Battery Storage: Is the Middle East ready yet?

A joint study by Dii Desert Energy and Arthur D. Little

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Content

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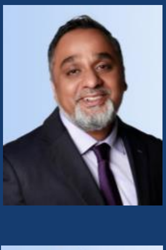

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About the report

The present piece is a joint study conducted by Dii Desert Energy and Arthur D. Little. The study analyzes the battery energy storage value chain, the players across this value chain, the use cases and their applicability, and the positioning of global benchmarks within this space; A close-up analysis on the MENA region is conducted to identify the current and future trends in energy storage in the region as well as the enumeration of the opportunities and challenges of the region in view of the growing global trends for the adoption of energy storage systems.

Dii Desert Energy

Launched in 2009 as an industry initiative in Germany (initially called 'Desertec Industrial Initiative') for exploring the potential of renewables in the desert areas of Northern Africa and the Middle East, improving market conditions and examining the synergies to be captured through connecting the European and MENA power markets.

In 10 years' time, Dii Desert Energy has grown from a rudimentary 'Desertec Vision', initially mainly concentrated on power from the deserts for Europe, (Desertec 1.0) via a focus on the conditions of renewables in the local markets (Desertec 2.0) toward a highly recognized market enabler for 'green electrons' and 'green molecules' from the deserts of MENA for MENA's own population, and for MENA to become a 'Power House' for the world markets (Desertec 3.0). Today, Dii Desert Energy are looking at the entire power system starting with various forms of Renewable Energy (RE) generation, grids, new technologies & innovations, energy storage, e-mobility, smart cities, towards the long-term objective of 'energy without emissions`.

Vision – Increased ***competitiveness of renewables*** shall swiftly lead to economic growth and secure 100% energy supply without harmful emissions or waste

Mission – Towards a ***fully emission free energy supply*** in MENA before 2050 and making MENA a 'power house' for the global energy markets offering benefits to the region

Strategy – Connecting the international industry active in the MENA region with authorities and institutions. Focus on practical conditions for ***'green electrons' and 'green molecules'*** along the energy value chains leading to tangible and profitable projects and other benefits for local and international stakeholders

Dear friends of emission-free technologies,

Storage of energy and power will be a key application for efficient and reliable energy systems based on wind and solar generation. With the global trend towards renewable energy, storage will grow out of the niche.

After a first glance at storage technologies and potential for cost reductions between 2011-2013 as an integral part of "Desert Power 2050", the Dii Storage Working Group 2.0 intends to give market insights and potential business models to provide guidance to project developers and decision makers in this promising business field.

Launched at the 9th Dii Desert Energy Leadership Summit in October 2018, we first highlighted the steep decline of costs of battery technologies, with much more to come. Now, the Dii Storage Working Group 2.0 is delighted to present this report together with our partners Arthur D. Little. This report offers valuable market knowledge and more importantly for the first-time concrete project examples and use cases with focus on battery applications in the Mena region. For further information please visit https://dii-desertenergy.org/

Special thanks from coordinators of this group to those who contributed to the success of this report.

Arthur D. Little

Arthur D. Little is a global management consulting firm that has been at the forefront of innovation since 1886. We are an acknowledged thought leader in linking strategy, innovation and transformation in technology-intensive and converging industries. We navigate our clients through changing business ecosystems to uncover new growth opportunities. We enable our clients to build innovation capabilities and transform their organization.

Our consultants have strong practical industry experience combined with excellent knowledge of key trends and dynamics. Arthur D. Little is present in the most important business centers around the world. We are proud to serve most of the Fortune 1000 companies, in addition to other leading firms and public sector organizations.

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Introduction and report overview

Variable Renewable energy deployment over the last decades has posed unprecedented challenges for the planning and operation of power systems. In the context of increasingly decentralized and intermittent generation, power utilities[1] and system operators need to rethink their portfolios, business models and positions in the market in order to be resilient to these changes and benefit from them.

Battery storage has gained strong interest as an option to respond to these new challenges and provide flexibility to the system to cope with high levels of renewables. Driven by increased usage in the automotive industry, costs of batteries have significantly dropped since 2010 (84% decrease for lithium-ion batteries[2]), although further cost reductions are necessary for widespread use in the power sector.

Actors all along the energy value chain find themselves facing a number of key questions when considering how energy storage may affect their businesses:

- In what applications will battery storage play a key role in managing the future grid?
- What will be the most attractive business models? For which (combination of) actor(s) along the value chain?
- What factors influence the choice of battery technologies?
- Which battery technologies will likely be the most important in each application?
- What are the drivers, enablers and alternatives to battery storage deployment?
- Where do MENA region countries fall within the global scene for battery storage deployment?
- How will the MENA region's deployment of renewables facilitate the deployment of storage?

In this report we respond to the above questions and describe the results of a study in which we have reviewed battery applications, battery types, drivers & barriers to battery storage and trends in key markets, with a specific focus on the MENA region, based on interviews with major market players in the energy sector. We have explicitly addressed what's in it for the different types of stakeholders along the value chain. The key conclusions of our study are summarized below:

Deployment of stand-alone batteries to provide grid services such as frequency response and frequency regulation has mainly been achieved in selected markets where ancillary services are attractive, as well as in the MENA region under pilot projects. Widespread deployment has been hindered by high costs and regulation uncertainty, but grid-scale storage for frequency regulation[3] is still seen as one of the most promising applications to date although the total market size in MW is limited. Large-scale hybrid battery configurations, to stabilize and manage the latency of renewables output, is the biggest driver of battery storage adoption in MENA. Finally, hybrid residential battery configurations have seen a significant boost in some markets, such as Germany, where incentives are put in place.

DSOs and TSOs can use batteries for grid-support applications such as congestion avoidance, frequency regulation, frequency response[4] and voltage stability, and tend to see co-ownership as the most likely option for making a positive business case. Indeed, all market players generally see the combination of several applications as essential to make battery solutions economically viable. However, system operators are only likely to make major moves when the regulatory framework for ownership and operation of storage technologies has been further clarified.

Compared to system operators, power utilities can leverage batteries for a wider range of applications and less constrained by regulation. They can potentially use batteries to generate revenues from arbitrage in the market, decrease exposure to imbalance costs and provide grid services to system operators. Vertically Integrated Utilities (VIUs)[5] can also deploy

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[1] For the purpose of this study the term "power utilities" includes generators (i.e. IPPs) and vertically integrated utilities (involved in generation, trading and retail), and excludes system operators, which are considered separate categories.

[2] Bloomberg New Energy Finance, 2018.

[3] Equivalent of FCR in ENTSOE terminology

[4] Equivalent of FRR in ENTSOE terminology

[5] Power utilities involved in several steps of the supply chain, including generation, trading and retail (e.g. Engie, EON).

batteries as part of their offerings to end-customers, this will likely be the case in the MENA region considering that energy markets are mainly led by VIUs in the region.

Partnerships between VIUs and aggregators as well as battery manufacturers/ system integrators and aggregators have been developed over the last few years to generate revenues primarily from ancillary services and the wholesale market with batteries at residential, commercial and industrial levels. The roles of aggregators continue to evolve, and the emergence of aggregators acting as software providers rather than technology operators is reshaping the position of VIUs in the market.

In conclusion while battery storage, globally, remains a market for early adopters today, with more mature business models for some players (e.g. power utilities) than others (e.g. system operators), time for inaction is over. For the MENA region, the introduction of renewables for purposes of energy sufficiency and sustainability will present a strong case for the deployment of energy storage and several countries are moving in that direction already.

Whenever the technology shall be cheap, it will belong to those who invested in its development. Once the regulation will be more facilitating, the opportunities will be captured by those who have a business model ready.

This is the moment for markets to be shaped, regulators to engage with and early strategic actions to be performed for actors along the energy value chain to make sure they will be part of the future framework and at the forefront of market trends.

1. Batteries to support the energy transition

The power grid is in the midst of unprecedented change. Large amounts of renewables are being added to the grid in many parts of the world, coal is increasingly disfavored, and there is a shift from the old centralized model of generation, transmission, and distribution to a more dynamic grid incorporating diversity of generation assets on a range of scales.

While generally positive from an environmental perspective, such changes present a number of challenges to grid operation, particularly for managing the integration of intermittent renewable generation technologies such as solar PV and wind. Among several solutions[6], energy storage will likely play a critical role in managing such challenges, for example, by smoothing the output from renewable sources and storing energy in times of high generation for later release when demand is strong.

Due to their flexibility, applicability on wide scale, and potential synergies with other applications such as electric vehicles, electrochemical storage technologies have received particular attention in recent years.

While the amount of battery storage installed remains marginal (~4 GW) today[7], the announcements of several large-scale commercial projects and some major transactions over last few years are clear signs that the sector is taking off.

Several models have emerged in which existing and new players in the power sector deploy and operate batteries to respond to the new challenges. Progress on both the technology and costs, as well as regulation fronts are required to clear uncertainties as to whether batteries are economically sound, and for whom.

This paper analyzes how battery storage can contribute to the energy transition and addresses:

1. The applications of batteries and business models across the value chain.
2. Subcategories of electrochemical batteries, their characteristics, costs and specific fields of application.
3. The drivers for battery deployment and diagnostics in key country archetypes.
4. The growing interest in the Middle East for their deployment.

Figure 1: Recent major transactions and alliances in the battery storage sector

ENGIE acquired 80% stake in California based energy storage company Green Charge Networks

Shell bought German BESS manufacturer Sonnen

Total acquired French based battery manufacturing company, Saft

Samsung electronics and Korea Electric Power Corporation set to jointly develop peak management pilot projects

Tesla acquires American battery manufacturer Maxwell technologies

Swell partnered with Verengo Solar to offer home battery storage solutions to end consumers

Freudenberg Sealing Technologies has become majority stakeholder in XALT Energy

Generac Power acquires Pika Energy

Tesla acquires Ontario based battery manufacturing specialist Hibar systems

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[6] Interconnection, Demand Side Management, flexible generation

[7] https://www.iea.org/newsroom/news/2019/february/battery-storage-is-almost-ready-to-play-the-flexibility-game.html

2. A business for all, except for system operator

Batteries can be used at different levels of the electricity system and in various applications, from providing grid-support services to generating revenues from price differences in wholesale markets. The main applications are briefly described below.

