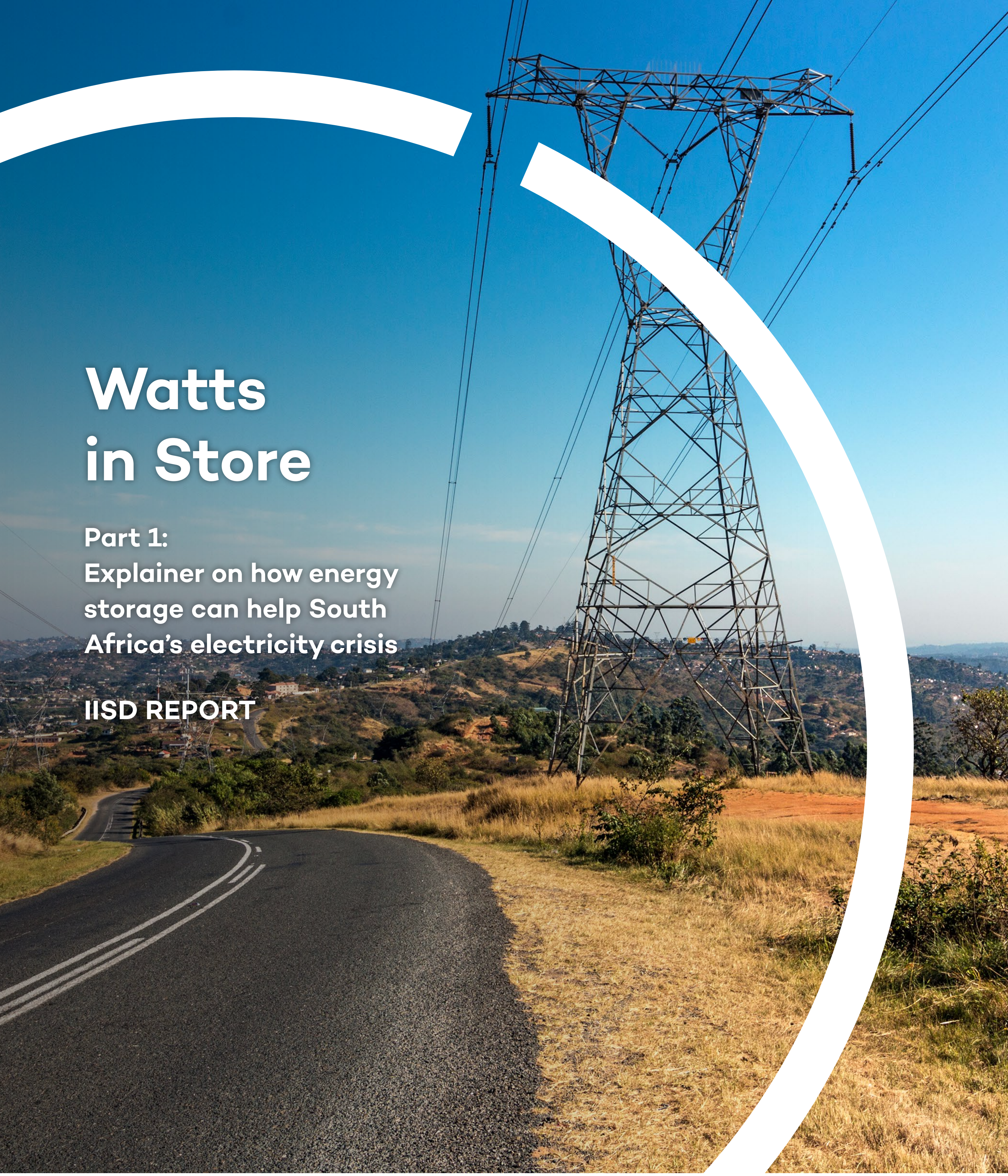

Watts in Store

Part 1: Explainer on how energy storage can help South Africa's electricity crisis

IISD REPORT

International Institute for Sustainable Development

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Written by Richard Halsey, Richard Bridle, and Anna Geddes

Photo: iStock

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About This Series

This paper is the first in a two-part series about energy storage in South Africa. Part 1 covers how energy storage can contribute to solving the electricity crisis in South Africa. It then explores why grid-located batteries are a strategic focus area and the status quo of current plans and projects. Part 2 will take a deeper look at grid-located batteries: how to maximize benefits, minimize risks, and create a more enabling environment for deployment.

Part 1 is written as an explainer piece in accessible language. The intended audience consists of decision-makers in national and local government, researchers, and the wider public interested in energy issues.

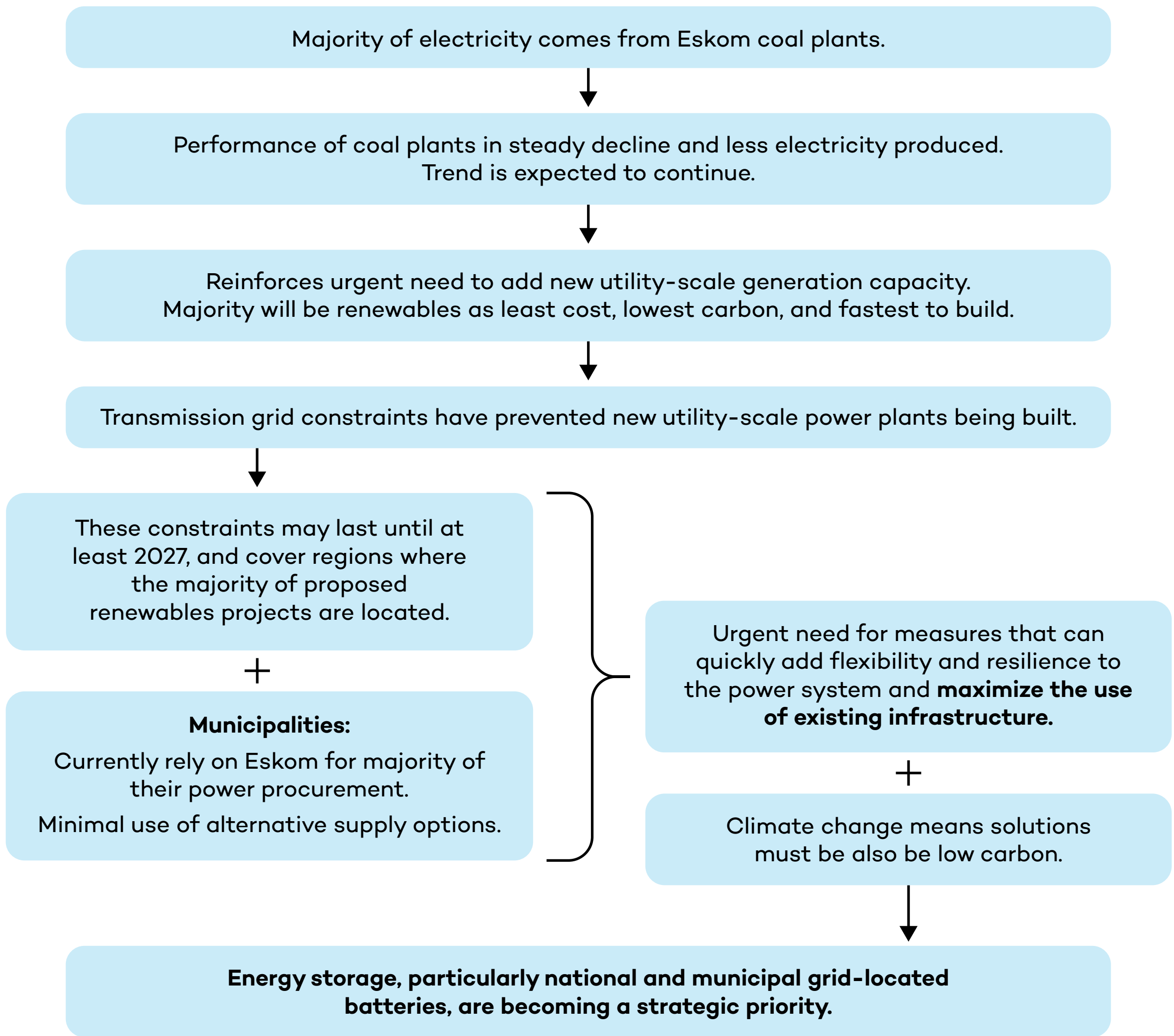
The authors have summarized relevant points from existing literature and included inputs from a wide range of stakeholder conversations.

Executive Summary

South Africa's power system has fallen into crisis, and the national electricity utility, Eskom, can no longer provide sufficient supply to balance with demand. In response, frequent scheduled power cuts (commonly known as load shedding) have become more prevalent. As of mid-May, 2023 was already the worst year on record. While there is much debate around the various options to resolve the crisis, what is clear is that the cost of inaction, in the form of the economic losses caused by constant power cuts, is more expensive than the least-cost options available for its resolution.

The factors summarized in Figure ES1 have resulted in a situation where technologies like energy storage, which can add resilience and flexibility to the power system, are increasingly important.

Figure ES1. Key challenges to increasing national electricity supply



Source: Author diagram.

Energy storage can be described by its location in the power system: either on the grid (transmission or distribution) or with the consumer.[1] The scale of the energy storage facility is independent of location. For example, utility-scale batteries could be built on the transmission grid, the distribution grid, or at a large consumer site, like a mine. Similarly, smaller batteries may be useful at any location in the network.

How Energy Storage Can Benefit the South African Power System

Energy storage decouples electricity generation and supply times, which can provide a wide range of services to stakeholders. For example, energy storage can help balance electricity supply and demand, improve grid stability, and increase financial returns for energy providers. Of these many services, Figure ES2 summarizes a subset of seven benefits that are particularly important for the constrained South African power system in 2023. Further energy storage services will become more important over time and improve the business case for energy storage projects.

Table ES1. Seven benefits energy storage can provide for the South African power system

<table>
<tr><th colspan="3">Immediate effect on load shedding</th></tr>
<tr><td colspan="2">1. Adding batteries to consumer-located generators (mainly solar) can further decrease demand for Eskom electricity supply.</td><td>2. Existing pumped hydro can "smooth out" load shedding: more total hours of load shedding but lower severity when electricity supply is most needed.</td></tr>
<tr><th colspan="3">Improved infrastructure utilization and expansion</th></tr>
<tr><td></td><td>Existing</td><td>Future</td></tr>
<tr><td>Power plants</td><td>3. Better use of existing plants. Potential excess supply at times of low demand is stored rather than being lost. This can then be used at peak times to help meet demand.</td><td>4. Complements new utility-scale renewable energy, which is intermittent, allowing it to supply electricity at a wider range of times.</td></tr>
<tr><td>Grid</td><td>5. Energy storage can optimize the use of constrained and congested grids, effectively squeezing more out of limited infrastructure. Fast solution while grid is expanded over time.</td><td>6. In some cases, particularly at the municipal distribution level, energy storage could be a cost-effective alternative to immediate network expansion.</td></tr>
<tr><th colspan="3">Grid storage contributes to just energy transition</th></tr>
<tr><td colspan="3">7. Grid storage improves the public supply of electricity, which directly benefits all electricity users compared to the indirect system benefits provided by consumer storage that is primarily designed for private benefit.</td></tr>
</table>

Source: Author.

[1] Grid storage is also called "front-of-the-meter" storage and consumer storage is also called "behind-the-meter" storage.

For municipal electricity distributors, energy storage could reduce penalties for exceeding demand limitations and improve the profitability of electricity sales at peak times.

Significance of Grid Storage and Focus on Batteries

Although it is important to better understand and improve how consumer storage contributes to the evolution of the power system, the deployment of consumer batteries is already happening at pace in South Africa. Conversely, deployment of new grid storage, especially batteries, is only beginning in South Africa, and at a much slower pace than is required. Therefore, this paper focuses on grid storage rather than consumer storage.

A key recent development in the global energy storage space has been the exponential growth of utility-scale battery deployment. This growth has been driven partly by cost reductions for lithium-ion batteries of approximately 80% since 2013. This increasing deployment offers more opportunities for "learning by doing" while the growing market attracts further investment into the sector, which is expected to continue to drive improvements in the future. Importantly, grid batteries can be deployed more quickly than other grid storage options. They are, therefore, especially relevant to the electricity crisis in South Africa, which requires fast, effective measures.

While South Africa's existing grid storage includes pumped hydro schemes and thermal energy storage coupled to concentrated solar plants, the prevailing dynamics indicate that short-term growth is expected in batteries. Recognizing this reality, Eskom has tripled the allocation of grid batteries in its latest transmission grid development plan. Up to 2030, all the new grid storage capacity in power system modelling outputs is in the form of batteries.

The key findings of this paper are as follows:

1. Energy storage already provides some relief from load shedding.

Uncoordinated, self-funded consumer batteries are being widely and rapidly deployed. When coupled with consumer solar, they can reduce demand from Eskom. However, batteries alone configured to recharge as soon as load shedding ends can also create demand spikes that are difficult to manage. Existing pumped hydro that is usually used to help meet peak demand is now also being used to more evenly distribute load shedding stages to lessen its impact.

2. Energy storage can provide many services to the electricity system in addition to complementing renewable energy.

Narratives that focus only on the role of energy storage to address the variability of renewable energy underplay the overall value that energy storage can add to the power system.

3. Despite the importance of grid storage, it has yet to gain direction or momentum in South Africa.

Grid storage has received relatively little attention in discussions on how to combat the electricity crisis and requires more political support. Most potential grid storage facilities are delayed. National and municipal grid storage strategies are needed, which will also signal to the energy storage industry that it can develop local supply chains.

4. An informed decision on advanced stage pumped hydro proposals is required.

Pumped hydro can usually provide longer-duration storage than batteries, along with other benefits, so it should be considered a complementary technology. South Africa has several advanced-stage proposals that should be decided on after a thorough analysis of the latest technological, economic, and environmental considerations.

5. Grid batteries are an immediate strategic priority

Grid storage can assist in several of the key challenges facing the South African power system, and batteries can be deployed faster and offer more services than other energy storage options.

