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Solving The World's Wasted Energy Problem

An Examination of Transmission, Batteries, and Computing

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Wind and solar generation are the dominant new forms of electricity generation in the United States. They will be for the foreseeable future. This trend is being driven by decreasing costs and increasing demand from utilities and companies seeking affordable, clean electricity.

However, renewable energy brings with it a unique circumstance of intermittency – the fact that the wind does not always blow and the sun does not always shine. As a result, while renewable energy development grows dramatically, power operators face one of the biggest challenges to the economics of renewable energy: wasted energy.

Wasted energy, often referred to as curtailment, is “a reduction in the output of a generator from what it could otherwise produce given available resources, typically on an involuntary basis.” Put simply, it is the problem of not being able to sell all of the clean energy that has been produced back to the electricity grid.

Using data from Regional Transmission Organizations (RTOs) and Independent System Operators (ISOs), we estimate that at the end of 2021 there were 14.9 TWh of wind and solar generation curtailed, or the equivalent of $610 million in lost revenue. This is an increase from 7.9 TWh in 2017 or $318 million in lost revenue.

The renewable electricity wasted in 2021 was enough to power 1.3 million households for a year.

And this represents only 5-8% of total renewable electricity being curtailed. Forecasts from ISOs estimate that 60% of renewable electricity could be curtailed if the electric grid were to move to 100% clean generation.

Reviewing multiple reports, we have identified three ways solar and wind developers, owners, and operators can mitigate curtailment at their sites:

Transmission

Battery Storage

Flexible Computing

Comparing these solutions, we conclude each will have a role to play in enabling renewable generation and mitigating curtailment. Many developers are just coming to realize that flexible computing is one of the three primary tools they can use to directly mitigate the risk of curtailment with significant advantages over battery storage and transmission.

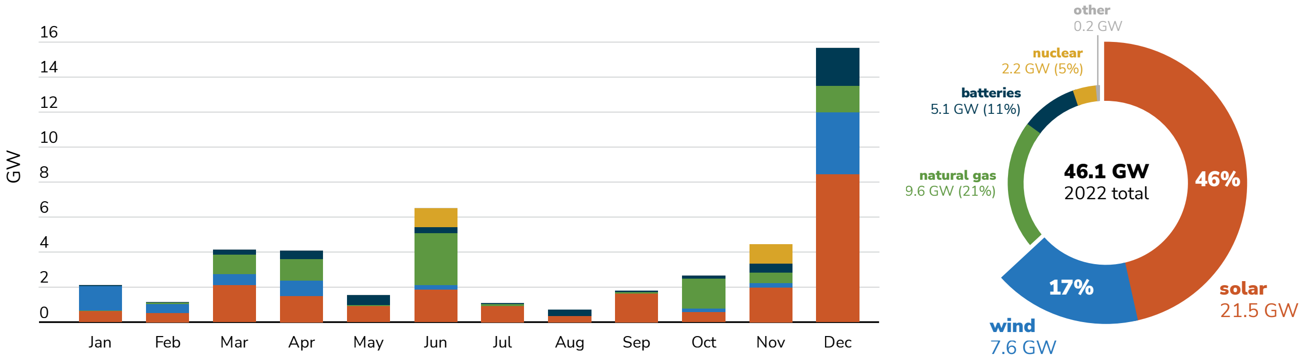
The growth of solar and wind

Wind and solar generation are the dominant new forms of electricity generation in the United States and will be for the foreseeable future.

This trend is being driven by decreasing costs and increasing demand from utilities and companies seeking affordable, clean electricity.