Table 1: The use cases for energy storage systems

Terms[8]	Description
Self-supply & TOU	Combined physically (hybrid systems) or virtually with distributed renewable sources, distributed storage behind the meter or on the distribution network allows at least partial self-sufficiency, resulting in decreased costs for grid supply and reduced exposure to price fluctuations. Savings could also be achieved by optimizing consumption based on time of use (TOU) and related price profiles Stand-alone, they improve reliability and power quality to end users in systems with poor security of supply or access to power supply
Arbitrage	Batteries potentially located at any level on the grid (distribution, transmission or behind the meter aggregated as a virtual asset) are used to exploit the wholesale electricity price spread and charge during off-peak periods while discharging in peak periods (peak shaving) *Note that Time of Use (TOU) included in the above application is also a form of arbitrage but operated by end- users (residentials, industrials).*
Frequency regulation[9]	Under normal operating conditions, continuous charge and discharge of batteries located at distribution or transmission can maintain demand and supply in balance and keep frequency within required limits
Frequency response[10]	Under contingency conditions, when system failure leads to major and sudden frequency variation, batteries are activated to restore primary control. Batteries at distribution, transmission or behind the meter are aggregated as virtual assets
Voltage stability	Batteries, at specific locations in the distribution and transmission network, release or absorb reactive power to maintain power quality locally
Congestion avoidance	Charge and discharge of batteries, at specific locations in the distribution and transmission network, enable postponing investments, remaining compliant during works on the network, and increasing renewable penetration where the limits of the grid are reached in order to avoid congestion at substations during local peak periods
Black start	Batteries, at specific locations in the distribution and transmission network, are used to energize pieces of the network when there is a black-out
Stable output	Batteries at distribution or transmission level, combined with intermittent renewables (e.g. wind, solar) enable the generator to smooth output to comply with regulatory duties or mitigate imbalance

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[8] Ancillary services/operating reserves required by TSOs/DNOs have been classified into frequency regulation, frequency response, voltage stability and black start. Planned/ strategic reserves (e.g. capacity mechanism) are considered as a way for batteries when operated under a specific application to capture additional revenues.

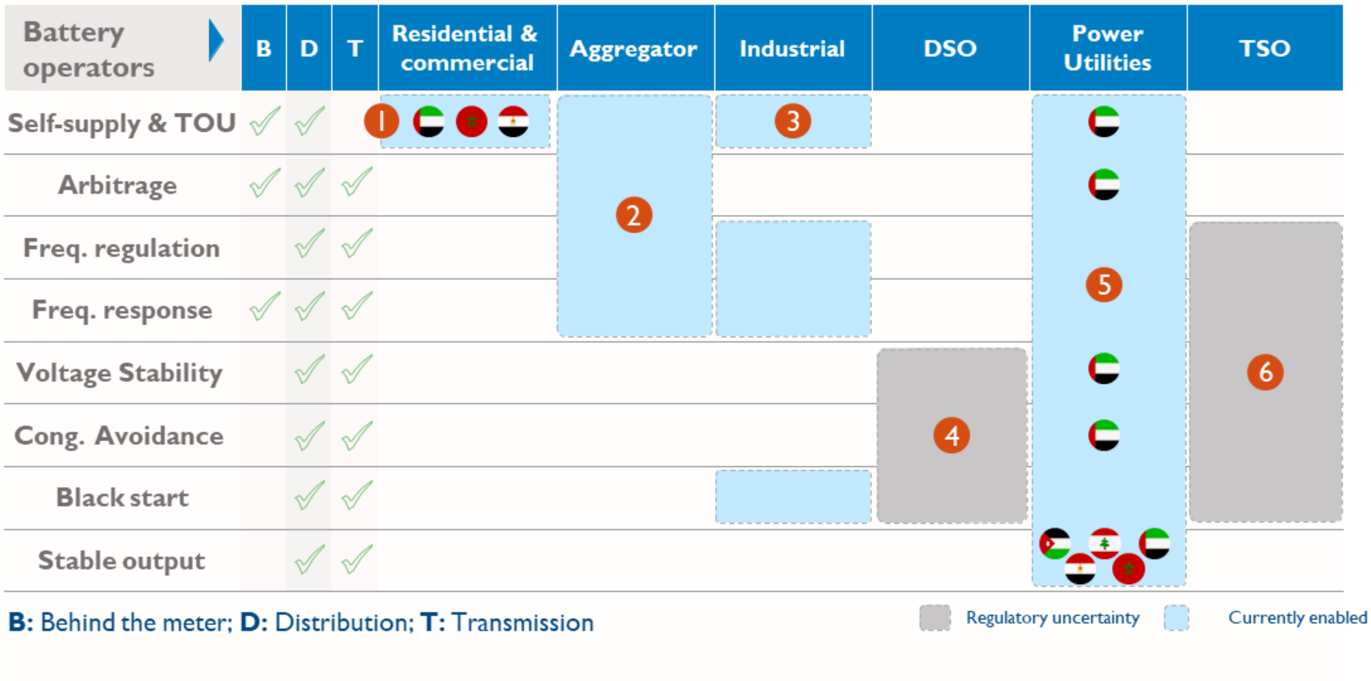
[9] Equivalent of FCR in ENTSOE terminology

[10] Equivalent of FFR in ENTSOE terminology

Most of the above applications can be clustered together based on energy requirements and the most demanding application, allowing the operator/owner of the battery to capture the value across several services. For example, a wind-farm operator would install a battery to stabilize its output and limit imbalance costs while also capturing revenues through the provision of ancillary services[11].

Figure 2 maps stakeholders across the value chain to the potential applications they will address when operating batteries. It also shows the positioning of MENA region countries across the value chain

Figure 2: Mapping of battery operators & key applications



Battery operators	B	D	T	Residential & commercial	Aggregator	Industrial	DSO	Power Utilities	TSO
Self-supply & TOU	✓	✓		①		③			
Arbitrage	✓	✓	✓		②				
Freq. regulation		✓	✓						
Freq. response	✓	✓	✓					⑤	
Voltage Stability		✓	✓						⑥
Cong. Avoidance		✓	✓				④		
Black start		✓	✓						
Stable output		✓	✓						

B: Behind the meter; **D:** Distribution; **T:** Transmission

Power utilities, and in particular vertically integrated utilities (VIUs)[12], are the only players in a position to address all major applications, from providing support to the grid to maximizing revenues from the wholesale market and operating batteries to optimize consumption. However, their ability to stack these applications strongly depends on the accessibility and definition of these services and the extent to which they are mutually exclusive.

The MENA market, considering that energy generation is still significantly centralized under power utilities, is perfectly positioned to integrate several applications for battery storage together. Most of the MENA region countries are incentivized to incorporate energy storage into their generation mix to stabilize output, especially renewables' output which is characterized with variability and dependence on the weather and time of the day.

It is also worth mentioning that the UAE seems to be ahead of the curve in terms of adoption of battery storage with applications at the power utilities level, as well as for residential and commercial

The same application often sees several competing models across the value chain (R&D, development, ownership, operation and maintenance). Ability to provide the services and possible structures or business models are discussed below:

Residential & commercial

Three main reasons can lead the residential & commercial sector to operate batteries:

- Poor security of supply, with frequent outages: battery is an emergency back-up if an outage occurs. However, the business case remains challenging and depends on the value of stable supply and loss load, which is especially hard to assess at residential level.
- Poor access to the main grid and the possibility, with battery storage combined with distributed generation, of remaining off-grid. Battery storage

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[11] Services identified as necessary by the transmission or distribution system operator to enable them to maintain the integrity, stability and power quality of the transmission or distribution grid

[12] Power utilities involved in several steps of the supply chain, including generation, trading and retail (e.g. Engie, EON, DEWA)

is, for example, installed in telecom towers and responds to the needs of telecommunication networks willing to expand to the remotest places in the world and provide uninterrupted supply. The telecom sector is the leading market for commercial use of battery storage so far and, as such, the market is expected to grow at 18% over the next five years[13] in key markets such as India and Africa.

- Desire to become more self-sufficient and reduce electricity costs by combining storage and distributed generation (e.g. PV panels) and increase self-production.

OEMs and system integrators[14] such as Tesla sell directly to end users or through the intermediary of official suppliers[15], which install the technology at the end user's premises. End users, in turn, operate and own or more often lease[16] the devices. A leasing business model for residential batteries can be particularly interesting in facilitating the combination of storage applications that span multiple stakeholders. In Germany, for example, residential hybrid PV/ battery systems are mainly used to increase self-consumption during summer months, and the batteries' usage rate is near zero during the first three months of the year. This means system operators could potentially use residential batteries for grid-support applications during this period. Such a business model could be facilitated through a leasing contract and enables residential and commercial customers to benefit from the use of batteries for other applications and improve the business case.

In Dubai, United Arab Emirates, Enerwhere, an Energy company has been leasing Tesla battery systems to construction sites to combine it with a PV-generator hybrid system operating on PV energy during the day and on the battery system at night and resorting to the hydrogen generator only if needed.

Other business models have been developed to leverage batteries owned by residential and commercial customers to capture price spread and/or ancillary revenues via aggregators and Vertically Integrated Utilities (VIUs).

> "Today, modern utilities and grid operators are utilizing battery technology like never before. The next step in tapping the potential of energy storage is putting together thousands of batteries to form an energy network that utilities can use to deliver immediate value for the electric system. For instance, Tesla can now bundle Powerwall and Powerpack batteries into a single portfolio, also called aggregation, to make the grid cleaner and more efficient. Meanwhile, Powerwall customers who allow Tesla and the utilities to use their battery when energy demand is highest will not only have home backup power, but will also receive compensation for its use on the grid"– Tesla & Green Mountain Power Program Announcement

Aggregators

The aggregator role has developed to fill the gap left by increasingly distributed generation that is unable to participate in the energy and ancillary services market. Aggregators effectively aggregate a large number of generation and demand sources into controllable power plants referred to as virtual power plants (VPPs).

