vulnerable communities.

- Use of DERs can improve air and water quality in communities disproportionately affected by pollution from hydrocarbon fueled power plants.

Employment, Economic Development and Opportunity Costs. The deployment of microgrids will require thousands of local skilled workers that will install and maintain these systems.

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[124] If not appropriately set up and managed, DER systems could cause voltage oscillations, create reverse power flows (on circuits not designed for two-way flows), and cause other impacts on the system that could increase the frequency and durations of outages.

[125] Yes, utilities and other entities make a wonderful job at keeping our lights on every day. The system is not broken but could be much better suited for the challenges that the Southeast will face in the upcoming years.

[126] Not pointing at anybody, but you can see the complete list of the U.S. crude oil imports in the following link: https://www.eia.gov/dnav/pet/pet_move_impcus_a2_nus_ep00_im0_mbbl_m.htm

In any case, the Southeast is already experiencing the effects of aging energy infrastructure, which will need to be repaired, repurposed, or replaced at some point in the next few years. If we sum these costs to those of grid hardening and after-storm restorations, it could potentially make more sense to start investing in more resilient infrastructure that can both withstand natural disasters and be better to meet the energy and data needs of the 21st century.

1. **Establish clear and well-designed state level regulations that address rules regarding smart microgrids.**

The main obstacle for further smart microgrid adoption in the Southeast is the legacy regulatory environment that persists today. Given the high degree of complexity of the US electricity system, the most important advances in this matter can be achieved through responsible, comprehensive, and clear regulations at the state level. These state regulations will need to guide all stakeholders in the process of defining the best possible locations for deployment of smart microgrids, as well as provisions regarding net metering, revenue streams, ownership rights, financing schemes, grants and incentives, interconnection processes, quality of systems, among others.

2. **Require Electric Utilities to have clear standards and guidance for development and interconnection of smart microgrids to the grid.**

Utilities should be involved in discussions as early as possible and should be required to leverage their expertise on the system. Their technicians should prepare and share technical standards, guidance, and best practices to allow other stakeholders to fully understand the nuances of integrating smart microgrids to the distribution grid.

For instance, utilities in the Southeast could tap into accumulated experience from utilities in California, NY, and Texas, given their long history working with microgrid technology.

3. **Create federal, state, and local guidelines to determine economic benefits of resilient infrastructure, as well as pathways to access federal grants and funding for these projects.**

State governments will need to cooperate with other levels of government to establish clear rules for stakeholders to determine economic benefits of smart microgrids as tools to improve reliability and resiliency in the power system. These rules should be based on community, environmental and structural impacts, as well as considering resource potential in different regions.

Guidance should be directly provided to those projects that have determined feasibility and high impact potential to streamline financial and technical resources to make them happen. Perhaps, utilities will have a fundamental role in taking advantage of different financial incentives and helping guide other stakeholders in the development process.

4. **Assess the value of creating a Southeast ISO, which can replicate innovative and competitive practices in CA, TX, and NY.**

Evidence shows that smart microgrids tend to thrive in more competitive power markets. The Southeast is still predominantly regulated under a traditional vertically integrated utility model. Therefore, stakeholders in the Southeast energy industry will need to evaluate the feasibility of creating a Southeastern ISO. California, Texas, and New York provide good examples how different regulations can be combined to achieve a higher degree of competition, as well as improve reliability and resiliency of power supply.

* * *