In December 2021, the U.S. Energy Information Administration estimated that solar and wind generation would account for 63% of all new generation capacity *(fig. 1.1)* installed in the United States in 2022. This is just the most recent data point in a long trend: wind and solar are now cheaper to build than new gas generation plants. In some places, it is cheaper to build new wind and solar generation than to operate existing coal and natural gas power plants. As manufacturers learn how to more cost-effectively make solar panels and wind turbines and developers become more efficient at building these power plants, the costs of wind and solar generation continue to decline.

fig 1.1: Planned U.S. utility-scale electric generating capacity additions (2022)
gigawatts (GW)

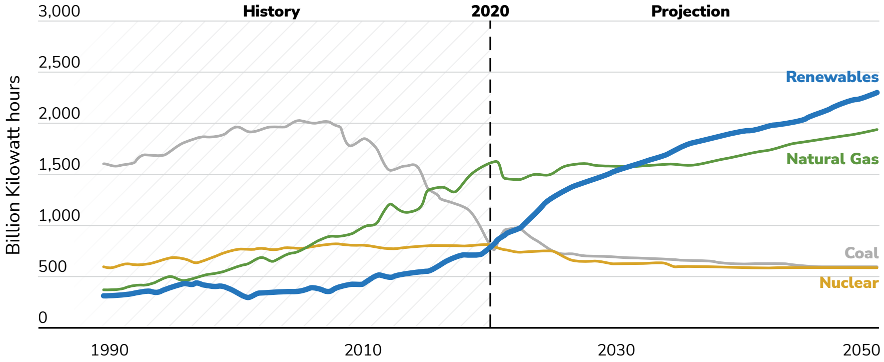


Source: U.S. Energy Information Administration, Preliminary Monthly Electric Generator Inventory, October 2021

In addition, over the last 4 years, utilities, fortune 500 companies and U.S. states have all committed to 100% clean energy in response to environmental, social and governance concerns about the impacts of climate change. In states like California, Washington and throughout the Northeast, generating power with fossil fuels has increased associated costs, further buoying demand for renewable energy projects.

Increase in demand and decreasing costs is causing utility-scale solar and wind to become the dominant new generation being added to the U.S. grid. And the forecast from the U.S. Department of Energy points to continued growth through 2050.

fig 1.2: Reference case



Curtailment: not being able to sell all that wind and solar electricity

Curtailment is defined as "a reduction in the output of a generator from what it could otherwise produce given available resources, typically on an involuntary basis."

Curtailment is caused when renewable generation cannot safely send electricity to the grid.

While renewable energy is growing dramatically, renewable developers, owners, and operators are experiencing challenges.

Solar and wind are variable renewable energy sources: they only produce energy when the wind is blowing or the sun is shining. This means that during the windiest and sunniest times of the day, all these renewable power plants are producing at their peak.

This can result in more electricity being generated than can be safely sent onto the electric grid, which in turn results in solar and wind plants not being able to sell all their electricity to the grid. In the energy industry, this result is called curtailment. The National Renewable Energy Laboratory defines curtailment as “a reduction in the output of a generator from what it could otherwise produce given available resources, typically on an involuntary basis.”

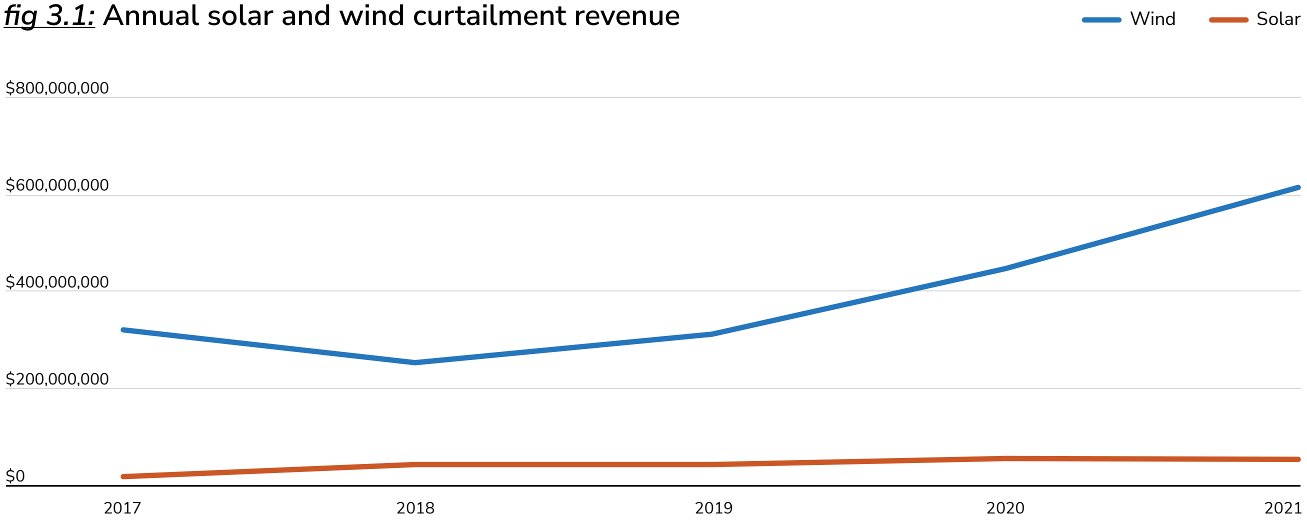
The operator for California’s electric grid further breaks down renewable curtailment into two categories: systemwide curtailment and local curtailment. Systemwide curtailment occurs when there is more supply than demand for electricity. Local curtailment occurs when there is congestion on a section of wires in the electric grid preventing renewable electricity from safely being delivered to places where there is the most demand.