The overarching recommendation of this paper is the need to develop national and municipal strategies for the deployment of grid batteries along with a supportive environment to implement grid battery projects.

Next Steps

This paper addressed the "why" question of grid batteries, explaining their value in the South African context and as a strategic priority in the short-term. In Part 2 of this series, we will tackle the "how" question. This subsequent paper will explore how to create an enabling environment for grid battery deployment that maximizes benefits and minimizes risks. This will include optimal rollout factors, such as location, capacity, duration, battery chemistry, and local value chain potential. It will also cover governance issues like policies, legislation, regulations, and procurement.

Table of Contents

List of Figures

List of Tables

List of Boxes

Abbreviations and Acronyms

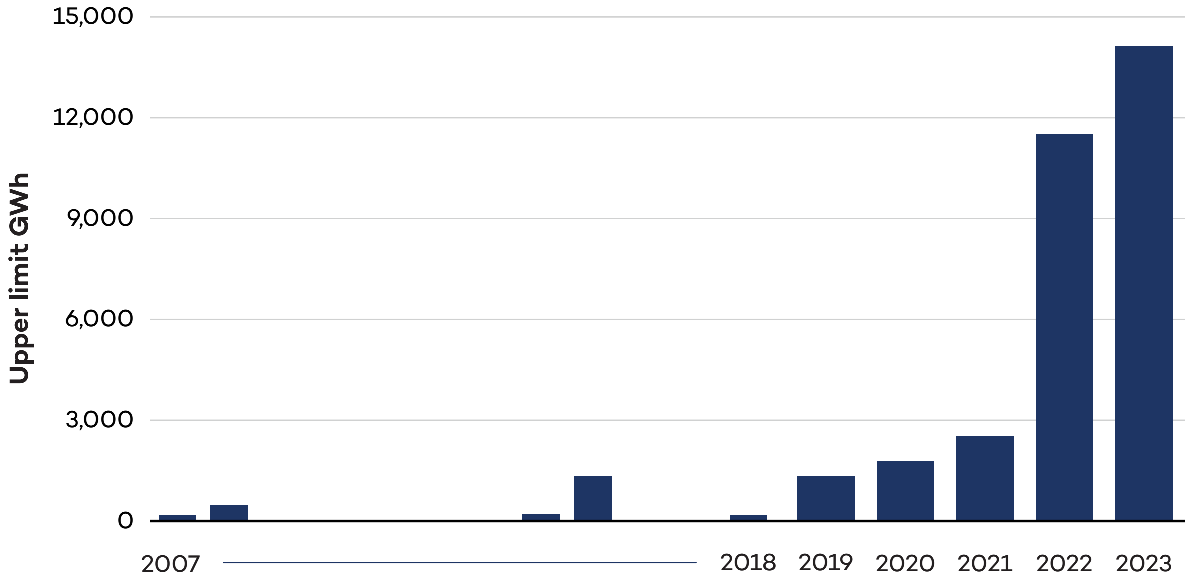
BESS	Battery energy storage systems
DMRE	Department of Mineral Resources and Energy
GHG	greenhouse gas
GW	gigawatt
IPP	independent power producer
IRP	Integrated Resource Plan
kW	kilowatt
LCOE	levelized cost of energy
MW	megawatt
PV	photovoltaic
TDP	Transmission Development Plan

1.0 Solving South Africa's Electricity Crisis

The electricity crisis in South Africa has dominated news headlines in 2023. By mid-May, 2023 was already the worst year on record for power supply disruptions. Eskom, the public electricity utility, is regularly unable to supply enough electricity to meet demand. At the core of this supply-side problem is the steadily declining performance of Eskom's aging fleet of coal-fired power stations, coupled with an insufficient build rate of new power plants. **To keep the power system stable, supply and demand must be in balance**. If there is insufficient supply, then the system operator at Eskom must effectively reduce demand. One of the ways this is achieved is by load shedding—the scheduled, rotational power cuts among supplied regions to maintain overall grid stability.

Load shedding is measured in numbered stages, where each stage equals 1 GW of generation shortfall (Eskom, n.d.-a). The higher the stage, the longer and more frequent the power outages.

Figure 1. Load shedding per year in South Africa since 2007



Source: Author diagram, based on data from Council for Scientific and Industrial Research, 2023 and Abisoft, 2023.
Note: 2023 data is from January to the end of May.

As indicated in Figure 1, the first instance of load shedding was in 2007, but it has gotten significantly worse since 2018. In 2022 more load was shed than all prior years combined, and collective 2022 outages totalled 157 days.[2] This happened despite electricity demand in 2022 being 2.2% lower than in 2019 (Council for Scientific and Industrial Research, 2023). So, the problem to date has been decreasing supply, not increasing demand. In the future, if demand

[2] 3,773 hours of outages divided by 24 hours per day gives 157 days, or about 43% of the year.

for Eskom electricity increases, then the load-shedding situation will get even worse if the supply issues are not resolved.

Load shedding is essentially a symptom—and potentially a measure—of how constrained the power system is. Load shedding has a severe negative impact on the South African economy: it reduces manufacturing output and service provision, diminishes investor confidence, reduces prospects for economic development, and leads to job losses. Regular disruptions to power supply damage and reduce the lifespan of electrical infrastructure in addition to lowering people's quality of life.

Some estimates for the direct, short-term cost to the economy in 2022 for load shedding are over ZAR 500 billion (USD 30.6 billion)[3], but when secondary effects are considered, it could be in the trillions (Hartley & Mills, 2023). Quantifying the economic impact of power disruptions is very complex and depends on many variables where data may not be reliable or available. As a result, the cost estimates of load shedding vary enormously.

More important than an accurate figure is the consensus that **most interventions to reduce load shedding will cost less per unit of energy than load shedding**. For example, even Eskom's most expensive electricity supply option of burning diesel, at a high of ZAR 5.47 (USD 0.33)/kWh in 2022 (Eskom, 2022a), is almost half of a low-end estimate for the cost of power disruptions at ZAR 9.53 (USD 0.58)/kWh (Walsh et al., 2021).[4]

Finding a solution to load shedding is a national priority, and in July 2022, President Ramaphosa announced a plan to tackle the crisis (Ramaphosa, 2022). To increase the supply of electricity, this plan relies heavily on improving the performance of Eskom's coal fleet and adding new power plants (The Presidency of the Republic of South Africa, 2022). While these proposed actions do tackle two of the root causes of load shedding, in practice, there are challenges in implementing either of them in the short term, as described below. In 2023, a State of Disaster[5] was temporarily declared as the electricity crisis continued (Ramaphosa, 2023).

1.1 Key Challenges to Increasing Public Electricity Supply

Over 80% of nationally supplied electricity in South Africa originates from Eskom's coal-fired power stations (Eskom, 2022a). Therefore, the performance of these plants is central to the electricity crisis.

[3] Historical exchange rates (2022 and earlier) are from Organisation for Economic Co-operation and Development, n.d.

[4] This cost of load shedding (covering regular, planned outages) for 2018/19, is in 2020 prices. Inflation adjustment to 2022 prices (as per Eskom figure) will push this figure up to ZAR 10.4 (USD 0.64)/kWh. An estimate for the cost of unserved energy (covering short, unplanned outages) is much higher, at ZAR 101.73 (USD 6.18)/kWh in 2020 (Minnaar, 2021).

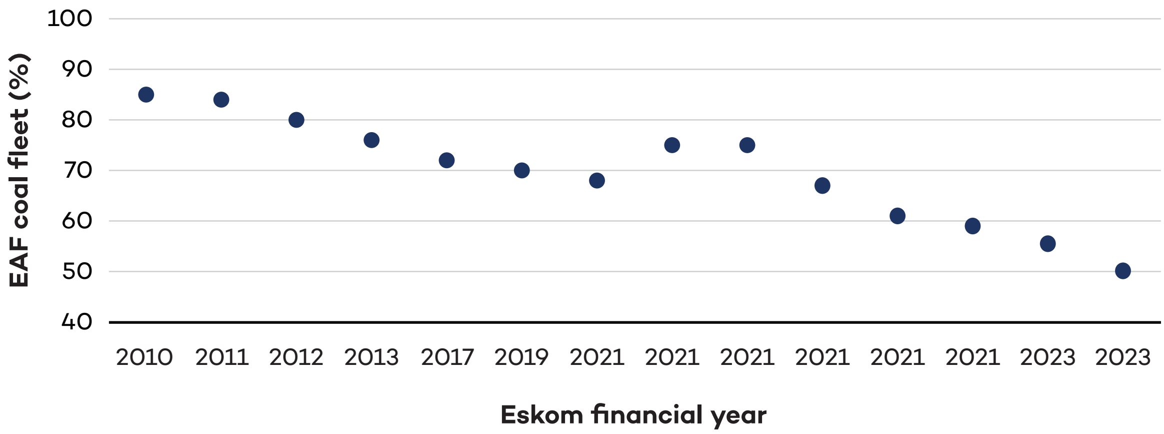
[5] A State of Disaster allows the government to make regulations to deal with the disaster.

Declining Energy Availability Factor of Eskom Coal Fleet

Energy availability factor (EAF) is the percentage of maximum capacity that a power plant is capable of supplying to the electrical grid. Reductions in power output include planned maintenance, unplanned breakdowns, and other losses in capacity.

For the last 14 years there has been a steady decline in the EAF of the Eskom coal fleet,[6] as shown in Figure 2. Furthermore, the average age of units at Eskom coal power stations in 2023 (excluding the two newest plants: Medupi and Kusile) was over 42 years, with a design life of 50 years (Eskom, 2022a). Eskom's most recent system adequacy outlook report "**expects a downward trend in plant performance to continue in the medium term,**" while 4.9 GW of coal capacity will be shut down between 2022 and 2027 due to plant end of life (Eskom, 2022b).

Figure 2. Energy availability factor of Eskom coal fleet



Note: Eskom financial year (FY) runs until end of March each year, so FY2010 = April 1, 2009 to March 31, 2010 etc.

Source: Author diagram based on data and analysis from Meridian Economics, with FY2010–FY2021 figures from Eskom System Status Presentations. FY2022 and FY2023 calculation based on Eskom Data Portal.

This deteriorating performance contributed to the steady decrease in total electricity output from Eskom's coal fleet by 10% between 2015 and 2022 despite an increase in total installed coal capacity of 17% over the same period (Eskom, 2015, 2022a).

[6] There are many reasons for this including: inadequate maintenance and refurbishment, aging plant performance reduction, and sabotage. These factors are compounded by Eskom's strained financial position, operational inefficiencies, high utilization rates of old plants, skills shortages, and parts theft.

For planning purposes, the declining EAF, decreasing electricity output, age structure, and decommissioning schedule of the Eskom coal fleet reaffirm the urgent need to add new generation capacity to provide electricity supply rather than relying on improvements in the existing, unreliable power stations.

Unfortunately, the status of the transmission grid poses a challenge in adding new power plants in this part of the network.

Geographical Transmission Grid Constraints

Eskom's latest published *Generation Connection Capacity Assessment* (GCCA) 2024, released in March 2022, details the expected ability to connect generators (in MW) to the transmission network in 2024 (but not beyond).

This analysis confirmed that **geographical constraints on transmission grid capacity are a major obstacle to adding new utility-scale generation capacity** (Eskom, 2022d). Illustrating this, the Northern Cape is one of the best locations for solar photovoltaic (PV) but has zero expected transmission grid connection capacity in 2024. This means that no new utility-scale generation facilities will be able connect to the transmission grid by 2024, based on committed projects, Eskom allocation rules,[7] and existing transmission network expansion plans.

In July 2022, in response to the electricity crisis, President Ramaphosa increased the allocation of Bid Window 6 of the Renewable Energy Independent Power Producer Programme[8] (REI4P) from 2.6 GW to 5.2 GW (Ramaphosa, 2022). This was later revised down to 4.2 GW (3.2 GW wind and 1 GW solar) by the Department of Mineral Resources and Energy (DMRE) (DMRE, 2022b).

However, when the preferred bidders for Bid Window 6 were announced in December 2022, only 860 MW of solar projects were awarded.[9] Onshore wind projects totalling 4.1 GW bid for the 3.2 GW wind allocation, all in Western and Eastern Cape, but none were successful as there was no available transmission grid connection capacity in these locations (DMRE, 2022a).

So, what went wrong? It seems that much of the grid connection capacity cited in the GCCA 2024 (totalling 3,420 MW in the Western and Eastern Cape) was legally claimed by private generation projects[10] before the REI4P bids were evaluated (SAWEA, 2023).

[7] Even though electricity output from the Eskom fleet is declining due to EAF, this does not free up grid capacity, as the power plants keep their full grid allocation while they are still operational.

[8] The REI4P is the national procurement mechanism for renewable energy projects. Eskom purchases the electricity from independent power producers (IPPS) which feeds into the public electricity supply.

[9] An additional bidder was subsequently selected to meet the full 1 GW solar allocation (DMRE, n.d.-b).