The German, French, Belgian, UK markets have been incubating virtual power plants for several years now whilst the United Arab Emirates followed suit in early 2019. VPPs have started to become viable, but this evolution will accelerate by decreasing battery cost and involvement of strong players in the market such as Tesla. In Germany, Tesla and Sonnen signed deals with VPP player Lichtblick to link residential batteries to the control platform in 2015. Savings can be passed on to customers in multiple ways (not comprehensive): through direct payment to the end customers when the aggregator is using the scheme or fixed yearly payment (preferred models so far); under a profit-sharing model; or upfront as a discount on the battery investment costs (with the challenges that it poses in terms of forecasting reserve-auction results).

The provision of ancillary services by aggregators is a proven model tested through demand-side response for years now. Electricity trading by aggregators for arbitrage, on the other hand, faces more hurdles because of the volume of imbalances it can cause for balance-responsible parties (BRPs) prior to the settlement process.

Therefore, coordination between aggregators and BRPs is needed for aggregators to operate in a deregulated energy market (e.g. day-ahead or intraday). Aggregators

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[13] Research and markets, October 2018

[14] System integrators are responsible for packaging the batteries and adding auxiliaries such as control systems

[15] VIUs or distributors of battery solutions

[16] The leasing model is quite common for solar PV and CHP

have been working hand in hand with VIUs, which enable aggregators to not only overcome the balancing-responsibility issue mentioned above, but also channel their business propositions to end customers. However, as the market matures, we can observe a progressive split between aggregators willing to remain operators of flexibility in the system and those focusing more on selling the demand-response management software (e.g. AutoGrid Flex from Autogrid). This evolution might, in turn, fuel a shift for VIUs, which will reposition themselves in the market and offer these services without aggregators.

More specific to the commercial and industrial sectors, energy service providers (e.g. Dalkia, part of VIU EDF) have also acknowledged the potential of acting as aggregators. We can expect them to play an important role in leveraging additional value from battery storage building on their current client bases and further transform the aggregator landscape in the near future.

Industrials

Furthermore, this operator can be integrated into a VPP of a utility company the same way households are integrated, to cope with power-outage issues and become more self-sufficient, as well as reduce network charges where consumption is measured at certain times of the year. Industrials will either operate their battery storage themselves in the same way they participate in ancillary services or outsource the operation to power utilities or aggregators.

Depending on their size and the part of the network they are connected to, industrials could be partnering with Distribution System Operator (DSOs) and Transmission System Operators (TSOs) in order to optimize their consumption patterns while generating revenues from grid-support activities (e.g. voltage stability, black start). We see few applications of this business model to date, but it can be a particularly good alternative for system operators that have their hands tied regarding their roles in storage activities.

DSO

The integration of renewables poses a number of challenges for DSOs in terms of power quality and grid reinforcement to accommodate renewables at their maximum potential.

Renewables, being characterized by high variability and dependence on weather and time of the day lead unstable supply. The instability of supply makes the integration of renewables difficult to achieve without further grid reinforcement to thwart that variability. Batteries deployed in strategic locations of the network have the potential to relieve grid congestion and therefore avoid or postpone grid reinforcement. Battery storage, in this case, finds itself playing a role in the medium- and long-term operation and planning of the system. However, batteries today remain, in most markets, too expensive and do not present favorable economics relative to the critical time of use and/or alternative system-wide upgrades.

Another field of application for batteries is the provision of voltage control to improve the quality of supply, but this is likely to be only as part of a wider set of applications, given that it can be achieved through other, cheaper components of the network (e.g. stand-alone inverters).

In Europe, the unbundling of the sector has confined system operators (DSOs, TSOs) to owning and operating transmission and distribution assets only. It has not been clear so far whether some regulatory bodies consider battery storage a generation asset, but the European Commission (EC) in 2016 proposed a definition for energy storage and the principles of its deployment (see box page 16-17.) This will hopefully mark the end of a period of uncertainty regarding the exact roles that system operators can take with batteries. In the meantime, system operators are already considering innovative business models to deploy batteries without entering the energy market.

Examples of such business models are the deployment of batteries at complementary locations in the network (centralized and congested areas) in order to neutralize the charging and discharging effects on the energy market and avoid interacting with wholesale markets to balance the network (Tennet, the Netherlands).

Regulatory uncertainty so far and challenging business cases explain why the track record of commercial battery deployment for distribution-grid applications remains poor today. While many pilots have been running in Europe and worldwide to test the technology and its performance for specific applications, actual commissioning of battery solutions for commercial grid applications is limited.

The aforementioned regulatory uncertainty regarding TSOs and DSO in the MENA will not be a deterrent for the adoption of battery storage systems for system operators, mainly, because utilities are vertically integrated in many MENA countries and therefore, the integration of battery storage for TSOs and DSOs is anticipated to be smoother.

The vertically integrated utilities of the MENA region will take full advantage of deploying battery storage systems to respond initially to their grid stability requirements, but their integration will facilitate the use of these batteries across the entire chain from generation to distribution

> "The landmark deployment [of grid scale energy storage in Abu Dhabi] ensures sustainable energy supply across several key sites in Abu Dhabi as part of an integrated plan to secure sufficient electrical power production to meet growing demand for energy in the Emirates; the battery plant is expected to secure additional electricity supply for 6 hours using storage batteries" – Awaidha Murshed Al Marar, Chairman of the Department of Energy

Partly, TSOs and DSOs are not able to play in the energy storage space due to regulations and limitations by the EU, the U.K. or the U.S. However, in the Middle East (e.g. UAE, KSA), TSO/ DSOs are integrated with the power utilities which might disrupt the norm and offer opportunities for energy storage at the distribution or transmission level.

Power utilities[17]

Vertically Integrated Utilities (VIUs), being at the interface between end customers and system operators, have the potential to play a significant role in the battery market.

In their capacity as retailers, they act as enablers for deployment of residential battery storage. In adding battery storage as part of their energy services packages, VIUs aim at differentiating themselves and benefiting from extra revenue streams.

> Several VIUs in Germany are offering battery solutions to their customers. E.ON, for instance, released its home storage system combining PV, storage, app and tariff in April 2016. While Duke Energy announced that the company plans to invest USD 0.5bn in battery storage in the Carolinas, USA over the next 15 years.

> In the Middle East, the Dubai Electricity and Water Authority (DEWA), a vertically integrated utilities (VIU), has been testing the deployment of a 7.2 MWh NaS battery storage system manufactured by Japan's NGK Insulators connected to a utility-scale photovoltaic plant to provide stabilization of output of renewable energy. DEWA is testing the implementation a battery energy storage system to help stabilize renewable energy outputs, but it is expected that if the viability of the technology is proven, then there will be a great opportunity to dispatch the batteries across DEWA's distribution and transmission networks to improve overall grid reliability

> In Benelux Eneco has been supplying the Tesla Powerwall to its customers since the start of 2016. A couple of months later it expanded its services to CrowdNett with the support of Tesla, SolarEdge and Ampard. The software developed by Ampard allows controlling residential batteries remotely so they can participate in the provision of ancillary services. In exchange for the use of 30% of the battery capacity, residential customers receive 450€ in compensation guaranteed over the next five years.

Beyond the retail side, battery storage represents a key opportunity for VIUs and generators in the following applications:

1. Decrease exposure to imbalance charge from renewables intermittency
2. Increase stable energy supply for countries with unreliable grids
3. Optimize your CAPEX investment and utility assets load levelling to cater to peak power usage, i.e. consumers' peak shaving
4. Optimize asset production and sales in the wholesale market based on market signals (arbitrage)
5. Capture revenues from ancillary services and capacity mechanisms
6. Support industrial or consumer groups in reducing system charges, where these are calculated based on consumption at peak periods, and negotiate to receive a portion of this saving

Among the above applications, the first two represent the most promising opportunity in several Middle Eastern countries as a result of an increasing interest in the development of renewable energy generation capacity to meet energy demands as well as the interest in improving the unreliability of the grid by stabilizing output and suppressing energy outages

> Egypt is also emerging as a potential country with future opportunities deploying energy storage systems. The main drivers in Egypt are like Jordan's. Egypt's growing electricity demand and dependence on energy imports along with ambitious environmental targets is leading the country to the development of renewable energy + battery energy storage system to respond to

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[17] For the purpose of this study the term "power utilities" includes generators (i.e. IPPs) and vertically integrated utilities (involved in generation, trading and retail), and excludes system operators, which are considered separate categories

the intermittent renewable energy and ensure stable output

On the other side, another strong driver for the deployment of battery energy storage systems is the unreliability of the grid in certain MENA countries. The negative capacity margins are driving countries like Lebanon in the direction of developing more renewable capacity couple with energy storage

The Lebanese government is undertaking several projects to develop renewable photovoltaic + storage power plants working in collaboration of the European Bank for Development and Restructuring with an expected generation capacity of 300 MW and a storage capacity of 210 MWh

The third application is expected to find considerable success in markets where energy time shifting is necessary around peak demands and especially with the introduction of high variability renewable sources (e.g. Solar) in the generation mix.

In the MENA region, Jordan is emerging as a trail blazer in the development and deployment of solar + energy storage systems. Jordan has commissioned the first ever solar + energy storage plant based on Li- ion technology provided by Tesla and is amid tendering a second project for the development of a battery storage plant to be able to respond to energy demands, stabilize output and add flexibility to its grid. One of the main drivers in Jordan is the country's reliance on imports of energy, which is leading the country to invest significantly in the development of renewable + storage systems

The UAE government in Abu Dhabi inaugurated a battery storage plant in 2019. The NaS battery technology supplied by NGK insulators Ltd. The system is said to substitute an investment in a new thermal generation asset and respond mainly to peak demand needs with its 6-hour charge time. The NaS system was chosen over an alternative (e.g. Li-ion) for its longer discharge time while being able to stand high temperature with no need for air conditioning of the cells

The last two applications are good entry points for new entrants, aggregators, energy traders and merchant players to generate revenues of battery storage under a more opportunistic approach than incumbents.

The United Arab Emirates is probably the most advanced in the MENA region in terms of energy storage and on top of experimenting with battery energy systems, the UAE is also building the first of its kind pumped hydro storage plant

The Dubai Electricity and Water Authority in the UAE is developing a first of its kind project in the region to develop a pumped hydro storage plant of a capacity of 250 MW. The plant is designed to use and store water from the existing Hatta dam, which was built in the 1990s, for generating electricity during peak demand periods –

"Our use of hydroelectricity is part of our drive to achieve the objectives of the Dubai Clean Energy Strategy 2050, to transform the Emirate into a global hub for clean energy and green economy, and to increase the share of clean energy mix in Dubai to 75 per cent by 2050." – H.E. Saeed Mohammed Al Tayer, CEO of Dubai Electricity and Water Authority

The possibility for power utilities to combine revenues from multiple applications improves the battery business case but depends on market design specifics (e.g. provision of multiple services to multiple parties at the same time).