How big is this problem today?

At the end of 2021, there were 14.9 TWh of renewable generation that was curtailed or the equivalent of $610 million in lost revenues.

With renewables dominating planned new generation and increasing demand for cheap renewables, this trend is likely to continue without solutions geared to address this.

fig 3.1: Annual solar and wind curtailment revenue

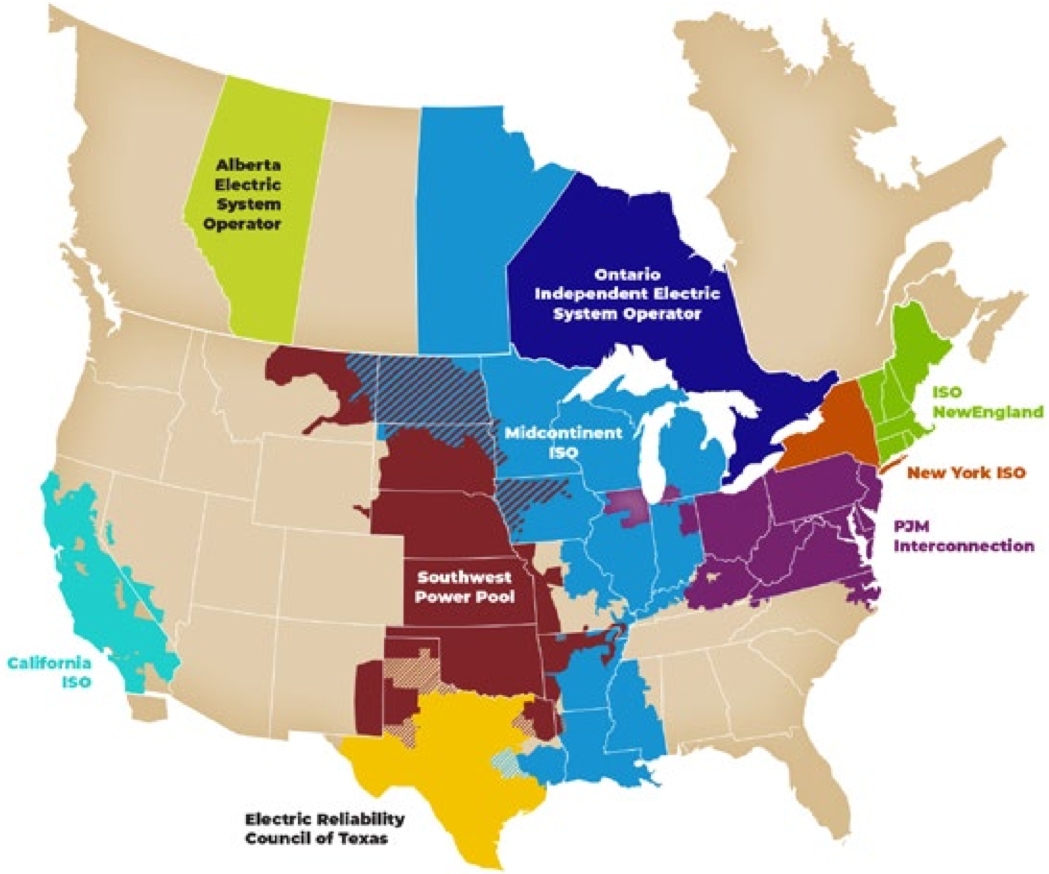


At the end of 2021, there were 14.9 TWh of wind and solar generation that was curtailed, or the equivalent of $610 million in lost revenue. This is an increase from 7.9 TWh in 2017 or $318 million in lost revenue. Currently, the vast majority of curtailment has come from wind generation.

To put this in context, the average US household consumes 11 MWh per year. We threw enough renewable energy away in 2021 to power 1.3 million households for a year.

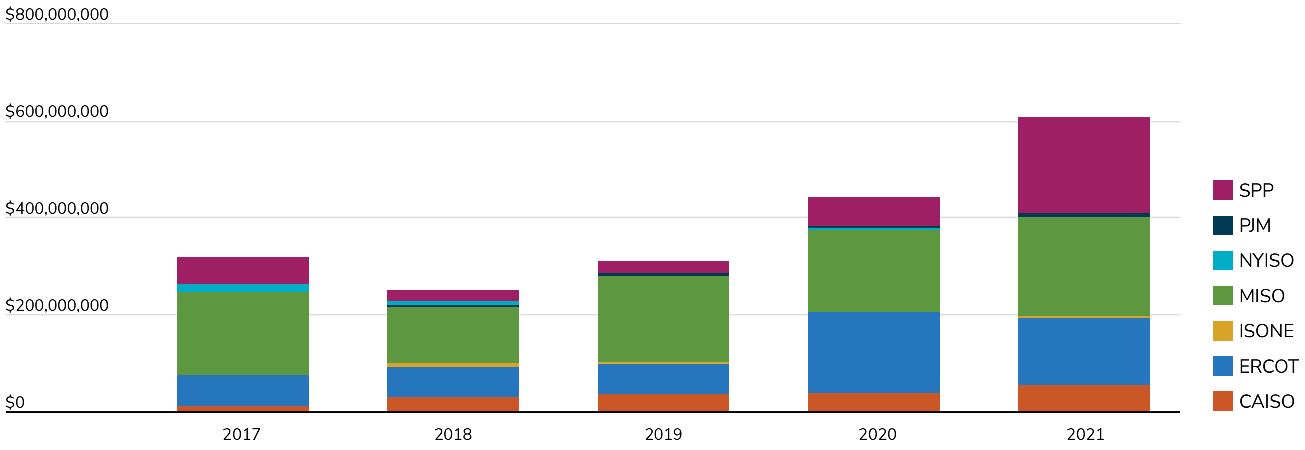
When we look over the last 5 years, curtailment has continued to increase. The Compound Annual Growth Rate during this time for the value of curtailed energy has been 13%. We can look at this by geography to understand more specifically where this is happening.

In the United States, there are some portions of the country where electric utilities do not own power plants and electricity lines. These are called deregulated territories. They are managed by Regional Transmission Organizations (RTOs) and Independent System Operators (ISOs). A map from the Federal Energy Regulatory Commission (FERC) illustrates where these are located across the US.



These ISOs and RTOs provide publicly accessible data on renewable curtailment. Only two, the Electricity Reliability Council of Texas (ERCOT) and the California ISO provide data on solar curtailment. All currently provide wind curtailment data.

fig 3.3: Renewable curtailment revenue by ISO & RTO



When we look at the curtailment revenue by ISO and RTO, we see that in addition to lost revenues from curtailment doubling from 2017 to 2021, curtailment across the country has also become more geographically dispersed. In 2017, curtailment in the Midcontinent ISO accounted for 51% of curtailment driven by wind projects across the Great Plains. By 2021, curtailment in the Midcontinent ISO had decreased to 27% of the annual total while curtailment in Texas and across the Southwest has taken off.