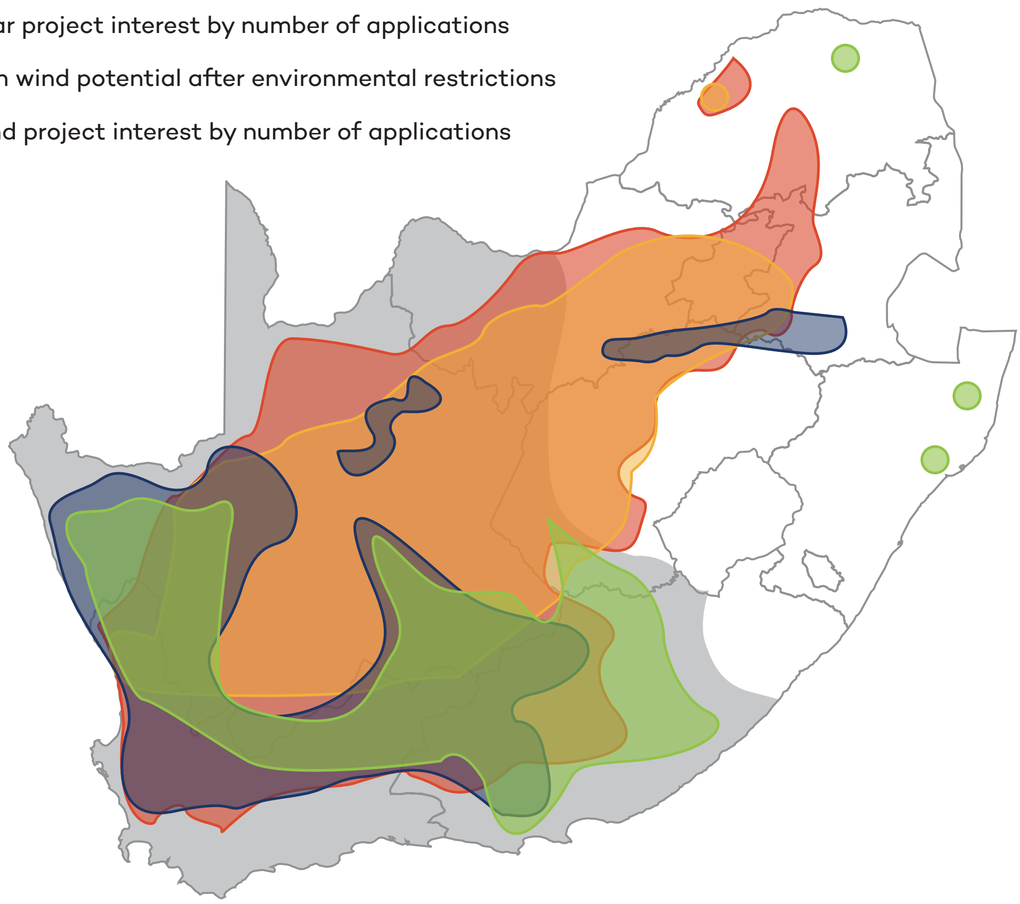
[10] These private projects are IPPs, including renewables, but are not part of the REI4P and do not feed into the public supply of electricity.

Through private power purchase agreements directly with offtakers (such as a mine), these claims on grid capacity should lead to some reduction in demand for Eskom electricity, but the amount of reduction is unknown. The private supply could allow offtakers to expand their operations and increase their energy use, which is not practical during regular load shedding. The offtakers may use these new sources of electricity to supplement what they already get from Eskom rather than entirely replace it.

So, while there should be a system benefit of these private generators coming online, renewables projects that feed into the **public** supply of electricity (like the REI4P) are still an essential part of developing the power system and will be necessary for Eskom to phase out coal.

Figure 3. Geographical grid constraints relative to potential solar and wind projects

Provincial borders
Limited or no transmission grid capacity in 2024
High solar irradiance after environmental restrictions
Solar project interest by number of applications
High wind potential after environmental restrictions
Wind project interest by number of applications



Source: Author diagram, shaded area boundaries based on data compiled from maps in Eskom's *Transmission Development Plan 2022* (Eskom, 2022c).

Whether new generation is public or private, the overriding issue is that the **transmission grid constraints in the entire Cape Region overlap with most utility-scale solar and wind project applications in South Africa**, as shown in Figure 3.

Long Bottleneck Time Frames

The GCCA gives an indication of near-term grid availability, but not by when the grid capacity will increase. This is covered by Eskom's Transmission Development Plan (TDP) to 2032, which indicates that, under the current trajectory, **these severe transmission grid constraints in the Greater Cape region will persist until at least 2027**. As a result, Eskom has allocated very limited new generation capacity in these areas over this time frame (Eskom, 2022c).

This 5-or-more year lag before key regions of the transmission network can accommodate more power stations is a major impediment to solving the power crisis is South Africa. Even if Eskom extends the operational life of some coal plants (Isa & Yelland, 2023), it seems unlikely that the electricity output from the coal fleet will improve significantly in the short to medium term.

The long time frames for transmission grid expansion or substantial improvement in Eskom's coal fleet highlight the need for measures that can quickly add flexibility and resilience to the constrained power system and maximize the use of existing components in the short term.

Minimal Use of Alternative Municipal Supply Options

In addition to buying electricity from Eskom for distribution to customers, municipalities could buy electricity directly from IPPs or from consumers who have their own small-scale generation systems, such as rooftop solar PV systems. This would increase their power supply options and decrease pressure on supply from Eskom.

Although legislative changes since 2020 have opened the door for municipalities to procure from IPPs, there remain regulatory barriers, and most municipalities are simply unable to engage directly with IPPs due to their financial position or lack of internal capability (Nyathi, 2022). In many cases, tariff structures for consumers feeding into the grid have not been developed or implemented, and arrangements for using the distribution grids to transport the electricity (known as wheeling) have not been finalized. In some cases, there is also a reluctance to break with the traditional model of centrally owned and managed power plants (research interviews).

Climate Change

Eskom's electricity production is the largest contributor to climate change in South Africa, responsible for about 43% of national greenhouse gas (GHG) emissions (Department of Forestry, Fisheries and the Environment, 2022). Furthermore, South Africa's electricity production releases more GHG emissions per unit of electricity than any other country in the G20[11] (Ember, 2022). Therefore, decarbonization (i.e., reducing GHG emissions) of electricity production is a crucial part of meeting international climate change commitments and securing international financial assistance linked to climate change. This means that **solutions to load shedding must be low carbon in addition to cost-effective and fast to implement.**

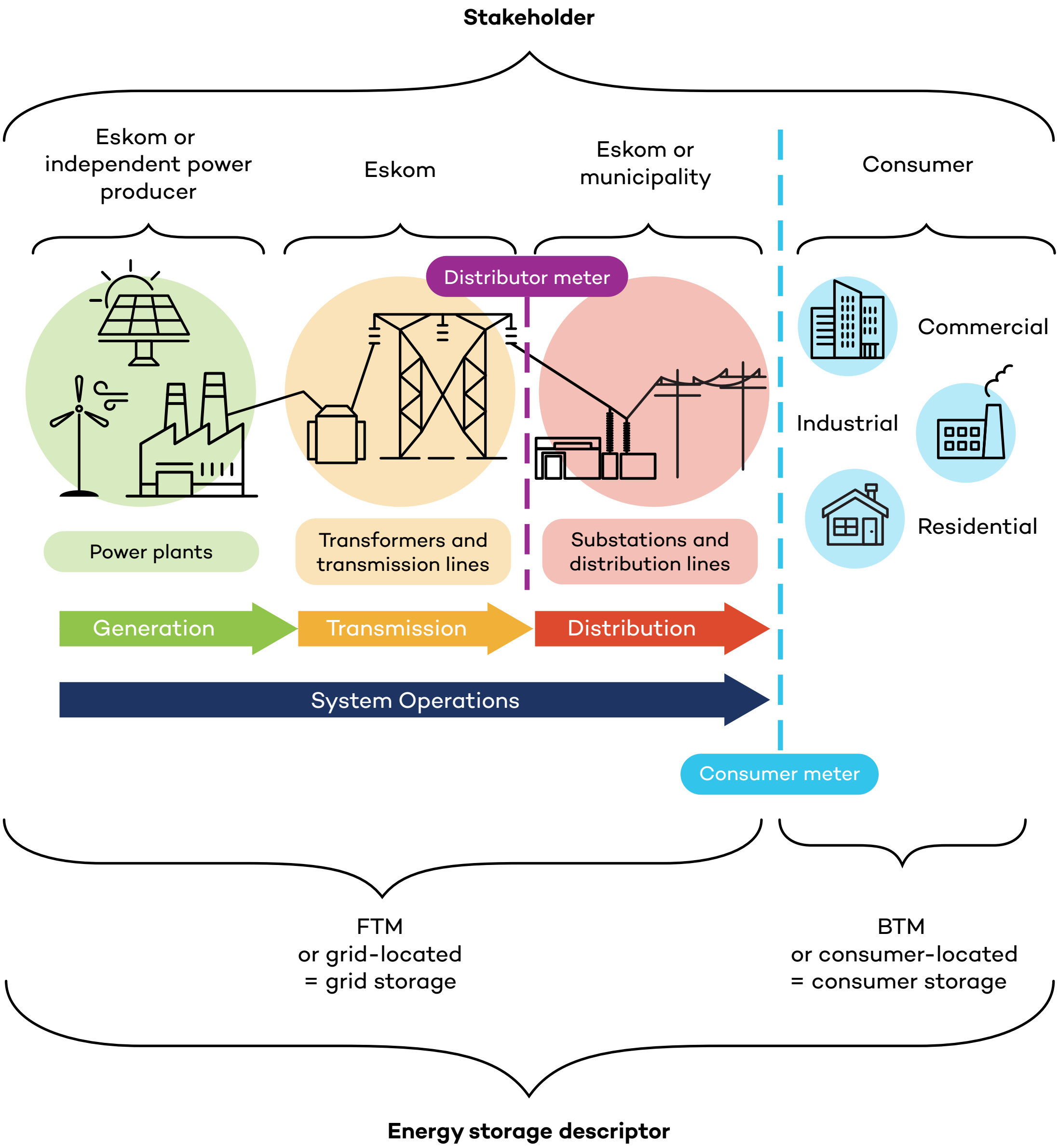
Sections 2 and 3 explain how energy storage, particularly batteries, can help with these key challenges in the short term.

[11] The G20 is an intergovernmental forum comprising 19 countries and the European Union, representing most of world's largest economies.

2.0 Understanding the Growing Role of Energy Storage in South Africa

Energy storage facilities are quantified by their capacity (measured as power output, e.g., MW) and maximum stored energy (measured in MWh). See Appendix A for a fuller explanation and how this relates to storage duration. The word "capacity" is also used to measure how much power a section of the electricity grid can handle. Appendix A also highlights that energy storage will change the future electricity demand profile.

Figure 4. Energy storage described by location within the electricity system



Source: Author diagram.

Figure 4 shows how energy storage can be broadly split into grid-located versus consumer-located. These positions can also be given relative to the consumer electricity meter. For simplicity, in this paper we use the terms "**grid storage**" for grid-located/front-of-the-meter (FTM) energy storage and "**consumer storage**" for consumer-located/behind-the-meter (BTM) energy storage. The location of energy storage within the network affects its applications, who controls it, and who benefits from it.

Where municipalities are responsible for electricity distribution, there is also a "distributor meter" (see Figure 4), as the municipality buys the electricity from Eskom and then distributes it to its customers.[12]

The term "utility-scale" is used for facilities with a capacity greater than the minimum limit. This threshold level is generally between 1 MW to 10 MW (depending on country or context), but utility-scale projects can be built either as grid or consumer storage.[13]

2.1 Energy Storage Technologies for South Africa

Energy storage technologies can be grouped by how the energy is stored (Appendix B), and each technology has different location, cost, scale, level of maturity, and ownership considerations. When assessing options for South Africa, they can also be split into the following:

1. those already established in South Africa;
2. those arriving in South Africa from 2023 onward; and
3. those on the horizon.

1a. Pumped Hydro

Pumped hydro involves pumping water up to a higher dam and releasing it through turbines at a later time to generate electricity. Eskom has three pumped storage stations totalling 2,724 MW/58,600 MWh and has been using this form of energy storage since 1981 (Appendix C).

Significant work, including design and environmental authorization, has been done for the 1,500 MW/21,000 MWh Tubatse pumped hydro scheme in the Limpopo province. Despite Eskom approval, the project was put on hold in 2008 due to the global financial crisis. Other potential pumped hydro schemes include Kobong (1,200 MW) in Lesotho and a 1,000 MW project near Ceres in the Western Cape (Van Dongen, 2022)

1b. Thermal Energy Storage

Concentrated solar power (CSP) plants use molten salt as a form of thermal energy storage. South Africa has 500 MW of CSP with associated storage of 2,265 MWh (Appendix 3).

[12] In this case, "in front of the distributor meter" would be on the transmission grid and "behind the distributor meter" would be on the distribution grid.

[13] In South Africa, the National Treasury recommends using 10 MW as the threshold for utility-scale (National Treasury, 2022).

A further 100 MW CSP with 1,200 MWh storage is expected to come online late in 2023 (ACWA Power, n.d.), but beyond that, no further CSP projects are being built in South Africa.

2. Battery Energy Storage Systems

Battery energy storage systems (BESSs) have seen rapid growth in deployment in the South African consumer market, particularly since 2018, when load shedding worsened. The first South African grid BESS projects started construction in 2022 (see Section 3.2). Lithium-ion chemistries have become the global market leader for grid applications and are starting to displace lead-acid chemistries in the consumer storage market.

3. Emerging Technologies

Internationally, the rapid growth in demand for energy storage has led to a wide range of emerging storage technologies, ranging in maturity from pre-pilot to commercialization. Many of these are alternative battery chemistries (for example, iron-air batteries), while others are different mechanisms of storing energy (BloombergNEF, 2020). Multiple emerging technologies claim advantages over lithium-ion batteries in either specific functionalities, levelized cost of energy (LCOE),[14] or both. However, as with any new technology, these claims will only be verified once commercial projects are operational.

For example, Energy Vault uses the process of lifting heavy blocks to store potential energy that can be converted back to electricity when the blocks are lowered. Suggested advantages of this **gravity-based system** include using local labour and established supply chains for construction, incorporating waste material into the composite blocks, up to 18 hours of storage, a 35-year lifetime, and a lower LCOE than lithium-ion batteries (BloombergNEF, 2020; Energy Vault, n.d.). While Energy Vault has received significant investment, the proof will be in how the first 25 MW/100MWh facility in China performs, estimated to be complete by June 2023 (Shankland, 2023).

A possible future long-duration storage option is **green hydrogen**, which is produced from the electrolysis of water into oxygen and hydrogen using renewable electricity. Once produced, it can be stored until needed, and then combusted in an engine or turbine to produce electricity. South Africa is very interested in green hydrogen due to the world-class renewable resources in the country. A hydrogen roadmap has been published (Department of Science and Innovation, 2021a) and geographical hubs for production have been identified (Department of Science and Innovation, 2021b). Despite this enthusiasm, it remains unclear when green hydrogen will be cost-competitive for grid storage in South Africa.