An example of production optimization/arbitrage can already be seen on a large scale in the US, where we expect that within four years the world's biggest storage capacity project in Los Angeles will be delivering over 100 MW for about four hours at peak period[18].

Finally, depending on local regulations, generators might have to comply with specific ramp-up and ramp-down profiles and therefore be obliged to couple intermittent generators with battery technologies on site. Islands are a good example of markets where such constraints have been put in place (e.g. Puerto Rico, La Réunion).

TSO

In the same way TSOs might contract with power utilities and large customers for ancillary services (frequency response, voltage control) and reserve (strategic reserve through capacity mechanisms), they could potentially meet their requirements by owning batteries.

However, similar to DSOs in Europe, the business models under which TSOs will be able to own and operate batteries remain to be defined in most countries. Market solutions are always preferred. The development and ownership of batteries by TSOs raise questions about market distortion and funding of regulated monopolies. But some players have highlighted the

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18 Scientific American, July 2016

necessity, when market conditions are not appropriate and a solution is required, to implement storage through a regulated solution (Red Electrica and ENTSO-E[19], Terna).

In Italy, the regulatory framework was adapted to allow for the TSO Terna to develop, own and operate batteries in the network. Two major pilots, respectively, of 40 MW in

Sicily and Sardinia (power-intensive projects) and 35 MW in South Italy (energy-intensive projects) have been installed are being led by Terna in collaboration with manufacturers universities and research companies to prove the applicability of batteries for system balancing, ancillary services, power quality and possibly tertiary reserve. The technologies under consideration include lithium-ion, flow and Sodium-Sulphur batteries from several different manufacturers. Such an early move by a TSO, before any regulation (national or European) would be elaborated, had multiple aims.

- investigate the available technologies and assess them through direct on-site operational comparisons;
- develop from scratch design skills for installation of completely new devices into power substations;
- explore the path for large scale field installation of new devices with peculiar and possibly critical characteristics, also from the authorization and permitting point of view; in particular, local construction permitting and compliance to anti-fire rules were a painful first-of-a-kind experience;
- derive guidelines for subsequent applications on both technical performances and building/permitting procedures;
- learn how to use the capabilities of the batteries and to best exploit their specific characteristics, while preserving their integrity and lifetime;
- test the performances in field application and real duty cycles (according to grid operational needs), which turned to be quite different from the factory datasheets and laboratory test;
- develop procedures and operational handbooks for replication and improvement of subsequent installations;
- monitor the operation in long term real conditions to assess the degree of utilization, the performances over time, the maintenance and assistance required from manufacturers;
- monitor the usage and use cases, the rationale and specific value added, the technical and economic benefits for the system;
- evaluate the benefits against the investment cost on a life-cycle basis and assess the economic feasibility for the system.

On the last point detailed and periodic reporting is given to the Regulator, who had allowed the relevant investment to be treated within the Regulated Asset Base, on which TSO remuneration is calculated. This Regulatory Sandbox, in the form of Pilot Project, is essential for this kind of initiatives.

Again, transmission system operators such as National Grid and Tennet agree on the fact, to make the business case positive, multiple value streams and collaboration between different market players are required.

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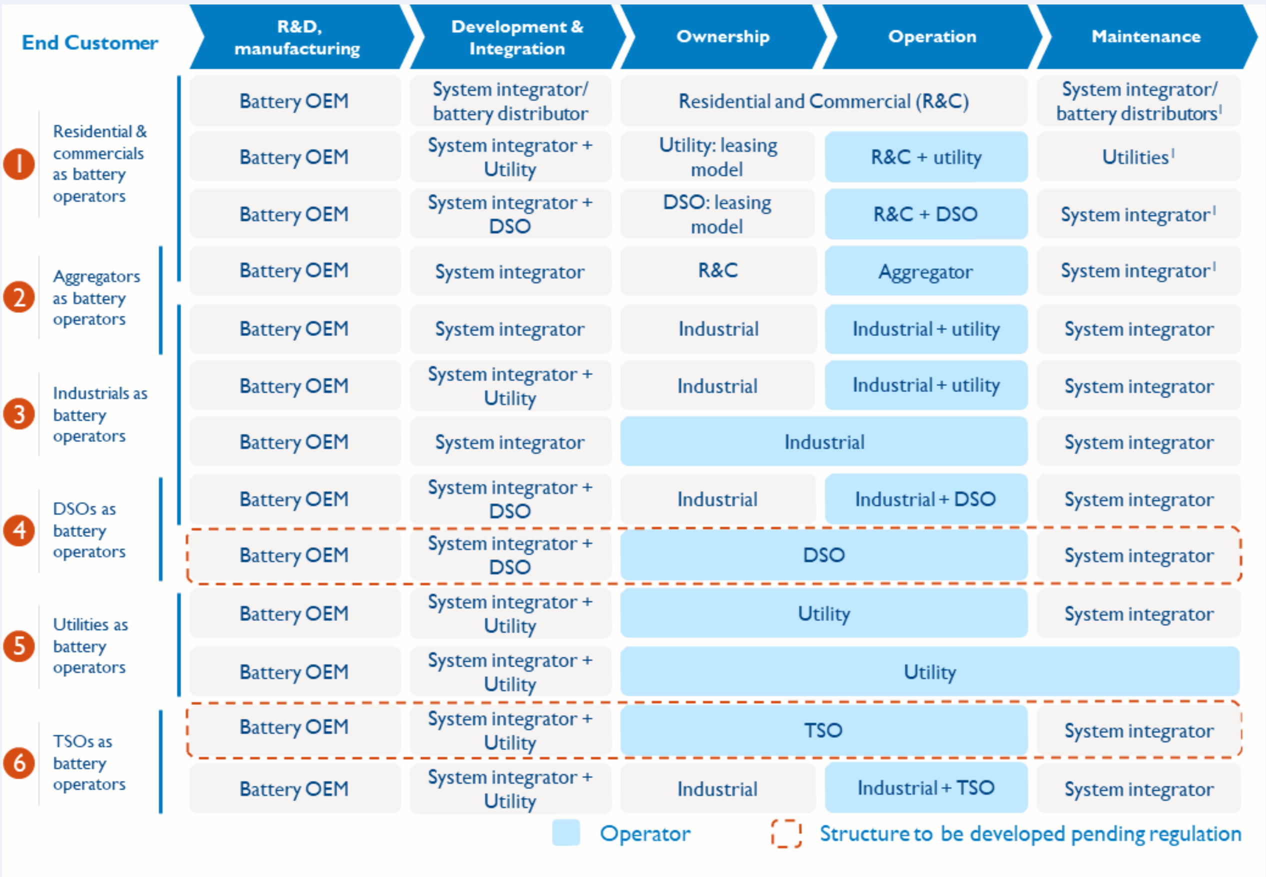
[19] Energy Storage, global conference – Brussels – 2016 regarding law adaptation for energy storage in Gran Canaria

Because of their scalability and the multitude of applications they address, batteries can be owned and operated by many market players. Figure 3 shows the position of key market players across the value chain and potential business models.

Figure 3: Potential business models across the value chain



End Customer	R&D, manufacturing	Development & Integration	Ownership	Operation	Maintenance
❶ Residential & commercials as battery operators	Battery OEM	System integrator/ battery distributor	Residential and Commercial (R&C)		System integrator/ battery distributors[1]
	Battery OEM	System integrator + Utility	Utility: leasing model	R&C + utility	Utilities[1]
	Battery OEM	System integrator + DSO	DSO: leasing model	R&C + DSO	System integrator[1]
② Aggregators as battery operators	Battery OEM	System integrator	R&C	Aggregator	System integrator[1]
③ Industrials as battery operators	Battery OEM	System integrator	Industrial	Industrial + utility	System integrator
	Battery OEM	System integrator + Utility	Industrial	Industrial + utility	System integrator
	Battery OEM	System integrator	Industrial		System integrator
④ DSOs as battery operators	Battery OEM	System integrator + DSO	Industrial	Industrial + DSO	System integrator
	Battery OEM	System integrator + DSO	DSO		System integrator
⑤ Utilities as battery operators	Battery OEM	System integrator + Utility	Utility		System integrator
	Battery OEM	System integrator + Utility	Utility		
⑥ TSOs as battery operators	Battery OEM	System integrator + Utility	TSO		System integrator
	Battery OEM	System integrator + Utility	Industrial	Industrial + TSO	System integrator

The gap in the regulatory framework regarding batteries in markets such as Europe has slowed down development of clear strategies and business models by system operators, but positive signs have been seen recently (ENTSOE, Ofgem, the European Commission) to establish a clear framework and market mechanisms for batteries.

1. To clarify the legislative framework in which batteries operate, the European Commission released the Electricity (EC) New Market Design Package in November 2016, providing clarifications on the role of system operators with respect to energy storage in their proposal for a revised electricity Directive. The EC states that *"Transmission system operators shall not be allowed to own, manage or operate energy storage facilities and shall not directly or indirectly control assets that provide ancillary services".*

However, under some conditions, TSOs could derogate from this obligation:

a) other parties, following an open and transparent tendering procedure, have not expressed their interest to own, control, manage or operate such facilities offering storage and/or non-frequency ancillary services to the transmission system operator;

b) *such facilities or non-frequency ancillary services are necessary for the transmission system operators to fulfil its obligations under this regulation for the efficient, reliable and secure operation of the transmission system and they are not used to sell electricity to the market; and*

c) *the regulatory authority has assessed the necessity of such derogation taking into account the conditions under points "a" and* "b" of this paragraph and has granted its approval."

In addition, the EC provides with a definition for energy storage as *"deferring an amount of the electricity that was* *generated to the moment of use, either as final energy or converted into another energy carrier".*

Despite those propositions, EASE (European Association for Storage of Energy) requests the EU to recognize energy storage as a separate asset class, alongside generation, transmission/ distribution and consumption to avoid the unwarranted double charging (energy imported from the grid and exported to the grid, including levies and taxes) imposed to storage facilities, which does not reflect the value of storage to the grid.