With volatility in energy markets and changes in contracting for renewable energy, we want to be transparent about how we arrived at these estimates. At a high level, we are taking the average levelized power purchase price ($/MWh) by region for each year and multiplying it by the total number of MWh curtailed. A more detailed methodology is highlighted in the appendix. We chose this average to reflect the reality of renewable contracting: an hour of lost MWh sales doesn't impact most of the revenues of a renewable plant whether the price of the real-time market is high or low.

Currently, curtailment only accounts for up to 5% of total wind energy and 8% of solar energy ISOs and RTOs. A forecast done by the New York ISO estimates that by 2029 in New York, curtailment could reach 12% of renewable generation. Looking farther out, a forecast from the Midcontinent ISO estimates that reaching 100% clean generation in the ISO's territory would result in 57%-65% curtailment of renewable generation. This is a significant risk for existing asset owners that are planning for renewable projects to be paid off over the course of 20 years or more. With renewables dominating planned new generation and increasing demand for cheap renewables, this trend is likely to continue without solutions geared to address it.

Computing is a better

Curtailment Solutions

Research on curtailment highlights five strategies to mitigate curtailment.

Of these, only three can be used directly by developers, owners, and operators of renewable projects.

There are, however, solutions to decrease curtailment. Across research from the California ISO, the National Renewable Energy Laboratory, Midcontinent ISO and New York ISO four categories of solutions have been put forward:

Improved grid operations for renewables

Increased demand flexibility

Expanded transmission

Battery energy storage

With the advent of flexible computing, ranging from projects done by Google and Microsoft to bitcoin mining, there is a fifth mitigation strategy developers can pursue:

Flexible computing

Only three of these five strategies can be implemented by an individual developer or asset owner: **expanding transmission to their site**, **battery storage**, or **flexible computing**. Before we dive into those, let's highlight some of the strategies grid operators and other participants can take to mitigate curtailment.

Ways to improve grid operations to incorporate more renewables include improved forecasts for wind and solar generation, changes in market regulations to enable solar and wind to provide grid services beyond just energy, and changing the operational limitations of fossil fuel power plants to be more variable. Each of these solutions will allow grid operators to better plan for and have more flexibility to respond to weather patterns that impact both demand and renewable generation. With the expansion of renewables across the US, we view these investments for grid operators as necessary decisions to incorporate clean and cheap renewable energy.

There is also mention of making demand more responsive to changes in renewable generation. This can be done through individual utility programs like demand response for smart thermostats, managed electric vehicle charging, participation of distributed energy resources in wholesale markets, or changes in electricity tariff structures. While all of these changes in demand will hopefully mitigate curtailment, they are not able to be controlled by individual developers.

While the first two solutions are important, individual wind and solar developers are not able to directly mitigate curtailment at their sites by implementing these solutions. These first solutions are largely in the hands of market operators, utilities, regulators, and other actors. In addition, as the research from New York ISO and the Midcontinent ISO illustrates, these solutions will not be sufficient to mitigate increasing curtailment as more solar and wind are connected to the electric grid.

Solutions for renewable developers: Transmission, batteries and flexible computing

Each of these technologies will have a role to play in mitigating curtailment.

Renewable developers are just beginning to learn about the benefits of flexible computing compared to transmission and battery storage for mitigating curtailment.

By comparison, investing in battery energy storage, transmission expansion, and flexible computing are options developers can pursue to mitigate the risk of curtailment at their specific sites.

We want to outline how to compare these options across three categories developers need to consider: cost, time to deployment, and novelty. To measure novelty, we tracked the years the technology has been used for utility-scale applications. We measured the time to deploy in the months it would take for a developer to determine they needed a solution to actual implementation.