[14] LCOE gives a present value figure for what it will cost to produce a unit of electricity from a specific project. Over the lifetime of the project, total costs (including fixed costs, such as construction, operations and maintenance, and variable costs such as fuel) are divided by the total expected electricity output.

2.2 How Energy Storage Could Benefit the South African Power System

A core feature of energy storage is that it decouples generation and supply times. In a power system with no energy storage, there must be sufficient generation capacity to meet demand **in real time**. With energy storage, some of the energy generated can be supplied later, and this time-delay mechanism allows for a wide range of benefits.

It is widely recognized that energy storage is the next frontier of a low-carbon energy transition because variable renewable resources require complementary technologies to deal with intermittency. This narrative can lead to a narrow view where this is the only use for energy storage in a national power system. On the contrary, **energy storage provides many services**.

It is beyond the scope of this paper to cover all these services in detail. However, Table 1 indicates the extent to which energy storage (at various scales and locations) can benefit the power system, energy suppliers, and end users. Many of these services will become increasingly important as the just energy transition to a low-carbon power system progresses.

Table 1. Services that energy storage can provide

Use case	Description
Capacity services	**Link to balancing supply and demand, and therefore can help combat load shedding**
Demand reduction*	Combination of consumer-embedded generation and energy storage reduces demand for grid supplied power.
Capacity firming*	Makes outputs from renewable energy plants more predictable (firm).
Peak supply reduction*	Reduces supply required from generation assets at peak demand times.
Grid investment deferral*	Strategic location of energy storage can delay grid capacity upgrades under certain circumstances, but requires thorough analysis.
Load following	Rather than ramping fuel-based power plants up and down to meet peaks, these plants can run at a steady, optimal rate while energy storage follows the peaks.
Peak shifting	Changes the time at which peak supply from generators is required.

Use case	Description
Network decongestion	Reduces congestion on existing network infrastructure .
Reserve contribution	System operator uses energy storage for both reserve margin and spinning reserve that are required during unexpected demand spikes.
Mini-grid enabler	Reduced use of diesel generators.
Energy services	**Can help maximize financial returns for energy providers**
Arbitrage	Profit is made by charging energy storage at times when tariff is low, then selling at times when tariff is higher.
Curtailment reduction	Value gained from energy that would otherwise have been curtailed (where curtailment is the deliberate lowering of power plant output to meet power system requirements).
Asset use optimization	Peaking plants are expensive and inefficient when run at low capacity: energy storage can either avoid their use altogether or allow them run at the most fuel-efficient rate.
Backup power	Assist during unexpected failure of generation or grid assets, preventing revenue loss from power outages.
Ancillary services	**Help the system operator keep the grid stable**
Frequency and voltage regulation	Helps keep the frequency and voltage—maintains grid stability and improves power quality.
Ramp rate control	Where ramping of fuel-based generators is still required, energy storage can allow for flexible ramping and avoid the need for steep ramp rates.
Step change	Helps avoid damage to equipment caused by sudden changes in demand.
Black start	Contribute to restoring power after system blackout.

* Covered in more detail in this section.
Source: Compiled and edited from World Energy Council, 2020; IRENA, 2019; & Commercial Law Development Program, 2022.

Since **a single energy storage facility may offer multiple different services to one or more stakeholders,** revenue could be derived from several services if the policy and regulatory frameworks allow for it. Increasing the number of income streams for an asset improves the business case and likelihood of investment.

The exact combination of possible services must be assessed on a project-by-project basis, and the ability to "stack" such services also influences the size and technology choice of the energy storage system.

While the rest of this section focuses on some capacity services that can benefit a constrained power system from a technical perspective, the combination of other services is what could allow energy storage projects to become more attractive from a commercial or economic perspective.

1. Helps to Quickly Reduce Demand for Grid Supply

When grid-connected residential, commercial, and industrial customers install solar PV, it reduces their demand for grid supply when the solar PV is producing power. By adding energy storage to these systems, excess energy production during sunlight hours can be stored and later used when solar output drops.[15] This further reduces demand for grid supply.

However, if grid customers *only* install energy storage, grid demand could increase, as it would represent an additional load to charge from the grid.

In South Africa, all the various grid-based solutions to improve electricity supply (building new power plants, adding grid storage, expanding transmission network etc.) are likely to take at least a year to 18 months to implement, in the best-case scenario. By contrast, households and businesses are installing energy generation and storage systems daily.

Thus, consumer storage is potentially a low-hanging fruit to quickly reduce demand from the grid, which could, in turn, reduce load shedding. But this consumer storage should be in combination with solar PV (or some other non-Eskom generation); otherwise, it could increase demand and make load shedding worse.

It is also important *when* consumer storage is charged. If consumers charge from the grid (with Eskom supply) as soon as their load-shedding slot ends, it puts additional strain on the system. Incentives could encourage consumers to use their energy storage in a way that benefits the system as a whole. For example, if electricity distributors implemented residential time-of-use tariffs,[16] it would incentivize consumers to charge their storage at low-cost, off-peak times and then discharge for their own use at peak times, when Eskom supply is more constrained.

Consumer storage could also be part of a virtual power plant, which is a network of distributed energy-producing devices (e.g., residential solar PV and batteries) where the capacity can be aggregated and remotely controlled to provide services to the electricity grid.

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[15] Adding energy storage also allows consumers to size their solar PV larger than would typically be done for stand-alone solar PV.

[16] A time-of-use tariff means that the buyer pays different amounts for electricity at different times of day. Typically, the times are split in periods of "peak," "standard," and "off peak," and prices are highest at peak, lower at standard, and lowest at off peak.

The next six benefits are all for grid storage.

2. Smooths Out Load Shedding

In an unconstrained power system, energy storage is usually charged from excess supply at times of lower demand. Between September 2022 and May 2023, Eskom had to implement near-continuous load shedding, meaning there was not the expected excess supply to charge energy storage as would typically be needed. In some cases, load shedding was intentionally continued (or initiated) at night when demand dropped so that Eskom could replenish upper reservoirs in its pumped hydro facilities (Creamer, 2022b).

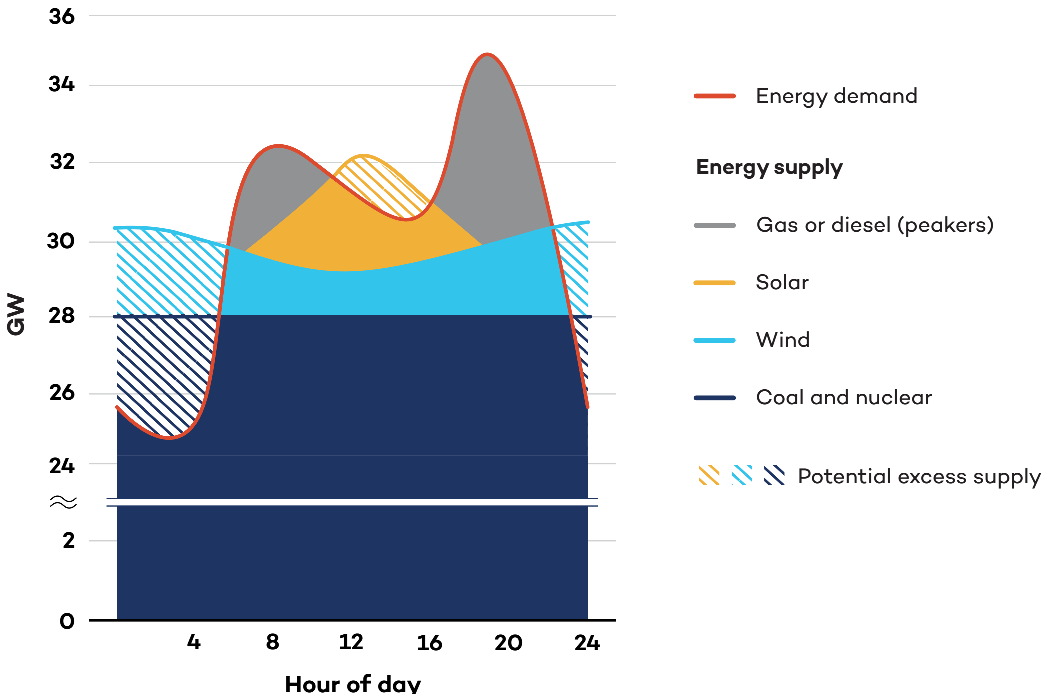
This enables Eskom to use pumped hydro storage to help meet morning and evening peaks the following day and reduce the stage of load shedding at those peak times. Overall, this may result in, for example, Stage 3 load shedding for 24 hours a day rather than no load shedding at night and then jumping to Stage 6 at peak times. **This scenario has more hours of load shedding, but the *severity* of load shedding is less when households and businesses need the power more**. This "smoothing out" of load shedding is generally not a planning goal for energy storage, but in this period of crisis, it is an additional benefit.

Quickly reducing demand for grid supply and smoothing out load shedding are short-term benefits energy storage can provide, while the more long-term objective is to build a resilient and secure electricity system in South Africa.

3. Allows Better Use of Existing Power Plants

A key value of energy storage is that it can be **charged from excess supply that would otherwise be lost** (see Figure 5 for an illustrative example). Excess supply could arise when consumer demand drops below the supply from baseload power stations that run at a steady rate or from renewable energy that is produced at times of lower demand or exceeds IPP contractual arrangements.

Figure 5. Balancing electricity supply and demand without energy storage



Note: This is just the top demand portion of a full energy supply and demand graph (see Appendix A). Coal and nuclear outputs may fluctuate but are shown as level for illustrative purposes.
Source: Author diagram.

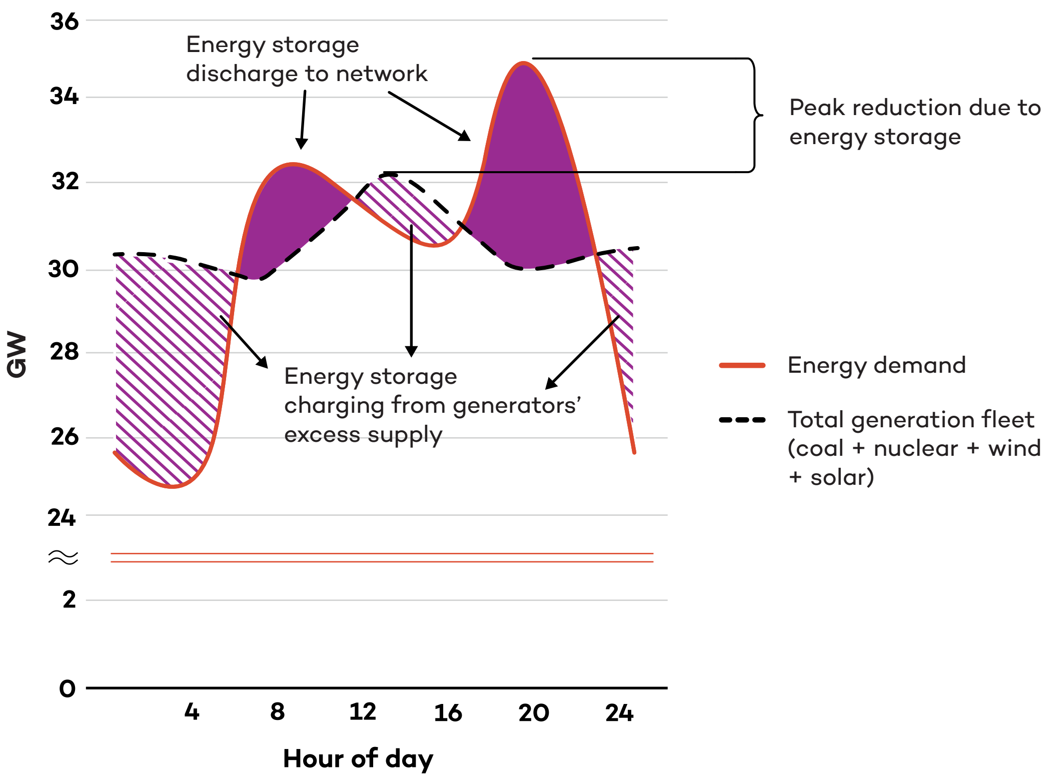
Peak Reduction (or Peak Shaving)

If energy storage is added to the illustrative system in Figure 5, then the potential excess supply at off-peak times, which would otherwise have been lost, can now be used to reduce the supply needed from generators (particularly peaking plants) to meet peak demand (see Figure 6).

The extent to which daily peak demand can be met by storage is partly a function of how much excess energy is available and how much of this excess can be stored. In the Figure 6 example, there is sufficient excess generation supply and sufficient storage to completely remove the need for expensive peaking plants on this day.

In South Africa, Eskom has used pumped hydro to apply this principle for many years, but the limitations on excess supply and storage capacity have often meant that peak demand has to be met with a combination of pumped hydro and peaking plants. The use of energy storage for peak reduction is thus not new to South Africa, but as energy storage technology has improved dramatically in recent years, there are now more energy storage options available that are becoming cost competitive. In addition, the constrained status of the South African power system means there is added value in storing any excess generation that may occur at low-demand times for later use.

Figure 6. Balancing electricity supply and demand with energy storage



Source: Author diagram.

Box 1. Steenbras pumped hydro

At a municipal level, the City of Cape Town is the only city in South Africa that owns and operates a pumped hydro scheme.[17] Originally intended for use in peak reduction, the use of the Steenbras dams has also allowed Cape Town to regularly protect customers from Stage 1 or 2 load shedding, or, when Eskom has implemented Stage 3 or higher load shedding nationally, Cape Town has often been one stage lower (City of Cape Town, n.d.).

The problem here is that under a situation of prolonged load shedding for 24 hours a day, there is no excess supply. This means charging the storage from Eskom supply under continuous load shedding increases demand from Eskom and puts additional strain on the national power system.