2. In the U.K., Office of Gas and Electricity Markets (Ofgem), released the "Smart systems and flexibility plan" aiming to remove barriers for smart technologies such as energy storage. Among the interventions of the plan:
    a) The definition of energy storage as a subset of the generation asset class. (Modifying license charges to exempt storage systems from final consumption levies)
    b) Clarify the frameworks for the co-location of storage with renewable energy generation plants without impacting existing agreements such as "Contracts for difference and feed-in-tariffs"
3. In the United States the Federal Regulatory Energy Commission (FERC) Orders 755/841/ 854 has mandated that
    a) Regional transmission organizations and independent system operators pay storage asset owners for providing ancillary services such as frequency regulation
    b) Market operators allow storage to provide every product that the resources are physically capable of providing capacity, energy, and ancillary services
    c) Revision of "generating facility" to include electricity storage explicitly by revising interconnection rule sand protocols for storage
4. In 2017, China released its first national level guiding policy document covering energy storage entitled: "Guiding opinions on Promising Energy Storage Technology and Industry Development" which is a document that is structured around:
    a) Affirm importance of energy storage in relation to development priorities such as smart grids, high renewable grid penetration and the internet of energy
    b) Set development goals and key tasks over the upcoming 10 years
    c) Outline necessary supporting policy directions to be enacted to achieve these goals including the definition of and establishment of policies governing pricing mechanisms, technology standards, IP protection, and battery material recycling. As well as listing out plans to bolster support from continued trial demonstrations, clarifying compensation mechanisms, guiding investments and continuation of power system, market reform
5. Establishment of pilot projects in countries that do not have significant utility-scale battery storage (e.g. South Africa, UAE)
    a) South African company secured a grant from the US Trade and Development Agency to develop a pilot project that demonstrates the performance of an energy storage system
    b) The UAE Virtual power plant pilot projects in Abu Dhabi and Dubai suggest that an update to the regulatory frameworks will be put in place in the near future to facilitate further deployment

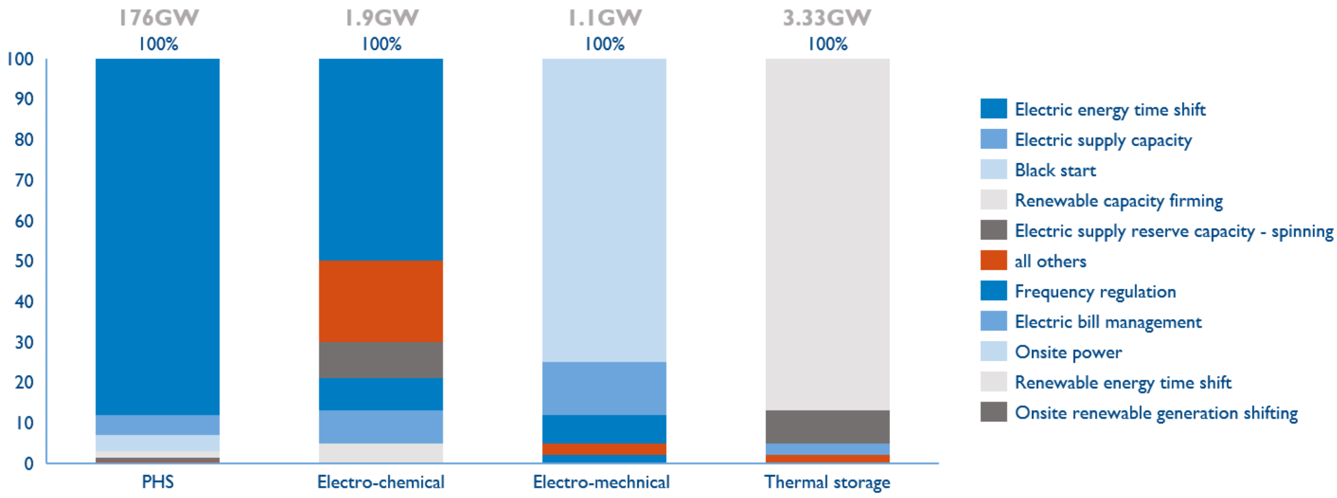
> "Power utilities, especially in MENA markets where utilities are mainly vertically integrated, are the only players in a position to address all major applications, from providing support to the grid to maximizing revenues from the wholesale market and operating batteries to optimize consumption."

3. High synergies with other sectors will push Li-Ion batteries

Technical features

Historically, pumped hydropower storage (PHS) has been dominating the energy storage industry due to its reliability and the fact that the technology for electrochemical storage was not attaining the performances that will make it a viable option. As of late, even though PHS is the runaway leader in terms of deployed capacity, new trends are underway within the energy storage space such as the rise of Chemical (e.g. Li-ion, NaS), Electro-mechanical (e.g. Compressed air energy storage (CAES)), and thermal energy storage. Figure 4 shows a distribution of the global energy storage power broken down by technology group and by use case

Figure 4: Global energy storage power capacity by main use case and technology (mid 2017[20])



The numbers shown in Figure 4 are expected to grow at an exponential rate for Chemical (e.g. Li-ion, NaS), Electro-mechanical (e.g. Compressed air energy storage (CAES)), and thermal energy storage. Although Pumper Hydro Storage (PHS) is also expected to grow, the growth for PHS will be lower in comparison to the other technologies. Pumped hydro storage (PHS), although it has been the technology of choice for storage applications, has some disadvantages such as the requirement for water resources as well as the lack of portability of the system.

As per a Bloomberg 2019 energy outlook (Figure 4), energy storage market (all technologies excluding PHS) is expected to grow 122-fold (from 9 GW in 2019 to 1,095 GW in 2040) for the next two decades as a result of falling prices, strict environmental targets and improvement in the battery technologies. A strong contributor to the growth will be the growth in production of Li-ion batteries which will be benefiting from wide adoption of EVs and as a result their cost of production will drop significantly leading to a commoditization of the technology. The other technology that is expected to grow steadily during the forecast period is Sodium-Sulfur (NaS) battery technology; especially considering that the technology is receiving considerable interest in grid-scale applications where discharge time and reliability are of a prime concern. Flow batteries have started to move out of development phase – in fact China is building the largest energy storage systems with flow batteries and Australia is in talks to build a 50 MW grid scale flow battery storage facility. Solid state is promising, but the pace towards commercialization is frustratingly slow with several startups and established technology companies racing to develop and bring a solid-state battery to the market. For instance, Dyson decided to end its electric car development project and focus its manufacturing efforts on the development of solid-state batteries.

The rate of adoption of battery storage system is set to increase in the future, driven by several factors, the expectation is that other regions of the globe – Marked as

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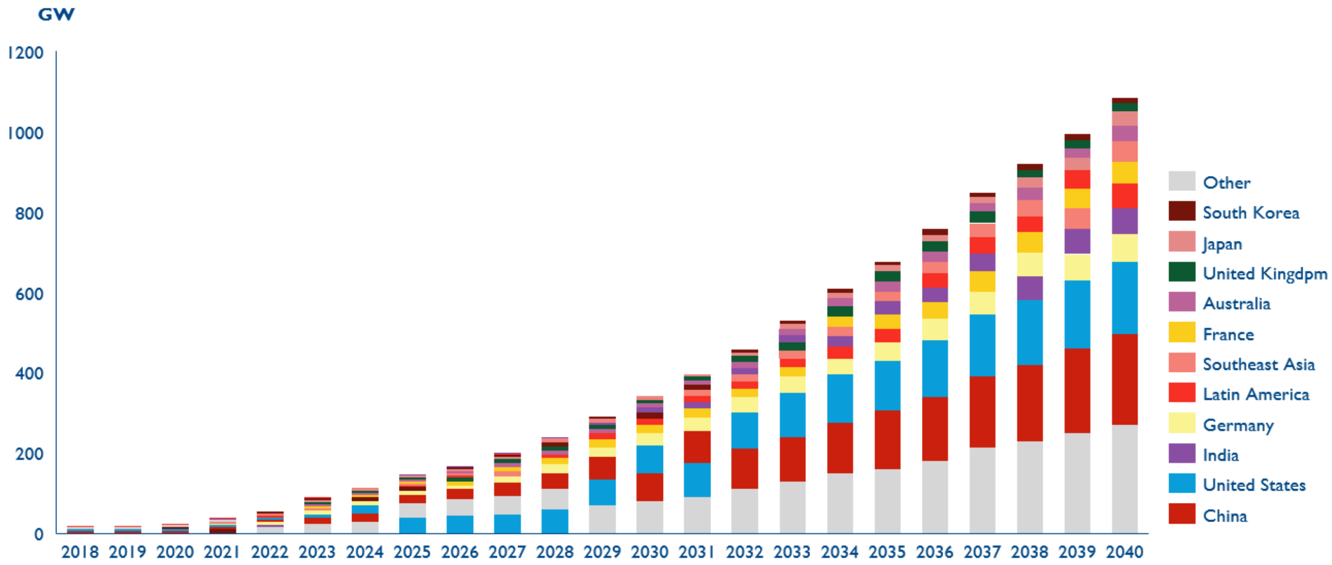
[20] IRENA Energy Storage outlook

“Other” on Figure 5 below – in which the MENA region falls, will record the most growth considering how nascent the market is today.