Comparing costs across these diverse solutions is not quite as straightforward. Reviewing analyses from Lazard's Levelized Cost of Storage and analysis from Lawrence Berkeley National

Laboratory, the appropriate metric is comparing the Levelized cost of implicit storage on a $/MWh basis. A summary of our findings is listed below:

	Levelized cost of storage ($/MWh)	**Time to deployment** (Months)	**Novelty** (Years in market)
Transmission	1-10	12-120	100
Utility battery storage	85-158	12-24	15
Flexible computing	n/a	<6	<5

Let's explore the strengths and weaknesses of each solution:

Transmission

The process by which electricity is transported (sometimes over long distances) from site of generation to consumers.

Strengths

Transmission expansion has been the industry standard for power plants predating solar and wind development in the United States. The technology is mature and when it can be built over short distances can be quite cost-effective. A recent analysis of completed solar and wind projects estimates that the levelized cost of transmission for renewable projects is 1-10 $/MWh.

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Challenges

The analysis from Lawrence Berkeley National Lab also highlighted that many larger planned transmission projects could cost significantly more. One of the challenges with transmission is that costs can increase dramatically the farther the line has to travel. A common industry back of envelope estimate is a million dollars per mile of additional transmission. Longer transmission lines also can get bogged down in siting in a county by county or even landowner by landowner basis. Some longer transmission plans can take over 10 years to complete or have had to be abandoned entirely because of local opposition. Depending on the specifics of the site, expanding transmission lines can be cost-prohibitive for the project's economics.prohibitive for the project's economics.

Lithium ion battery storage

A type of rechargeable battery using lithium ions as its primary component

Strengths

In the last 10 years battery storage costs for lithium-ion batteries have come down dramatically, enabling them to be economically advantageous in many solar and wind projects. Batteries are able to respond to changes in signals from the grid or remote operators within fractions of a second. This enables them to provide multiple values to the grid while mitigating curtailment. Some additional common uses are arbitraging cheap renewables to be discharged during times when electricity is expensive. Because batteries are designed in factories, they do not need to be custom-built for each site.

Financiers have largely become comfortable underwriting these assets and associated revenue streams to justify financing. They take up a small footprint relative to the size of a utility-scale solar or wind installation. They also can be installed behind the point of common coupling with the electric grid to avoid additional grid upgrades. For all these reasons, projections from the

Department of Energy estimate that by 2030 there could be three to five times the annual demand for energy storage as there was in 2020.

Challenges

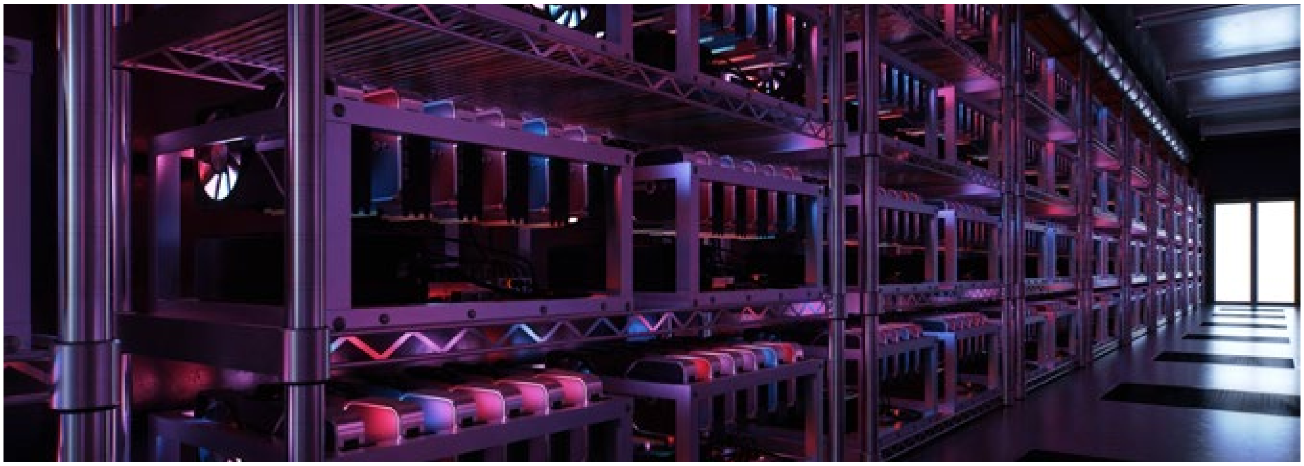
While a valuable addition to many renewable projects, lithium-ion batteries also present different challenges for mitigating curtailment. With each charge and discharge cycle, Lazard estimated that 15-23% of electricity is lost. Additionally, batteries are estimated to degrade 2% per year, potentially resulting in challenges in the battery to provide the services needed during the full 20 or more years of the project's operational life. The cost of lithium-ion batteries is still a challenge in some applications.