Charging this pumped hydro during extended load shedding from non-Eskom primary energy supply, such as wind or solar IPPs, would benefit the entire national power system. The City of Cape Town has been pushing to be able to procure electricity from non-Eskom sources since 2015 (Davie, 2020).

[17] The other three pumped hydro schemes in South Africa (Appendix C) are all Eskom facilities.

4. Enables New Utility-Scale Renewable Energy

In South Africa, there is broad consensus among energy analysts that the most important action to address the electricity crisis is to get new utility-scale generation capacity online as soon as possible (research interviews). Utility scale can be achieved by larger plants on the transmission grid or, potentially, by aggregated smaller facilities within distribution grids.[18] The majority of this capacity will be renewable energy as it is now the lowest cost, lowest carbon, and fastest to build.

Since renewable energy is variable or intermittent, grid storage can allow renewables to cover demand at a much wider range of times. For example, a solar PV plant with energy storage can store excess production during the day and discharge it after the sun sets. Energy storage can also reduce renewable energy curtailment, where curtailment is the deliberate reduction of power generation from these plants when supply is more than the grid can accommodate.[19] For these reasons, **grid storage must be a key part of South Africa's energy transition as it complements renewable energy.**

By 2021 the full life-cycle costs for producing electricity from a combination of renewable energy and storage were already competitive with alternatives like gas-fired peaking plants (Lazard, 2021a, 2021b). An increasing proportion of renewable projects are being built as hybrid facilities with storage, including at the municipal level. For example, the City of Cape Town is investing ZAR 1.2 billion (USD 66.3 million)[20] in a 60 MW combined solar PV and BESS project (Omarjee, 2023)

In addition to enabling a long-term shift from fossil fuels to renewables, energy storage has an important short-term role to play, as described below.

5. Optimizes Use of the Existing Grid

Section 1 indicated how transmission grid constraints have prevented the buildout of much-needed new generation capacity, particularly wind. An important consideration is that these **grid constraints are time dependent** (in addition to location specific). Eskom currently allocates a generation facility its maximum capacity with equivalent grid connection capacity for 24 hours a day (research interviews). However, in the case of a solar PV plant, it only operates at maximum capacity for part of day, so this connection is not used to full potential during daylight hours, and the connection is not used at all at night.

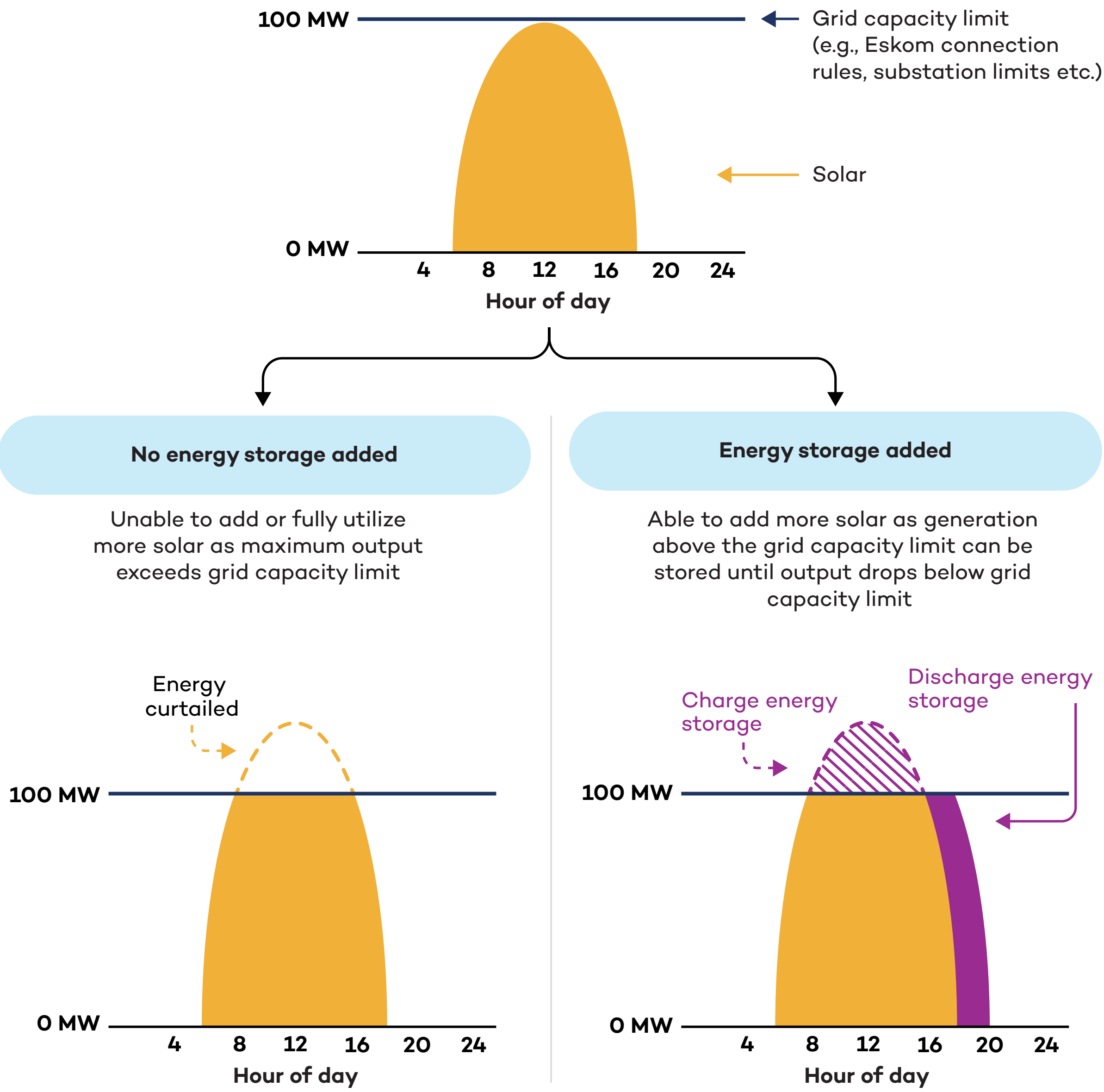
As Figure 7 illustrates, herein lies an **opportunity for using energy storage to get more out of existing limited grid capacity**. Additional measures like IPPs being offered and accepting a certain level of curtailment and changes to Eskom connection rules could further increase the amount of new generation that the existing grid can handle.

[18] For example, in an urban setting, multiple warehouses could provide the roof space for distributed solar PV projects where the collective capacity is controlled by the power producer.

[19] In this case, the real-time excess supply is stored (up to available storage capacity) rather than curtailed to balance with the required demand.

[20] ZAR:USD exchange rate of 18.1:1 used for April 2023.

Figure 7. Energy storage could allow more generation to be added at grid-constrained sites

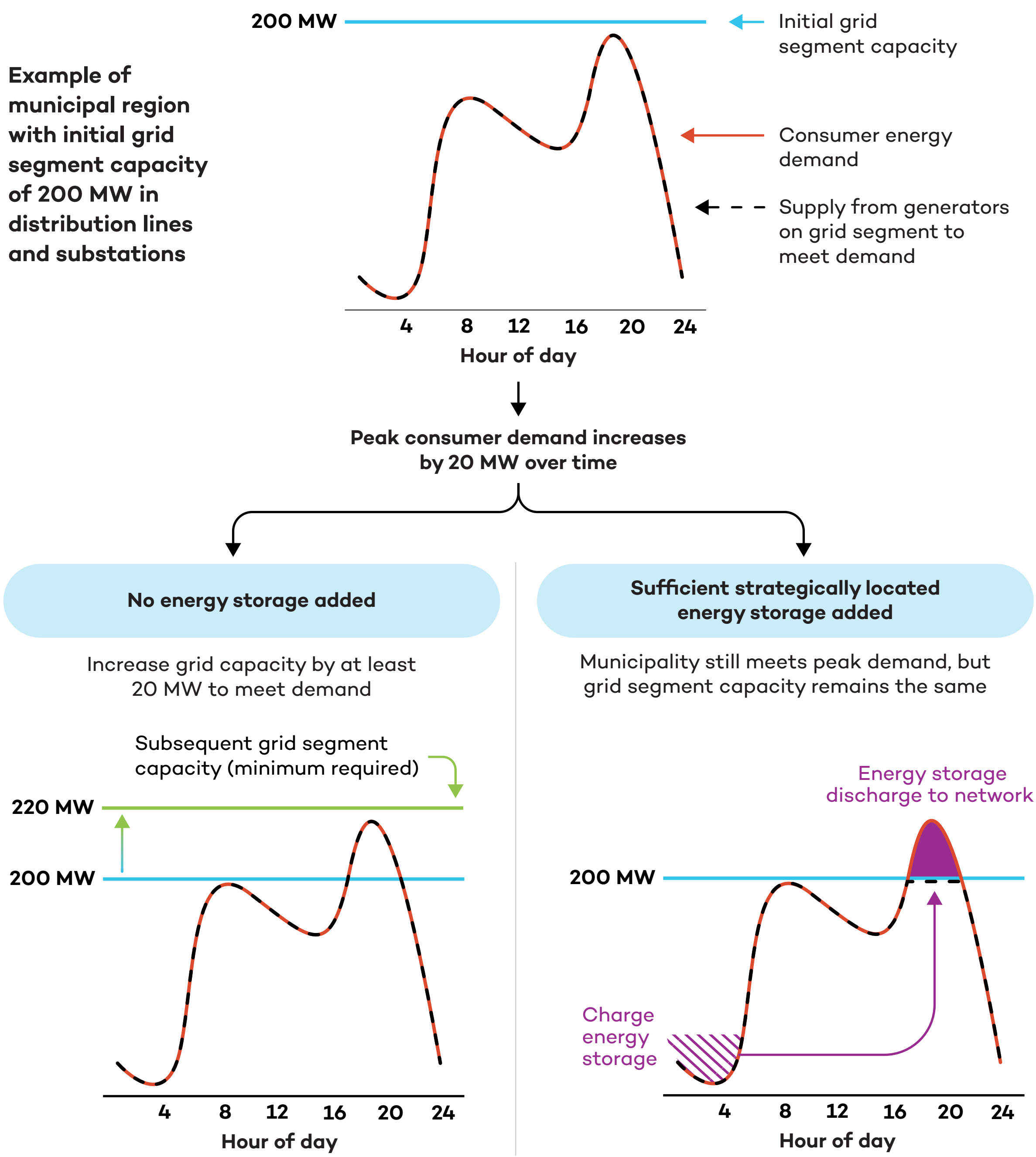


Source: Author diagram.

6. Defers Grid Expansion in Some Cases

Balancing the supply and demand of electricity is not just about producing enough supply, but also moving the energy to where it is required. This is the role of the transmission and distribution grid. This infrastructure (including the wires, transformers, and substations) limits what can be supplied at a particular time. If more than this limit is required, then one solution is to build more network infrastructure. However, a more effective short-term solution may be to deploy energy storage at strategic locations to meet peak demand, leaving existing network infrastructure to meet non-peak demand periods (Figure 8).

Figure 8. Energy storage could defer network expansion



Source: Author diagram.

For example, in 2020, the system operator for Wisconsin developed an energy storage project including 2.5 MW/5 MWh batteries for USD 8.1 million (ZAR 133.3 million) to maintain customer supply in Waupaca, which was cheaper than the alternative of USD 11.3 million (ZAR 186 million) for transmission line and substation upgrades (Hale, 2020). In 2023, a study for New York State put the capital savings of a proposed battery solution (200 MW/200 MWh) compared to transmission upgrade at USD 580 million (ZAR 9.86 billion),[21] along

[21] ZAR:USD exchange rate of 17:1 used for January 2023.

with an annual saving of USD 13.1 million (ZAR 222.7 million) for congestion relief (Brown et al., 2023)

In the context of the South African electricity crisis, this approach could provide several advantages in addition to cost savings. **Energy storage has the potential to be built faster than network expansion and in a more flexible and incremental manner** (Brown et al., 2023).

Importantly, grid expansion is not the same as maintenance. It is critical that the existing network be properly maintained. Furthermore, the suitability of grid expansion deferral must be analyzed on a case-by-case basis. The research interviews for this paper suggest that in South Africa, the use of energy storage to defer grid expansion is likely to be more appropriate in small distribution networks rather than the transmission network.

7. Grid Storage Contributes to Just Transition and Equity

Broadly, a just energy transition (JET) is about applying justice and fairness to the shift from a high- to low-carbon energy system. In addition to the phasing out of coal in an orderly and just manner, the **principles of a JET include actions in the energy sector that benefit the greatest number of people and shield vulnerable groups**. This direct, society-wide benefit is why grid storage aligns more with JET principles than consumer storage (most likely batteries).

Despite the importance of consumers becoming more energy independent, there are implications of this grid defection that could run against JET principles if not carefully managed:

1. The majority of the population will not have the financial resources, suitable housing, or appropriate business premises to install their own energy generation and storage.
2. As a proportion of consumers become less dependent on Eskom, it means that Eskom has to recoup a higher proportion of revenue from the remaining majority of the population (including low-income and vulnerable communities) that is unable to reduce their Eskom dependence.
3. The installation of energy generation and storage at end-user sites is not an orderly transition, and through decreased purchases from Eskom, these consumers may effectively contribute less to the maintenance of the grid.

So, while increased consumer storage in combination with self-generation can reduce demand for Eskom supply, it could also shift the costs of keeping Eskom going onto those who can least afford to do so. The equivalent capacity of grid storage would directly improve the **public** supply of electricity in an organized manner, which addresses the social side of just transition.

Grid storage that improves the public supply of electricity can also reduce the economic impacts of disrupted power for all electricity users, rather than relying on an indirect benefit from consumer storage potentially reducing overall demand on the power system.