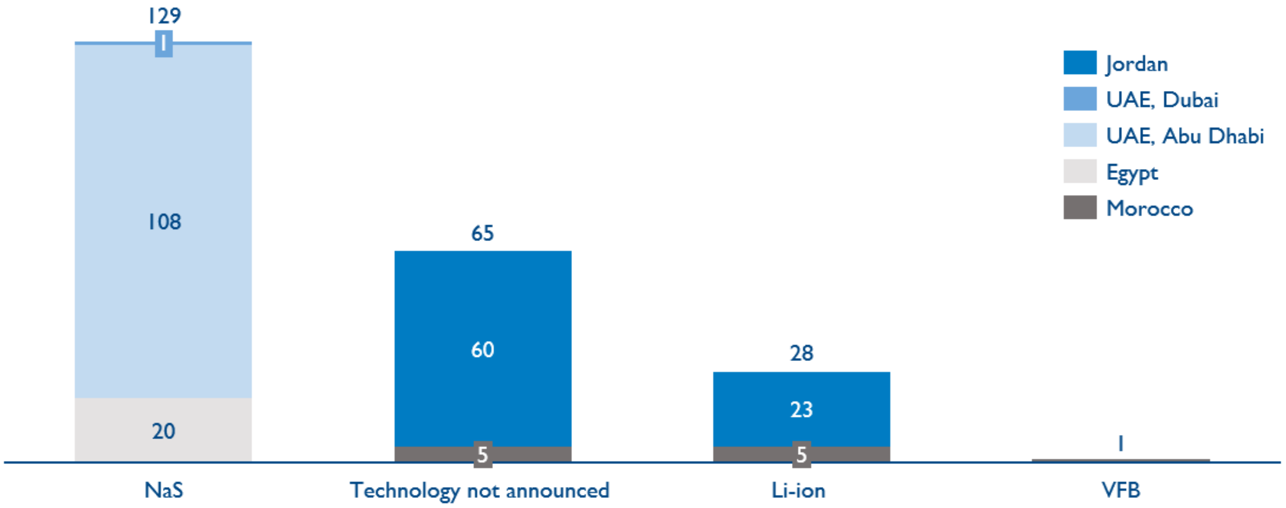
Figure 5: Growth of the energy storage capacity (excluding PHS) globally 2018-2040 (BNEF)



The growth in the adoption of energy storage systems will be seen in MENA – *Falling under the category “other” on Figure 5* – as a result of country policies to achieve more grid stability and strong push towards renewables. The UAE is already ahead of the curve in terms of deployed energy storage to support its grid during high demand hours with two NaS projects in Abu Dhabi and Dubai. Jordan, Morocco and Egypt, Lebanon have ambitious renewable energy targets and are working to achieve those targets through the construction of renewable energy plants and integrating them with energy storage for more reliability, and the stabilization of intermittent renewable energy sources.

KSA, although the country has very ambitious renewable targets as part of its vision 2030 and its high ambitions to diversify the energy mix and breakaway from its dependence on oil, has not seen any projects come to fruition. The country has signed a Memorandum of Understanding with Japan’s Softbank in 2018 for the development of 200 GW of renewable energy in the kingdom and EDF was anticipated to develop nearly 10 GW of energy storage, but the project has been dropped since and the country is not pursuing the development of large-scale energy storage projects as of now.

Figure 6: MENA region relevant chemical energy storage projects power capacity by technology and country (MW, ADL analysis)



The growth of the battery energy storage market will be seen around the world over the next two decades. This growth is mainly driven by countries' objectives to decrease their dependence on fossil fuels and the introduction of variable renewables into the energy generation mix. The introduction of intermittent renewables into the generation mix requires energy storage capabilities to keep supplying energy around-the-clock. This growth will be particularly observed, in electrochemical (e.g. Li-ion batteries), and thermal energy storage, through concentrated solar power (CSP) adoption, as a result of falling prices and improved technology. This growth will be witnessed in the MENA region as well, driven mainly by a desire from MENA countries to introduce more renewable energy into their energy mix to achieve environmental targets as well as achieving a more reliable and stable output from the grid

MENA countries adoption of renewables will be a major driver for the deployment of energy storage. Two archetypes manifest themselves in the MENA (Discussed in chapter 4) – countries with low capacity margin deploying renewables to increase their generation capacity and therefore they will resort to battery storage to ensure continuous output is delivered to the grid, as well as countries with a healthy capacity margin that will be adopting battery storage to couple them with their renewable plants in view of ambitious renewable energy targets. In either case, the expectation is that the MENA region will be deploying battery storage in the future.

For grid applications, three critical parameters characterize the performance of electrochemical storage technologies and are the most important in the selection of a technology:

- Power capacity rating is the rating of maximum continuous output/input being exchanged with the connected grid/device available to address flexibility needs
- Energy capacity rating, is the maximum amount of energy which can be stored in the battery, and it is expressed as discharge duration at rated power indicates how long a storage device can maintain its service to the connected grid/device output
- Response time is how quickly a storage plant can activate the energy exchange (charge or discharge) with the connected grid/device technology can be brought online and discharge energy

Potential applications for a given technology will depend on the balance between these parameters. For example, technologies with high power capabilities and rapid response but short discharge times will lend themselves to applications such as frequency regulation but will struggle with large-scale energy storage applications such as arbitrage. Conversely, technologies with very long discharge times but slow response times would be good for arbitrage or stabilizing output from renewables but may not be suitable for applications such as frequency response, which require rapid changes in output. Figure 7 maps applications to economically feasible power ratings and discharge times, and also indicates where some of the major technologies (see discussion below) are most applicable.

In addition to the main parameters, the following factors are important when considering an investment decision:

- Reliability, in terms of percentage of time that the capacity is available when needed. Utilities require >99% system availability
- Energy and power density, amount of power or energy stored per unit of volume and/or weight. Determines the practicality of a given application and technology combination particularly in space constrained environment.
- Calendar lifetime, time before the battery capacity decays below usable levels (usually a function of temperature, dynamics of operation and calendar time)
- Cycle lifetime, number of cycles (charge discharge) before the battery capacity drops below usable levels

Efficiency, in terms of delivered power versus input power including cooling and heating energy, >90% is desired, >75% is acceptable.

From a technology point of view, electrochemical systems encompass an array of chemistries, ranging from mature lead-acid and lithium-ion systems, to less well-developed approaches such as flow and Sodium-Sulphur batteries. The latter have been gaining in popularity and new projects in China (Flow battery), and UAE (NaS) are being implemented. Newer battery chemistries such as Zinc-air, Lithium-air, Sodium-ion and Lithium-Sulphur are emerging.

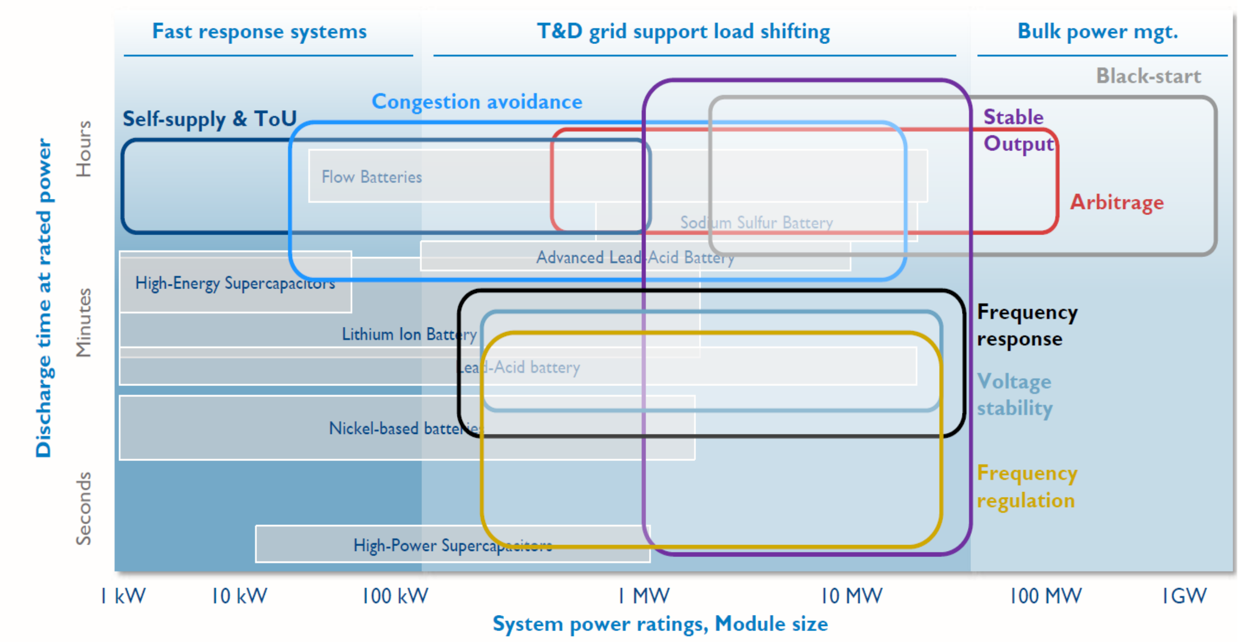
An overview of the cost of installing various batteries as well as future forecast is provided in Figure 8.

Due to strong synergies between power applications and both electric vehicles and consumer electronics, much of the recent focus of battery development has been on lithium-ion (Li-ion) batteries.

Indeed, Li-ion systems do have a number of advantages for grid applications, including high energy density, rapid response, very high efficiencies and flexible operation (discharge from seconds to four or five hours). These features enable lithium-ion batteries to be used for most applications in principle.

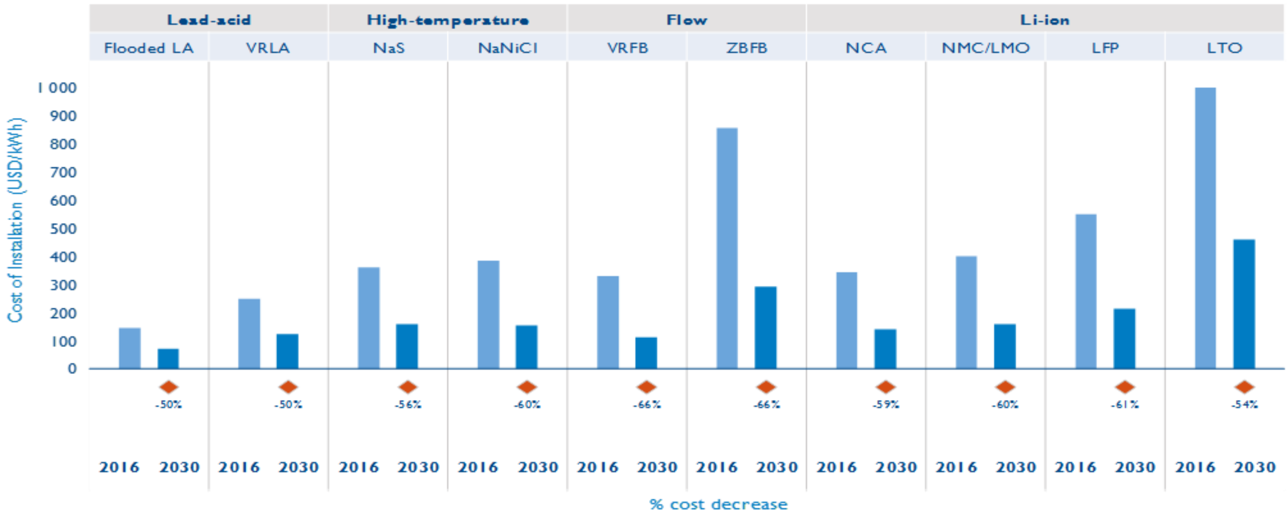
Furthermore, massive investment by companies such as Tesla/ Panasonic and LG Chem is pushing down costs (and raising production rapidly). For example, battery packs for vehicles from some of the major players decreased by 85% from 2010 to 2018[21] and they are expected to fall to even lower prices by 2020.