Some chemistries for battery storage are also competing with demand from electric vehicles. While that demand has helped drive down costs, it can also lead to supply chain constraints both for raw materials and battery packs.

While novel battery chemistries are on the rise, there are some chemistries of batteries that currently have an increased risk of spontaneously combusting.

Flexible computing

Computing that can be paused and resumed at will, without disrupting the computational process



Strengths

Flexible computing data centers create a hedge on only selling electricity to the grid. With flexible computing integrated into the site, the developer can sell electrons to an onsite data center. For the developers that choose to sell to these data centers, they will be able to guarantee to **sell every**

megawatt-hour they want to contract. Also, there is no equivalent of roundtrip efficiency loss like what is seen in battery energy storage because the electricity is being consumed for a computational need.

Computer processing is a mature technology and cloud computing is a ubiquitous business model. These data centers can do myriad tasks: mine cryptocurrencies, train machine learning algorithms, or help academic institutions analyze large data sets. Because of the need for computing, there is no limit on the duration of time that computing can consume excess generation. This is in stark contrast to current batteries that often only have 4 hours of storage.

Flexible computing data centers can be built modularly. As a result, like batteries, they can benefit from standardization from being built in factory environments. The individual processing units in these data centers are also modular. When an individual processor dies, you don't have to replace the ancillary hardware.

Furthermore, they have a small physical footprint and can be integrated into many renewable energy sites without additional land needs or siting.

Challenges

All the operational expenses of running traditional data centers are also present in a flexible data center with the added complexity of additional upgrades to enable the hardware, power distribution, and software to be able to turn off quickly. One way to measure this is to compare the power usage effectiveness (PUE) of flexible compute data centers versus traditional data centers. This is a metric used to estimate the amount of energy used at the data center that is only used for IT equipment versus all other data center operations. According to NREL, the industry standard is 1.8 PUE with extremely efficient data centers getting as low as 1.03 PUE.

By comparison, flexible computing data centers require little to no energy storage. For example, with efficient thermodynamics and modular design, Soluna's modular data centers are incredibly efficient with a PUE of 1.02 with consistent efforts to reach 1.01.

Another challenge for flexible computing data centers is the electrical waste they generate. If the data center is processing bitcoin or other cryptocurrencies, many of these processors have a lifespan of fewer than two years. There are processes and certifications companies can put in place to mitigate e-waste and develop effective recycling strategies. In contrast, many components in batteries can last 10 to 20 years.

The larger issue than the physical challenges of operating these plants is educating developers on a new business model. Flexible computing for mitigating curtailment of renewables is a model that many developers are just discovering. Unlike expanding transmission or battery energy storage, flexible computing hedges curtailment risk by creating a new off-taker that is collocated with the renewable installation. Developers do not have experience with this type of off-taker and are just learning to consider this as an option for their renewable power plants.

As renewable generation continues to grow, each of these solutions will have a role to play in enabling renewable generation and mitigating curtailment. We see flexible computing as one of the three primary tools developers can use to directly mitigate the risk of curtailment as more renewables come onto the grid.

Soluna's experience in developing flexible data centers for solar and wind generation gives them unique insights into this new resource for developers.

To learn more about how Soluna is enabling flexible computing, join our community here.

Appendix

Methodology

Curtailment estimates

Curtailment was estimated from each ISO or RTO website. Only ERCOT and CAISO provide solar curtailment data. All others provide public wind generation or wind curtailment data. When wind curtailment data was not readily publically available, this was estimated by determining wind generation data and then multiplying generation by percent curtailment for wind generation from the Department of Energy's Land Based Wind Market Report: 2021 Edition.