2.3 Potential Municipal Revenue Benefits

Where a municipality is responsible for electricity distribution, it may pay penalties if a pre-determined maximum demand is exceeded (National Energy Regulator Of South Africa, 2021) and/or it may need to sell electricity at a loss during peak times. Energy storage can help on both these fronts:

1. By using peak reduction (Point 3 above), the municipal distributor can avoid penalties as high demand can be met from stored energy rather than buying from Eskom in real time.
2. Most municipal distributors buy electricity from Eskom on time-of-use tariffs, so higher prices will be paid during peak times. However, many municipal customers just pay a flat rate per unit of electricity regardless of when it is used. By using arbitrage (see Table 1) the distributor can buy from Eskom when prices are low, store this electricity and distribute it to customers at peak times, thereby avoiding having to buy from Eskom when prices are high.

Section 2 has given some in-principle benefits that energy storage could bring to the constrained power system in South Africa. For real-world project implementation at municipal and national levels, there will be technical and economic nuances that determine how these potential benefits compared to the costs of an energy storage system. These will require detailed investigation, often on a case-by-case basis, which is beyond the scope of this paper.

3.0 Significance of Grid Storage and Focus on Batteries

In 2020, South Africa was estimated as the sixth largest residential energy storage market in the world, according to IHS Markit, with 185 MWh of capacity imported in 2020 (Broughton & van der Walt, 2022). Industry estimates suggest that by 2022 residential storage deployment had jumped to about 2 GWh per year (Jardim, 2023; research interviews).

While there is important work to be done in understanding and improving how consumer storage contributes to the evolution of the power system, the deployment of consumer storage is already happening at pace in South Africa.

On the other hand, deployment of new grid storage, especially batteries, is only just beginning in South Africa and at a much slower pace than required. This is part of the reason why the rest of this paper focuses on grid storage rather than consumer storage. The second reason relates to a JET: as outlined above, grid-located facilities can directly benefit more people than facilities located at end-user premises. Furthermore, grid storage can help provide electricity access to rural, remote, and off-grid communities.

3.1 Global Trends in Grid Energy Storage

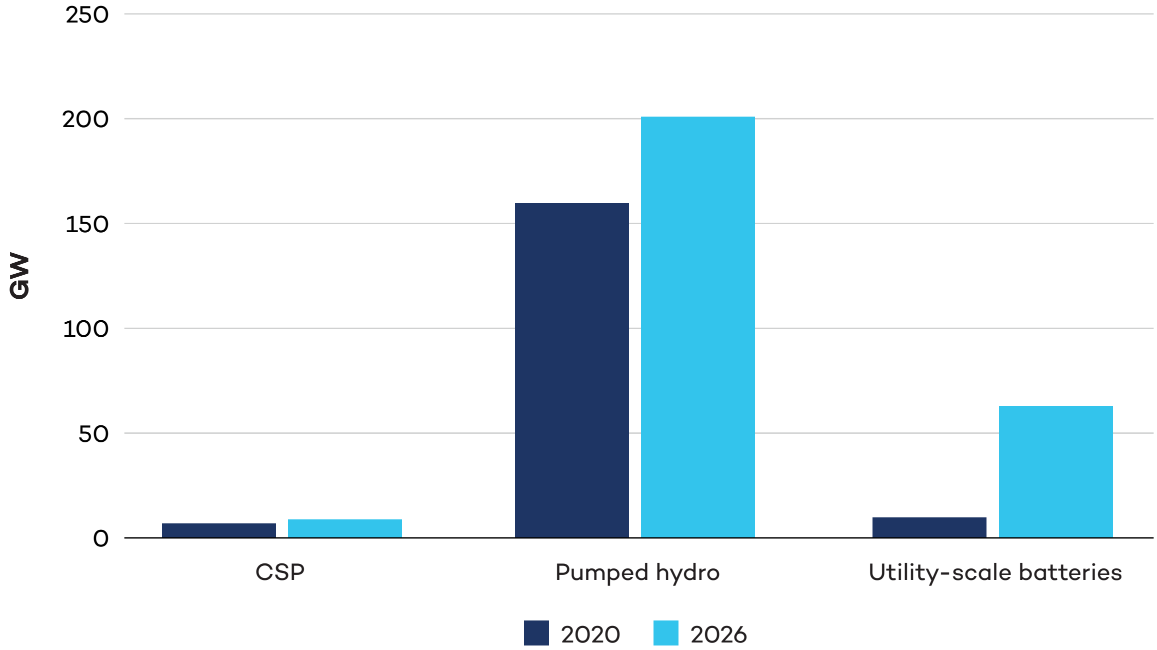
Global energy storage has seen rapid growth in recent years, with over 40 GW being added between 2011 and 2021, and this is a trend that is forecast to continue (Sandia, 2023).

There are several drivers behind this growth, including an increasing share of renewable energy and associated grid-resilience needs, the digital transformation of the energy sector, as well as cost reductions associated with rapidly evolving technologies. Energy storage also aligns with the shift toward decarbonizing the grid and the decentralization and democratization of energy.

In particular, governments have started to develop better policy-enabling environments to support storage deployment, including setting storage targets, removing regulatory barriers, and providing targeted subsidies and other fiscal incentives (International Energy Agency [IEA], 2022b).

Global installed storage capacity is predicted to reach over 270 GW by 2026, a 56% increase on 2020 storage capacity. **While pumped hydro accounts for the largest share of deployed storage, the greatest global growth is expected to come from utility-scale battery deployment**, which will see six-fold growth to reach over 60 GW by 2026 (IEA, 2021).

Figure 9. Concentrated solar power, pumped hydro, and utility-scale batteries, installed storage capacity in 2020 and predicted for 2026

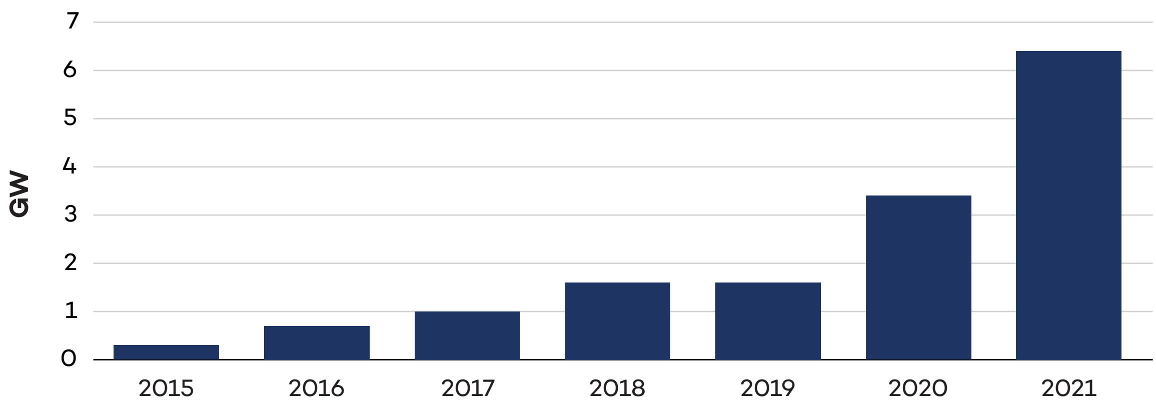


Source: Author diagram, based on data from IEA, 2021.

International Grid Battery Trends

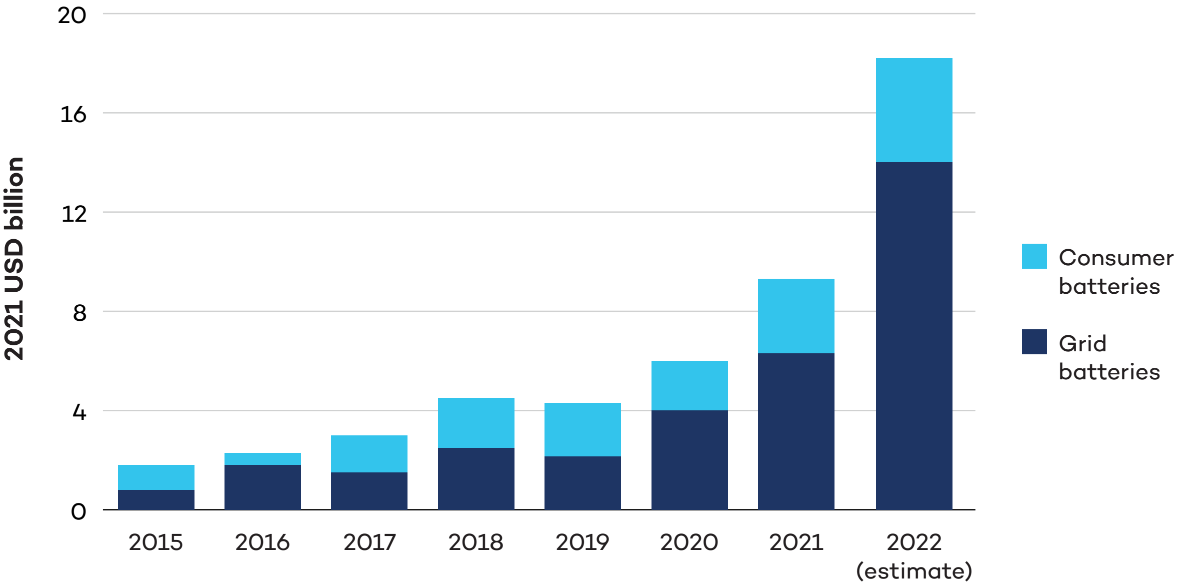
Utility-scale battery capacity has grown quickly (Figure 10), resulting in a total installed capacity of about 16 GW globally by 2021, with most of that added since 2016. Capacity growth appears to be following a near-exponential increase. This trend indicates further opportunities for cost reductions and technological progress. Utility-scale batteries are predicted to account for the majority of global storage growth into the 2030s, with the greatest share being made up of lithium-ion batteries (Bloomberg New Energy Finance [BNEF], 2022a; IEA, 2022b).

Figure 10. Annual global utility-scale battery capacity storage additions, 2015–2021



Source: Author diagram based on data from IEA, 2022b.

Figure 11. Global battery storage investment, 2015–2022

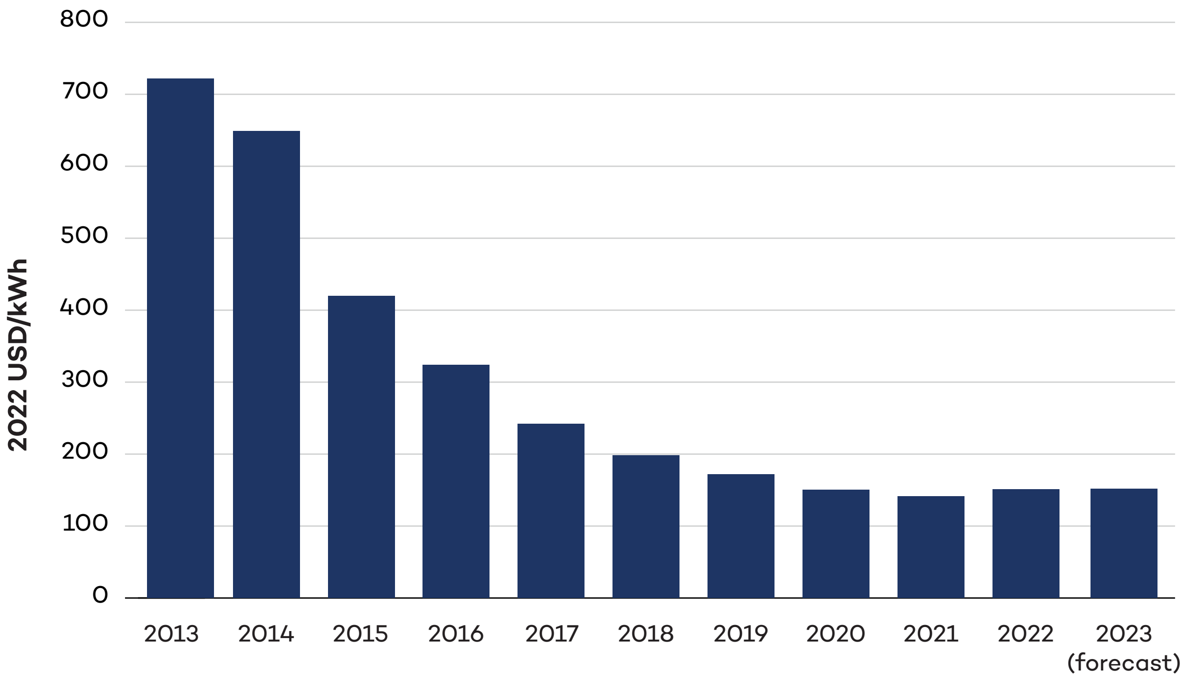


Source: Author diagram based on data from IEA, 2022a.

Global investment in battery energy storage continued to grow and was expected to almost double from USD 10 billion (ZAR 148.8 billion) in 2021 and hit closer to USD 20 billion (ZAR 327.1 billion) in 2022 (see Figure 11) (IEA, 2022a, 2022b). Grid batteries accounted for around 70% of this investment in 2021, with lithium-ion batteries making up around 90% of deployment in 2020 and 2021 (IEA, 2022b).

As more batteries have been deployed, they have also seen massive cost reductions associated with increasing economies of scale and rapidly evolving technology. Figure 12 shows the decreasing cost curve seen for lithium-ion batteries, showing an 80% drop in international prices since 2013. The battery requirements for electric vehicles have also driven improvements in lithium-ion technology. Although battery prices increased slightly in 2022 and will likely stay elevated in 2023 due to an increase in critical mineral prices, BNEF predicts that lithium-ion battery prices will continue to fall from 2024 until 2030 (BNEF, 2022b; BNEF & Transport & Environment, 2021).

Figure 12. Lithium-ion battery (cell and pack) prices 2013–2023



Source: Author diagram, based on data from BNEF, 2023.