Figure 7: Mapping of battery technologies and supercapacitors: applications to key functionalities



Source: Purdue, Arthur D. Little analysis

Figure 8: Electro-chemical battery storage systems costs drops by 2030[22]



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[21] Source: Bloomberg

[22] The range of capital costs for Li-ion batteries varies significantly due to variants in cell chemistry. These variants have different trade-offs between energy density, efficiency, safety, lifetime, etc.

Improvements in technology, economies of scale and high demand for battery energy storage systems will be the main drivers of the price drop by 2030

Jordan has commissioned a photovoltaic + a 12 MWh energy storage system based on Tesla's Li-ion powerpack.

Nevertheless, Li-ion batteries do suffer from some disadvantages. They remain still expensive (in comparison to other energy sources), despite recent cost reductions. Additionally, safety remains an issue as electrodes are thermally unstable, which can lead to a thermal runaway. This means complex electronic circuitry is needed to reduce the prospect of fires or explosions to an acceptable level, which adds further cost. And finally, recycling of Li-ion batteries could be challenging for some countries that do not master the technology and processes, but other countries such as China and South Korea are emerging as solid players in the recycling of batteries. Disadvantages reduce the prospects for Li-ion batteries to be used in bulk energy-storage applications requiring many hours of storage capacity, e.g. back up for renewable energy sources. The Disadvantages of Li-ion batteries make them more attractive in European markets, as in the MENA region, their attractiveness is second to that of NaS considering that several grid-scale applications in MENA will require +4 hours of energy storage as well as robustness operating in high temperature environments

Despite poor lifetime and average efficiency, lead acid batteries remain the technology with the best cost/performance ratio today in terms of capital cost per kWh and kW. There is room for further cost reduction through mass production. Disadvantages of lead acid batteries include low energy density requiring batteries of larger dimensions and weight to produce the required energy. Another disadvantage is the risk of pollution from toxic chemicals content. The technology is mature, but new generations of advanced lead acid batteries with improved performance (e.g. lifetime, energy density) continue to be introduced. Lead acid batteries can be used in most applications except arbitrage, given their energy density and therefore limited discharge capabilities at rated output. Sodium-Sulphur (NaS) batteries have high power, high energy density and high discharge time, and are therefore particularly suitable for intraday energy applications (arbitrage, self-supply & TOU, stable output). The technology is approaching the maturity phase. NaS batteries rank average in terms of investment costs, efficiency and lifetime, leading to levelized costs on average higher than lead acid batteries, with less cost reduction potential than lithium-ion and lead acid batteries. However, NaS has the great advantage of being reliable operating in high temperatures, which makes the technology appealing to MENA markets

These characteristics of long discharge times along with high stability and reliability operating at high temperatures led to NaS being tested and implemented in the UAE where Dubai is testing an NaS energy storage system manufactured by Japan's NGK insulators of 7.2MWh for purposes of renewable energy integration While Abu Dhabi is deploying more than 648 MWh of NaS storage to defer investments in thermal generation assets.

Flow batteries are at the R&D stage. One of their main advantages is the decoupling of energy and power. The main drawbacks to date include poor efficiency, low energy density and the use of toxic chemicals. Maintenance and reliability are also significant concerns. Similar to NaS batteries, flow batteries are best suited for large-scale energy applications such as arbitrage and stable output applications.

Nickel-metal hydride (NiMH) batteries remain costly today, with generally poor performance regarding lifetime and efficiency. They are particularly suited for frequency-response, frequency regulation and voltage-stability applications. Safety under high-power charge or discharge is an advantage versus lithium-ion technologies, and strong resistance makes NiMH batteries the preferred technology for applications in the transportation sector and extreme conditions (e.g. remote, off-grid).

Supercapacitors, which store charge in an electrostatic field, compete with batteries in fast response, low duration services: they have very quick reaction time and very high cycle lifetime, making them particularly fit for frequency regulation applications. However, they have low energy density and their costs remain prohibitive today for energy applications.

Costs

Today, the cost of battery storage technology is too high for large capacity commercial deployments lasting for longer duration, other than where local regulations incentivize its deployment (See Section 5). Values of the installation cost of battery storage by technology vary and Lead acid leads the pack with an average cost between USD 150/kWh and USD 240/kWh, Li-ion's cost of installation varies between USD 400/ kWh and USD 600/kWh, whereas NaS's cost average is around USD 400, and finally flow battery's costs vary between USD300/ kWh and USD800/kWh.

Calculating costs is a complex exercise, since it depends on the application characteristics, the overall system configuration, and the average shape of the charge and discharge curves, in addition to the basic parameters of the battery system (capex, efficiency, lifetime, etc.). It is thus expressed as Levelized Cost of Storage (LCOS: total lifetime cost of battery divided by the cumulated stored energy. The LCOS can be used as a first indicator to compare costs between different battery types and broadly position batteries compared to more conventional generation. Since levelized costs highly depend on the applications, they should only be compared on this basis.

The LCOS of electrochemical storage technologies is a function of the upfront capital costs, lifetime (calendar and cycle), efficiency and characteristics of the application (e.g. O&M, Charging, etc.). The levelized cost ranges are wide, even within specific applications, however, as noted above the cost of batteries continues to fall, particularly in Li-ion, in which leading players are making huge investments in a bid to drive down costs and penetrate multiple markets. Assuming past learning rates continue, the best battery packs should become competitive with alternative energy extrapolation of learning rates is rather simplistic, since the costs of battery technologies are determined by factors such as raw material costs and the fundamental physics of electrochemical processes, which may limit the ultimate potential for cost reduction. This may push back the date of competitiveness with alternatives. Of course, economics are not the only determinant of technology choice; aspects such as safety and portability also play important roles and they vary per application.

Below, we show an example of an LCOS analysis for 1) a Standalone battery energy storage system (BESS), and 2) A BESS coupled with PV generation.

■ LCOS study of a battery storage energy system ***(Standalone)***

The Levelized Cost of Storage LCOS, analogous to Levelized Cost of Electricity (LCOE), is a metric that calculates the cost of generating electricity from an energy storage system by considering the CAPEX, OPEX, and charging costs and dividing it by discharged electricity in Watt-hours. LCOS is powerful because it includes calculations that include several variables such as (cost of equity/ debt), system configuration (generated electricity, percent uptime in a year, etc.).

$$LCOS = \frac{\sum(CAPEX_t + OPEX_t + Fuel_t) * (1+r)^{-t}}{\sum MWh_t * (1+r)^{-t}}$$

Where $(1+r)^{-t}$ is the discount factor for year t;

Standalone BESS Use-Case Description:

1. Purpose of report: rough estimation, benchmarking and research purposes.
2. The use-case is a pure storage project rated at 100 MW / 400 MWh.
3. The costing is based on a long list of assumptions (input parameters).
4. The plant is connected at HV (see use case schematic).
5. The use case assumes 1 cycle per day, 365 cycles per year.
6. The use case assumes 100% energy shift of surplus solar PV energy.
7. The energy charging source is assumed to be a nearby GW scale PV plant
8. The energy source cost is assumed to be USD 2 cents per kWh.
9. The model includes 1D and 2D sensitivity analysis tables & charts for various input parameters.