Revenue estimates

Revenue estimates were determined by multiplying annual wind or solar curtailment by the average PPA price for the respective resource in each ISO or RTO. The wind and solar data were primarily pulled from Lawrence Berkeley National Laboratory's database of PPA prices for solar and wind. When there wasn't sufficient data to determine an estimate for a given year for a ISO or RTO, we supplemented this data with Level 10's average PPA price data for solar and wind summarized in two market reports.

In instances where neither data set had an estimate of renewable PPA prices, we used average real time prices as the closest proxy for pricing. With relatively limited renewable generation in New York and the Northeast, these were the geographies that had the least PPA data to inform lost value from curtailment. PPA prices illustrate the amount of lost revenue an asset owner loses on average for MWh curtailed.

This likely underestimates the true value because it doesn't include PPA prices for solar or wind installations that were installed prior to 2017. PPA prices have historically decreased over time and projects 5 to 10 years old likely have significantly higher PPA prices than prices for renewable PPAs today.

This methodology also underestimates the lost value of curtailment because it does not include estimated lost value for renewable energy credits (RECs). REC prices can vary by state and region. The estimated spot price for wind RECs has varied in different markets over the last 5 years from a low of less than $1 per MWh to over $40 per MWh.

This methodology also assumes the average production tax credit in line with the commence construction requirements for wind projects that year. For example, the average $/MWh for the production tax credit for existing plants in 2021 we assume to be $15/MWh.

Data tables

SUM of energy Curtailed (MWh)	*ISO*							
Year	CAISO	ERCOT	ISONE	MISO	NYISO	PJM	SPP	Grand Total
2017	379,405	1,535,512	0	4058674.927	42,600	244622.5828	1680000	7,940,815
2018	461,037	2,017,080	96,651	3927917.532	66,900	127702.9141	845000	7,542,288
2019	965,249	2,291,001	67,828	5774013.432	70,500	0	1184000	10,352,591
2020	1,587,491	4,706,060	55,187	3,576,559	62,700	78,298	2,050,000	12,116,295
2021	1,504,801	3,816,120	63,750	4,045,857	0	82009.81457	5455756.983	14,968,294
Grand Total	**4,897,983**	**14,365,773**	**283,416**	**21,383,021**	**242,700**	**532633.2574**	**11214756.98**	**52,920,283**

SUM of Revenue value	*ISO*							
Year	CAISO	ERCOT	ISONE	MISO	NYISO	PJM	SPP	Grand Total
2017	$16,436,603	$62,003,992	$0	$170,659,163	$1,879,725	$14,364,238	$53,515,000	$318,858,721
2018	$34,353,736	$62,044,762	$5,033,584	$119,605,089	$3,165,039	$5,274,130	$23,377,770	$252,854,110
2019	$38,043,745	$64,196,962	$3,108,557	$179,023,286	$2,404,755	$0	$26,711,040	$313,488,346
2020	$42,188,062	$162,229,995	$2,118,077	$171,674,813	$2,551,890	$3,617,365	$58,691,500	$443,071,702
2021	$59,332,114	$137,380,320	$3,912,359	$198,246,970	$0	$4,018,481	$207,318,765	$610,209,009
Grand Total	**$190,354,260**	**$487,856,030**	**$14,172,577**	**$839,209,322**	**$10,001,409**	**$27,274,214**	**$369,614,075**	**$1,938,481,888**

SUM of Revenue value	*Generational*		
Year	Solar	Wind	Grand Total
2017	$14,512,504	$304,346,216	$318,858,721
2018	$42,503,592	$210,350,518	$252,854,110
2019	$46,156,873	$267,331,474	$313,488,346
2020	$55,289,582	$387,782,120	$443,071,702
2021	$54,074,071	$556,134,938	$610,209,009
Grand Total	**$212,536,622**	**$1,725,945,266**	**$1,938,481,888**