3.2 Grid Batteries in South Africa

Energy System Analysis

Power system modelling helps inform what electricity infrastructure should be built in South Africa and when. The models aim to solve for the least cost way of meeting national electricity demand with a variety of supply options over time. While results differ between modelling teams in some areas, a review of five main published results[22] shows that they agree on some key points. Of most relevance to the immediate energy storage debate is the fact that, **to 2030, all new grid storage capacity in modelling outputs will be in the form of batteries**. Several models show that storage duration requirements can be met for several years with just 1- and 2-hour batteries,[23] and potentially up to 4 hours by 2030 (Roff et al., 2020; Wärtsilä, 2022).

In the most recent TDP, **Eskom has recognized the important role of batteries for the grid and has tripled the capacity to 2032** compared to the previous year's plan.[24] In line with other power system models, the TDP 2022 does not contain new CSP or pumped hydro to 2032.

[22] Sources: DMRE, 2019; McCall et al., 2020; National Business Initiative, 2021; Roff et al., 2020; Wärtsilä, 2022.

[23] Short duration may balance supply and demand, but longer duration would help with grid applications and potentially increase the number of services the batteries could provide.

[24] To 2030, TDP 2021 = 2088 MW batteries, TDP 2022 = 6550 MW batteries.

At the distribution-grid level, many municipalities have not yet started including energy storage in their plans. However, for those that have, it is also in the form of batteries. For example, the City of Cape Town is developing a detailed BESS strategy, with interest in the potential for deferring grid expansion (Creamer, 2022a). George Municipality is investigating introducing over 100 MWh of BESS into its distribution network ("What Is George Municipality Doing," 2023).

National Plans

The 2019 Integrated Resource Plan (IRP) for national electricity infrastructure development includes 2.1 GW of energy storage by 2030. This storage will be in the form of batteries, with the request for proposals for the first 513 MW released in March 2023 (DMRE, n.d.-a). An updated IRP 2023 was not released by May 2023.

Additional government plans, published in 2022, also specify batteries when indicating new energy storage capacity. These include the National Infrastructure Plan 2050 (Department of Public Works and Infrastructure, 2022), the actions to end load shedding released by The Presidency, (The Presidency of the Republic of South Africa, 2022), and the Just Energy Transition Investment Plan (Republic of South Africa, 2022).

Eskom also lists a 150 MW/600 MWh BESS to be included during the repowering at each of four coal-fired power stations (Hendrina, Komati, Camden, Grootvlei) as they are decommissioned (Republic of South Africa, 2022).

Why the Immediate Focus on Grid Batteries?

Other energy storage technologies are important, but in the short to medium terms, batteries have become the priority. There are lots of reasons for this:

1. **Short deployment and construction times**
2. Dramatic drop in price (both capital and per unit of energy)
3. Rapid improvements in capabilities
4. Fastest energy storage response time
5. Modular and easily scalable
6. Many possible installation locations
7. Wide range of services offered
8. Distributed nature aligns with energy transition trajectory
9. High round-trip efficiency
10. High energy density

Since South Africa already has CSP and pumped hydro, why are these not an immediate focus? In the case of CSP, it seems to have been economically outcompeted by the combination of solar PV and BESS.

Viable pumped hydro sites are limited by geographical and water source requirements. Moreover, these schemes take many years to build. The average construction time of Eskom's existing pumped hydro schemes is 8 years (Appendix C). Even where substantial work has already been done for potential new sites (Tubatse, Kobong, Ceres), the estimated build times are 5 to 8 years (Van Dongen, 2022). **Therefore, pumped hydro is not a short-term option for assisting the electricity crisis, though it remains an important consideration for the medium to long term due to its potential benefits.**

Grid Battery Capabilities

One of the advantages of grid batteries is the potential to replace fossil fuel peaking plants. As per Figure 5, peaking plants are often used to meet peak demand, but burn fuels like diesel or natural gas, which have associated GHG emissions. Recent improvements in battery capabilities and costs mean that, in some instances, it is now cost-effective to switch to batteries for peaking requirements, with the added benefit of the other services they can provide (see Table 1). For example, California started replacing existing gas peakers with battery storage in 2018 (Bade, 2018), and recent research in Australia calculated that 2- and 4-hour batteries are already 30% cheaper (in terms of LCOE) than equivalent capacity gas peakers (Clean Energy Council, 2021).

In South Africa, there is an ongoing debate about how much of the peaking plant functionality can realistically be done by batteries. Independent energy analyst Clyde Mallinson produced an alternative IRP in 2021, which only builds solar, wind, and energy storage to 2040 for least-cost electricity (Creamer, 2021). On the other hand, most of the other power system models still see a need for building both new battery and new peaking plant capacity in South Africa to complement renewables, but the peakers are run very infrequently.

To an extent, these debates are a distraction when considering the value of introducing grid batteries into a system that does not have any. Clearly, without any storage, the peakers will need to be used extensively, and the more the system operator can use energy storage to meet peak demand, the less need there will be to run peaking plants.

Therefore, batteries will play an important role South Africa in reducing fossil fuel use in peaking plants, and the **extent** of possible reduction will become clearer in the years to come as battery and grid technologies improve further.

Grid batteries also feature strongly in many strategies aimed at 100% renewable energy systems of the future. Although a comprehensive review of international studies supports the technical feasibility and cost-effectiveness of 100% renewable-electricity systems (Brown et al., 2018), it is not important that there is no consensus on this issue in South Africa. Since real-world examples exist where *most* electricity needs can already be meet by a combination of renewables and energy storage, this is sufficient evidence for the value of prioritizing investments in energy storage now.

As per Section 2, energy storage can help with many grid and power system applications, but there are also other technologies that may be more appropriate for specific functions or under certain conditions. For example, synchronous condensers are free-spinning motors connected to the grid that help maintain system voltage and stability.

Box 2. South Australia: Renewable energy and batteries now provide majority of electricity needs

In 2016 huge storms blew through the Australian state of South Australia followed by statewide blackouts (Baum & McGreevy, 2021). While some parties blamed renewables for the blackouts, a formal review found that widespread storm damage to infrastructure and overly sensitive power system protection mechanisms were responsible (Harmsen, 2017). Fortunately, political will ensured the state continued to roll out large amounts of renewables and storage, with the state government announcing commitments to 100% renewables by 2030, and 500% renewables by 2050[25] (McGreevy et al., 2021; SA Government Financing Authority, 2022). By 2022, renewables and storage accounted for 63% of the state's total installed capacity (Australian Electricity Market Operator, 2023).

Several large utility-scale battery projects have been developed, including the Hornsdale, Lake Bonney, and Dalrymple North projects (Hartmann, 2021; Parkinson, 2021). These big batteries (along with home batteries, virtual power plants, and new synchronous condensers) have helped provide dispatchable supply and critical system grid services that were once delivered by coal and gas (Hartmann, 2021; Parkinson, 2021). As a result, South Australia has not experienced load shedding since 2018, despite shedding 7 million hours of electricity in the 4 years prior (Hanley, 2021).

The South Australia case shows that system performance can be maintained—and even improved—with ever-increasing levels of renewables and storage. In 2022, 69.5% of the state's electricity needs were met by renewables and storage (Australian Electricity Market Operator, 2023).

Grid Battery Chemistries

There is a wide range of chemistries that can be used in grid battery systems.[26] This paper does not explore or compare the different chemistries but indicates which are of interest to South Africa and likely to be built in the short term.

By 2018, **lithium-ion** chemistries dominated the global market, with over 80% of installed battery capacity (Mongird et al., 2019), and have continued to improve in cost and capabilities since then. The majority of power system models now use lithium-ion cost estimates in their assumptions for battery costs. Within the lithium-ion-based chemistries,

[25] 500% renewables because South Australia aims to become a large exporter of renewable energy to other Australian states, and to develop a green hydrogen sector (SA Government Financing Authority, 2022).

[26] The main battery types by installed capacity are lithium-ion, sodium sulphur, lead acid, redox flow, sodium metal halide, and zinc-hybrid.

lithium iron phosphate (or lithium ferrophosphate) has emerged as the preferred candidate for stationary storage (research interviews).

Flow batteries also use a range of chemistries and configurations, but the vanadium redox flow battery (VRFB) is a forerunner technology. The largest cost in the production of VRFBs is the vanadium, and South Africa has significant vanadium reserves. Therefore, VRFBs provide an opportunity for developing a local value chain, and this potential is being analyzed (as of May 2023) by RebelGroup Advisory Southern Africa and Trade & Industrial Policy Strategies. Another advantage of VRFBs is longer duration of storage compared to lithium-ion.

The **liquid metal battery** is a relatively new entrant to the global battery market, but is also one to watch for in South Africa. The reason is that, as of May 2023, the largest capacity battery slated for deployment in South Africa is a 300 MW/1,200 MWh liquid metal battery ordered by Earth and Wire, an independent renewable energy retailer (Ambri Inc, 2022).

Grid Battery Projects in South Africa

Grid batteries under construction or in advanced-stage projects in 2023 fall under two main initiatives (Appendix D).

The first is the **Eskom BESS project**, which will primarily be used for peak reduction but also provide ancillary services. The Phase 1 projects (199 MW/833 MWh) will be located mainly at Eskom distribution substations (Creamer, 2022c), and construction began at the first site in December 2022 (Eskom, 2022f). Only one project site is expected to be completed by the original June 2023 deadline, and Phase 1 has been extended to end of December 2023 (research interviews).

The second are BESS components of the preferred bidder projects under the **Risk Mitigation Independent Power Producer Procurement Programme (RMI4P)**. These batteries were included to meet the tender requirements to provide dispatchable, flexible power (DMRE, n.d.-c). By May 2023, only the three Scatec sites had started construction (Scatec, 2022).

These **grid BESS projects are not necessarily larger in scale than private projects**. Many facilities being planned at end-user premises or with private power purchase agreements are much larger than those listed in Appendix D. Mines and other industrial sites with high energy demand are planning large BESS facilities. For example, Sereti Resources are planning a private power supply project in Mpumalanga that includes 800 MWh of storage capacity (Steyn, 2023), almost as much storage as the entire Eskom BESS Phase 1.

4.0 Findings and Next Steps

Finding 1: Energy storage can already provide several benefits to the South African power system, but it depends how it is used.

The combination of consumer solar PV and batteries can reduce demand for Eskom supply, and deployment of batteries at commercial, industrial, and residential sites is accelerating. This is happening in an uncoordinated manner and primarily as a self-funded response to protracted and worsening load shedding. While this consumer storage capacity is being added independent of government direction or support, there is still much that national and local governments can do to encourage the use of consumer storage in a way that gives the most benefit to the entire power system. The rules and tariffs for feeding power back into the grid require attention.

At grid level, existing pumped hydro is used to meet peak demand and helps lessen the severity of load shedding at times when it would have the highest impact on people and the economy.

Finding 2: Energy storage offers many services to the electricity system, not just complementing renewable energy.

To address the electricity supply shortfall, grid storage can contribute to optimizing the use of existing power generation and maximizing the use of the existing grid. South Africa's fragile power system is in urgent need of measures, such as energy storage, that can add resilience and flexibility. All these benefits can be realized before the critical role energy storage will have in complementing the massive rollout of renewable energy and network upgrades that South Africa requires.

Stakeholders and decision-makers in the energy sector should recognize the multiple ways energy storage can benefit the power system in South Africa.

While energy storage is the next frontier of the energy transition as a partner to renewable energy, it can offer much more than this function. Narratives that focus *only* on the role of energy storage to address the variability of renewable energy undermine the overall value energy storage can add to the power system. Furthermore, because South Africa still has a low penetration of renewable energy, such narratives could lead to the interpretation that energy storage is not a priority now.

Finding 3: Despite the importance of grid storage, it has yet to gain direction or momentum in South Africa.

Grid storage is certainly not a silver bullet for the electricity crisis nor a stand-alone solution for load shedding. However, as it can assist on multiple fronts, it is surprising that grid storage has received relatively little attention in mainstream discussions on combating the electricity crisis in South Africa. Energy storage can also be pursued at the same time as other load-shedding solutions, so it does not compete with these other efforts.

While BESS is included as required new capacity in national energy plans, **South Africa does not have a national energy storage strategy or roadmap**, nor does it appear that one is being developed. This is evidence that energy storage is not yet receiving the attention it requires. At local government level, most municipalities do not seem to have developed BESS strategies, but there are some exceptions where detailed analysis is underway.

At the project level, **the majority of potential grid storage facilities are delayed**:

1. The Tubatse pumped hydro scheme has been on hold for over a decade.
2. The first 513 MW of energy storage in the IRP 2019 was meant to come online in 2022, but the tender only went out in March 2023.
3. The Eskom BESS project has taken a long time to get going, and most of the Phase 1 sites have been extended by 6 months past the June 2023 deadline.
4. The RMI4P was meant to connect projects to the grid by June 2022, but four preferred bidders (which include BESS) have not even reached financial close as of May 2023.

Finding 4: An informed decision on advanced stage pumped hydro proposals is required.

Long construction time frames preclude pumped hydro from assisting the South African power system in the short term. However, these timelines also mean that if more of these projects are required, they must get underway soon, as it will be a long time before they are operational.

As the power system develops, there may be an increased need for longer duration storage. This is where pumped hydro could have an advantage over batteries. In addition, pumped hydro facilities have a long lifetime and can have high local content and service utilization during construction. They are a tried and tested technology, and the existing pumped hydro schemes provide a critical service to the system operator. Despite this, the future of several pumped hydro schemes is uncertain, and there is debate among energy analysts as to whether future projects should go ahead.

There are also mixed messages from Eskom about pumped hydro. For example, Tubatse appears in Eskom's JET project pipeline (Republic of South Africa, 2022) but not in its TDP 2023–2032 (Eskom, 2022c). If the debt relief measures announced by the National Treasury in March 2023 limit Eskom investments to grid infrastructure (National Treasury, 2023), then it is unclear how Tubatse would proceed, although it has already been suggested that it could run as an IPP (Zhuwakinyu, 2014).

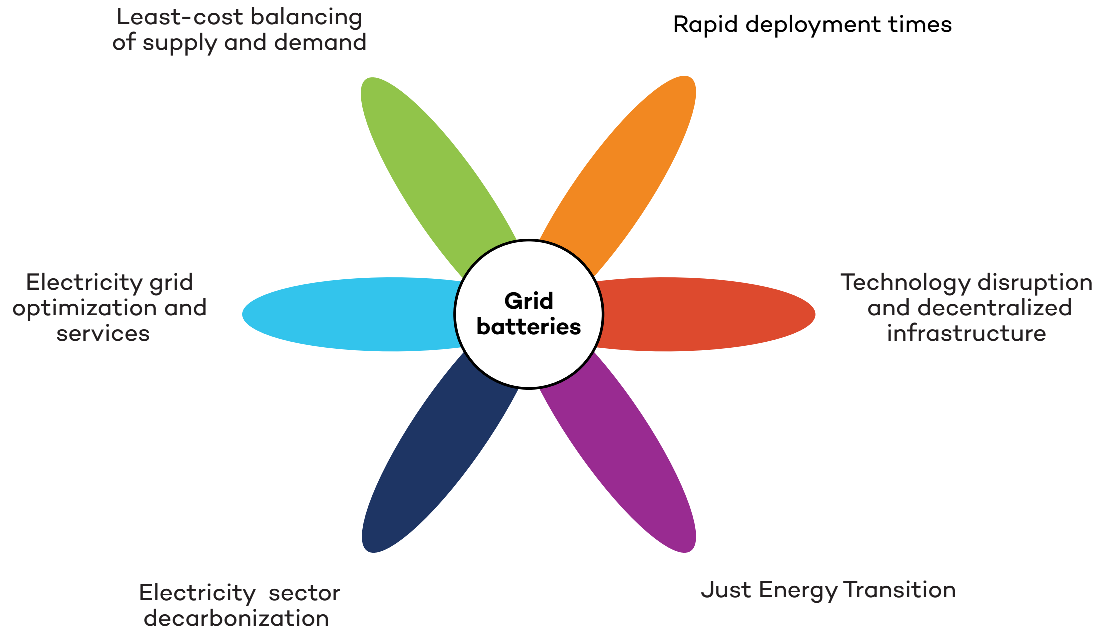
Overall, a verdict on advanced-stage pumped hydro proposals is required—it is not helpful for them to be permanently on hold. **A decision should be made based on a thorough analysis that balances the latest data on power system needs, environmental impacts, water management, and advances in alternative energy storage technologies.**

Finding 5: Grid batteries are an immediate strategic priority.

The South African energy market mirrors international trends, where the majority of existing energy storage is pumped hydro, but the most growth to 2030 is expected to be in batteries. Global grid battery trends show that deployment is increasing exponentially, leading to opportunities for technological learning and economies of scale. These forces are also impacting the market for energy storage in South Africa. The dramatic improvements in battery capabilities and costs have put them at the current forefront of technological disruption. Batteries are where the short-term opportunities lie, which is not the case for CSP, pumped hydro, or other emerging technologies.

Grid batteries emerge at the intersection of six energy planning considerations touched on in this paper.

Figure 13. Grid batteries and energy planning considerations



Source: Author diagram.

Next Steps: South Africa must create an enabling environment for grid battery deployment that maximizes benefits and minimizes risks.

To get the most value from grid BESS, an **optimal rollout strategy** must cover a range of factors, including costs, location, capacity, duration, battery chemistry and local value chain potential.

Despite the benefits of grid batteries and the rapid increase in deployment globally, there are serious risks that bear consideration. **There are concerns associated with the raw materials used in batteries, including mining practices (unethical labour practices and environmental damage); market competition for minerals; handling and disposal of hazardous chemicals; and historically low levels of recycling.** The operational lifespan and performance degradation of battery chemistries vary, and some are more prone to catching fire.

For BESS projects to be implemented, there will need to be an **enabling environment**. This will need to address a number of challenges and opportunities, including costs, policies, planning, regulations, procurement and incentives.

This paper has outlined the case for developing energy storage and battery energy storage specifically. Part 2 in this series will investigate *how* to create an enabling environment in South Africa for grid BESS that maximizes the benefits and minimizes the risks.

Part 2 will aim to provide advice to policy-makers as they consider their options to do the following:

1. Develop national and municipal BESS strategies.
2. Update policies, legislation, regulations, procurement, and incentives linked to grid BESS.
3. Collaborate with state-owned entities and subnational governments to create optimal rollout plans for grid battery deployment.
4. Engage with the energy storage industry on how best to support the implementation of grid BESS projects.

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Appendix A. Basic Energy Storage Concepts

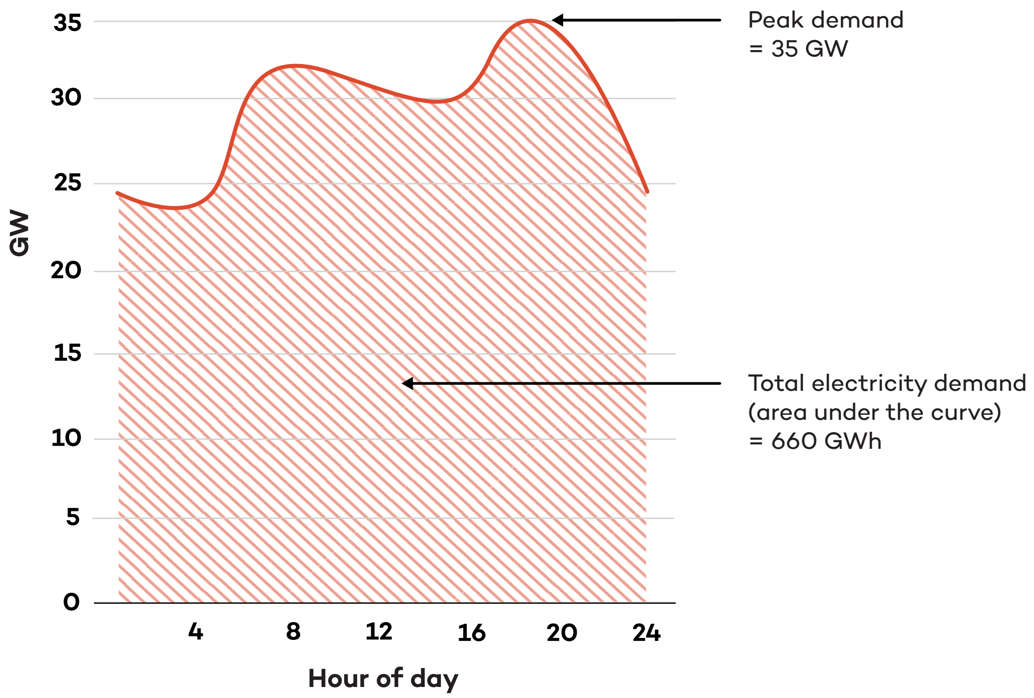
1. Power vs. Energy

Unit example: Megawatt (MW) vs megawatt-hour (MWh)

- Basic equation: energy = power × duration
  - So, 1 MWh = 1 MW × 1 hour
  - i.e., 1 MWh is the energy or electricity used by 1 MW of power acting for 1 hour
- Power is the rate of energy transfer, and capacity is the maximum power output an energy generator can produce.
  - Both power and capacity are for a specific point in time (i.e., instantaneous) and are measured in multiples of watts, e.g., kilowatts (kW), megawatts (MW), and gigawatts (GW).[27]
  - While capacity applies to power stations, transmission and distribution networks, it also applies to energy storage. Once charged, an energy storage facility can function as an electricity generator.
- Electricity demand and supply can be measured as either power (at a specific time **point**) or energy (over a specific time **period**).
  - For example: over the course of a day, the peak electricity demand on the South African grid may occur at 19:30 and be 35 GW. Over the same 24-hour period, the total electricity demand may have been 660 GWh (Figure A1).
  - Similarly, for a residential house, with all appliances turned on, electricity demand at that exact point in time may be say 5 kW, but over the entire day total electricity used may be 25 kWh.

[27] 1 GW = 1,000 MW = 1,000,000 kW = 1,000,000,000 W

Figure A1. Example of national electricity demand over the course of a day



Source: Author diagram.

2. Ratio of Power to Duration

An energy storage facility will have a nominal capacity rating and be able to supply energy at maximum power output for a certain duration. The same capacity facility could supply energy for a longer period, but this would need to be at a lower power output. This is analogous to getting longer life out of torch batteries when the torch is on a dimmer setting.

For example, a fully charged battery with a maximum output of 5 MW and 4-hour duration, could provide 20 MWh (5 MW × 4 hours) of energy if fully discharged. The same amount of energy could be supplied by this battery over an 8-hour period, but then the power output would be halved to 2.5 MW (20 MWh = 2.5 MW × 8 h). However, this 20 MWh of energy could *not* be supplied over a 2-hour period due to the capacity rating. The maximum energy that could be supplied over 2 hours would be 10 MWh.

Power system planners need to think about what ratio of power to duration is optimal to balance supply and demand in different scenarios. There will be storage technology choice and cost differences for varying applications.

For example, you could get 10 GWh of energy from a single storage facility in many ways: 10 GW × 1 hr, 1 GW × 10 hrs, 2.5 GW × 4 hrs etc. Or the same energy could be supplied by multiple facilities, such as 10 units each at 1 GW × 1hr each.

3. Energy Storage Changes the Demand Profile

An obvious but often neglected feature of energy storage is that it will change the typical daily demand profile illustrated in Figure A1. Current consumer demand drops during the middle of the day (10:00 to 15:00), but in a future energy system with lots of energy storage, this period of the day aligns with average maximum output from solar PV. As it makes sense to charge storage from the cheapest generations options when they are in excess, it is likely that total future demand will increase in the middle of the day. Similarly, when there is excess wind generation at night, that can be used to charge storage, which again increases demand at that time.

No storage technology is 100% efficient, so an energy storage facility itself always uses more energy to charge than it provides to the grid via discharge (i.e., a net consumer of energy).

Appendix B. Energy Storage Technologies

Figure B1. Energy storage technologies grouped by their principle

Principle	Subgroup	Technology
Chemical		Hydrogen; Ammonia; Synthetic natural gas
Mechanical	Potential energy	Pumped hydro; Compressed air; Gravity
	Kinetic energy	Flywheel
Thermal	Low temperature	Cryogenic; Aquiferous
	High temperature	Latent heat (Phase change); Sensible heat (Single phase, e.g., molten salt)
Electrical	Electrostatic	Supercapacitor
	Electrodynamic	Superconducting magnetic energy storage
Electro-chemical	High temperature batteries	Sodium sulphur; Liquid metal
	Secondary batteries	Lithium ion; Lead acid; Metal air
	Flow batteries	Vanadium redox flow; Zinc bromine

Source: Author diagram, adapted from European Association for Storage of Energy, 2023.

Appendix C. Operational Grid Storage in South Africa

Table C1. Operational grid storage in South Africa

Facility	Operator	Start year	Nominal capacity* (MW)	Duration (hours)	Max energy storage (MWh)
Pumped hydro					
Drakensberg	Eskom	1981	1 000	27.6	27,600
Palmiet	Eskom	1988	400	25	10,000
Ingula	Eskom	2016	1,324	15.9	21,000
Steenbras	City of Cape Town	1979	180	9.4	1,700
Thermal energy storage[28]					
KaXu Solar One	Abengoa	2015	100	2.5	250
Khi Solar One	Abengoa	2016	50	2	100
Bokpoort	ACWA Power	2016	50	9.3	465
Xina Solar One	Abengoa	2017	100	5.5	550
Ilanga 1	Karoshoek Solar One	2018	100	4.5	450
Kathu Solar Park	Kathu Solar Park Consortium	2019	100	4.5	450

*Total installed capacity less losses due to auxiliary power use and age of plant.

Note: Total construction periods of Eskom pumped hydro: Drakensberg (1974–1981), Palmiet (1983–1988), Ingula (2005–2017).

Sources: Abengoa, n.d.; Broughton & van der Walt, 2022; Eskom, n.d.-b, n.d.-c; 2011, 2022a; Kathu Solar Park, n.d.; National Renewable Energy Laboratory, n.d.

[28] These are all molten salt connected to concentrated solar power facilities.

Appendix D. Advanced-Stage Grid Battery Projects in South Africa

Table D1. Advanced-stage grid-located BESS projects in South Africa

Facility	BESS developer	Province	Proposed completion	Capacity (MW)*	Duration (hours)	Max energy storage (MWh)
Eskom BESS Phase 1				**199.04**		**833.16**
Skaapvlei	Pinggao	WC	June 2023	80	4	320
Pongola	Hyosung	KZN		40	4	160
Melkhout	**	EC		35	4	140
Hex	Hyosung	WC		20	5	100
Paleisheuwel	Pinggao	WC		9.5	4.7	45
Elandskop	Hyosung	KZN		8	4	32
Graafwater	Pinggao	WC		5	6	30
Rietfontein	**	NC		1.54	4	6.16
Eskom BESS Phase 2				**144**		**616**
Cuprum	Not issued to market yet	NC	Dec 2024	70	4	280
Kiwano		NC		40	5	200
Ashton		WC		17	4	68
Witzenberg		WC		17	4	68
RMI4P preferred bidder				**640**		**2,425**
Kenhardt 1-3	Scatec		2024	225	5.06	1,140
Oya Energy Hybrid Facility	To be finalized	WC	Unknown	40	4	160
Umoyilanga Energy		EC/NC		75	3	225

Facility	BESS developer	Province	Proposed completion	Capacity (MW)*	Duration (hours)	Max energy storage (MWh)
ACWA Power Project DAO	To be finalized	NC	Unknown	150	3	450
Mulilo Total Hydra Storage		NC		150	3	450

Abbreviations: RMI4P = Risk Mitigation Independent Power Producer Procurement Programme. WC = Western Cape, KZN = KwaZulu-Natal, EC = Eastern Cape, NC = Northern Cape.

* For RMI4P this is storage capacity not entire hybrid project

** In the market for re-tender.

Sources: Broughton & van der Walt, 2022; Creamer, 2022c; Eskom, 2022e; research interviews.

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