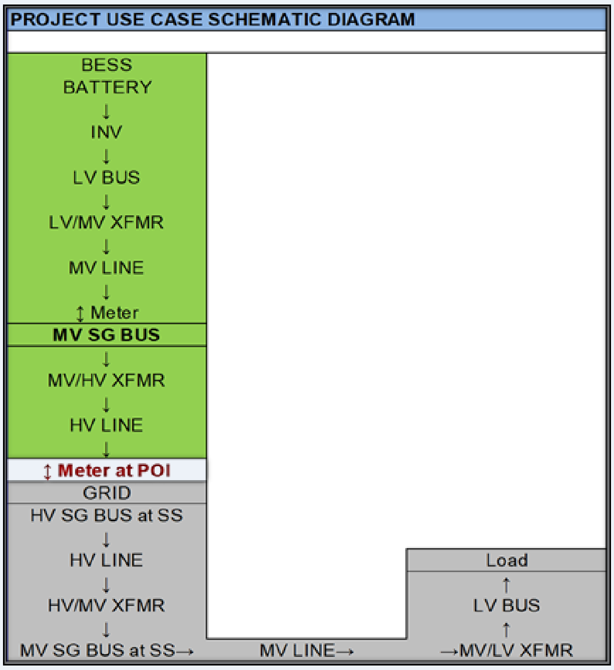
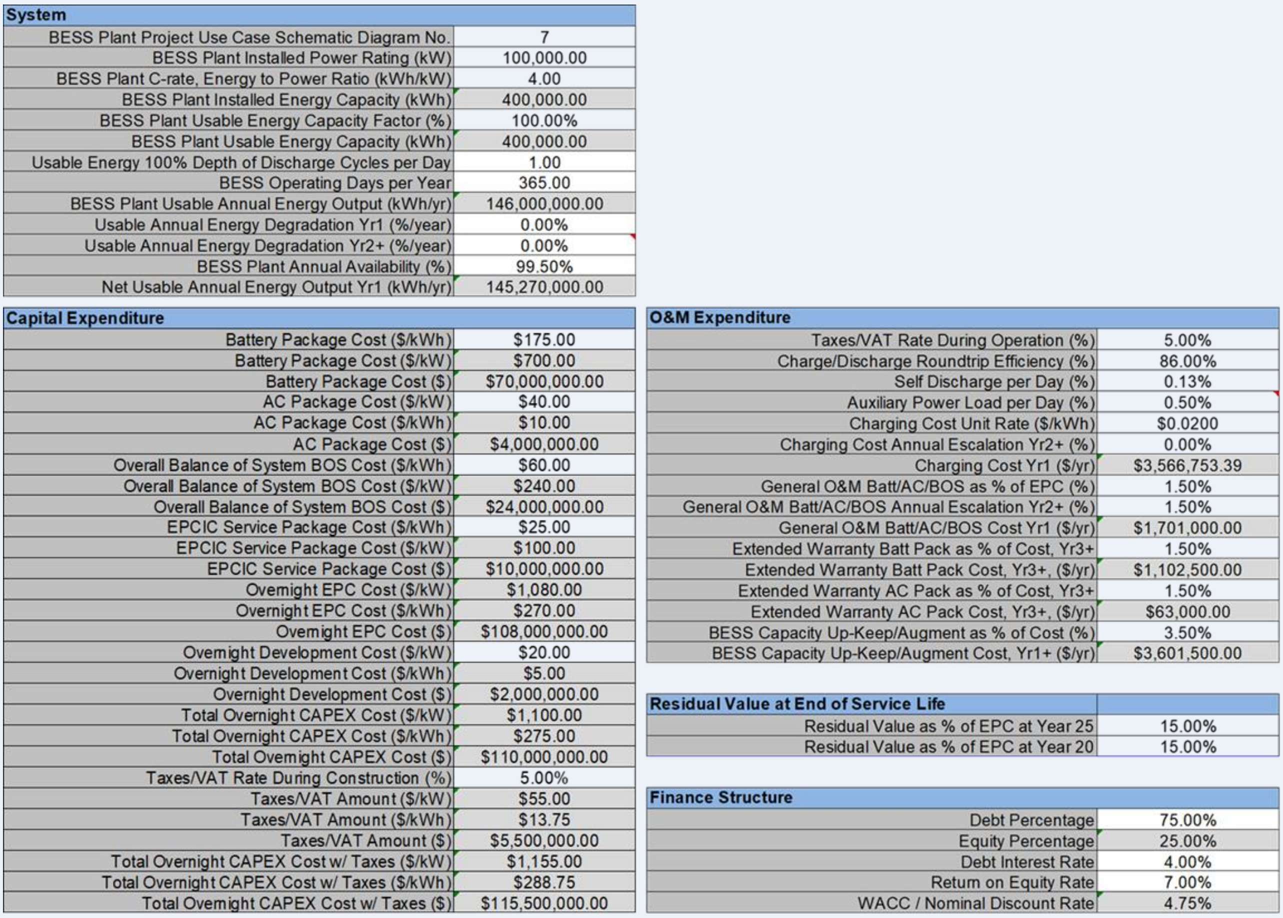


Exhibit -1: Key assumptions for the calculation of LCOS of a standalone battery energy storage system



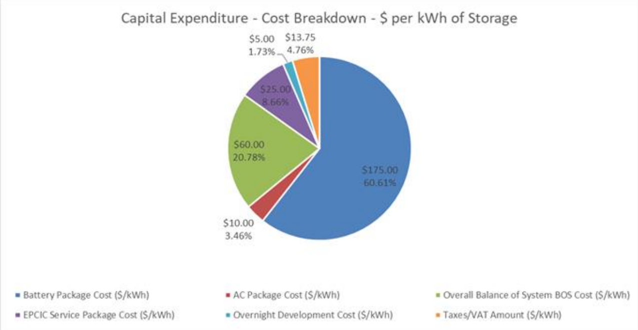
System	
BESS Plant Project Use Case Schematic Diagram No.	7
BESS Plant Installed Power Rating (kW)	100,000.00
BESS Plant C-rate, Energy to Power Ratio (kWh/kW)	4.00
BESS Plant Installed Energy Capacity (kWh)	400,000.00
BESS Plant Usable Energy Capacity Factor (%)	100.00%
BESS Plant Usable Energy Capacity (kWh)	400,000.00
Usable Energy 100% Depth of Discharge Cycles per Day	1.00
BESS Operating Days per Year	365.00
BESS Plant Usable Annual Energy Output (kWh/yr)	146,000,000.00
Usable Annual Energy Degradation Yr1 (%/year)	0.00%
Usable Annual Energy Degradation Yr2+ (%/year)	0.00%
BESS Plant Annual Availability (%)	99.50%
Net Usable Annual Energy Output Yr1 (kWh/yr)	145,270,000.00

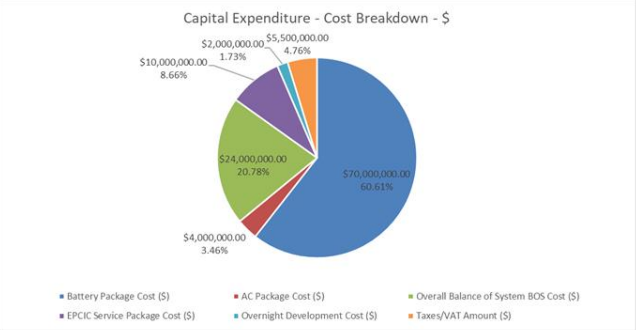
Capital Expenditure	
Battery Package Cost ($/kWh)	$175.00
Battery Package Cost ($/kW)	$700.00
Battery Package Cost ($)	$70,000,000.00
AC Package Cost ($/kW)	$40.00
AC Package Cost ($/kWh)	$10.00
AC Package Cost ($)	$4,000,000.00
Overall Balance of System BOS Cost ($/kWh)	$60.00
Overall Balance of System BOS Cost ($/kW)	$240.00
Overall Balance of System BOS Cost ($)	$24,000,000.00
EPCIC Service Package Cost ($/kWh)	$25.00
EPCIC Service Package Cost ($/kW)	$100.00
EPCIC Service Package Cost ($)	$10,000,000.00
Overnight EPC Cost ($/kW)	$1,080.00
Overnight EPC Cost ($/kWh)	$270.00
Overnight EPC Cost ($)	$108,000,000.00
Overnight Development Cost ($/kW)	$20.00
Overnight Development Cost ($/kWh)	$5.00
Overnight Development Cost ($)	$2,000,000.00
Total Overnight CAPEX Cost ($/kW)	$1,100.00
Total Overnight CAPEX Cost ($/kWh)	$275.00
Total Overnight CAPEX Cost ($)	$110,000,000.00
Taxes/VAT Rate During Construction (%)	5.00%
Taxes/VAT Amount ($/kW)	$55.00
Taxes/VAT Amount ($/kWh)	$13.75
Taxes/VAT Amount ($)	$5,500,000.00
Total Overnight CAPEX Cost w/ Taxes ($/kW)	$1,155.00
Total Overnight CAPEX Cost w/ Taxes ($/kWh)	$288.75
Total Overnight CAPEX Cost w/ Taxes ($)	$115,500,000.00

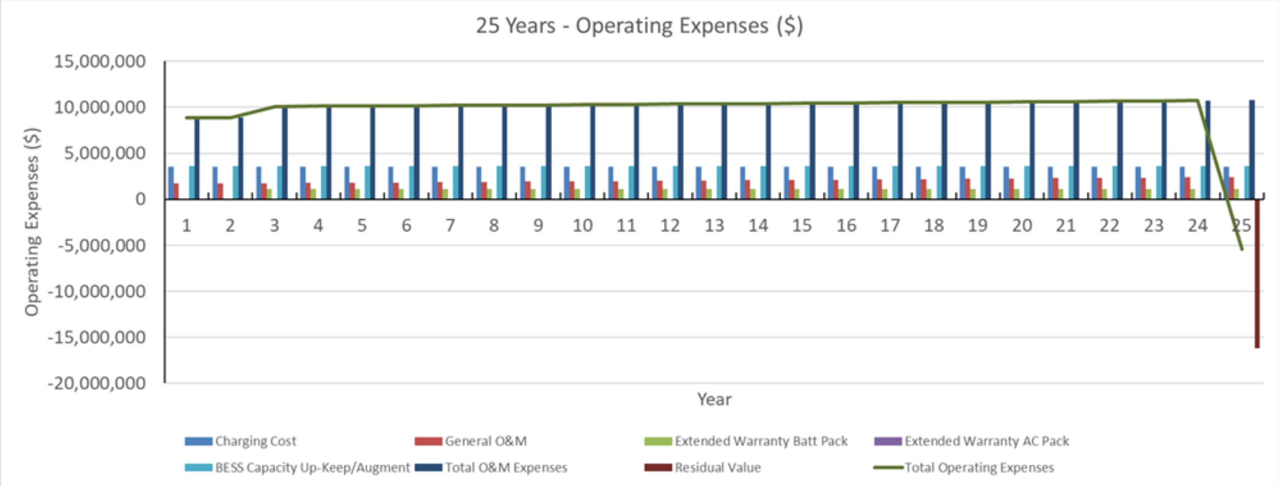
O&M Expenditure	
Taxes/VAT Rate During Operation (%)	5.00%
Charge/Discharge Roundtrip Efficiency (%)	86.00%
Self Discharge per Day (%)	0.13%
Auxiliary Power Load per Day (%)	0.50%
Charging Cost Unit Rate ($/kWh)	$0.0200
Charging Cost Annual Escalation Yr2+ (%)	0.00%
Charging Cost Yr1 ($/yr)	$3,566,753.39
General O&M Batt/AC/BOS as % of EPC (%)	1.50%
General O&M Batt/AC/BOS Annual Escalation Yr2+ (%)	1.50%
General O&M Batt/AC/BOS Cost Yr1 ($/yr)	$1,701,000.00
Extended Warranty Batt Pack as % of Cost, Yr3+	1.50%
Extended Warranty Batt Pack Cost, Yr3+, ($/yr)	$1,102,500.00
Extended Warranty AC Pack as % of Cost, Yr3+	1.50%
Extended Warranty AC Pack Cost, Yr3+, ($/yr)	$63,000.00
BESS Capacity Up-Keep/Augment as % of Cost (%)	3.50%
BESS Capacity Up-Keep/Augment Cost, Yr1+ ($/yr)	$3,601,500.00

Residual Value at End of Service Life	
Residual Value as % of EPC at Year 25	15.00%
Residual Value as % of EPC at Year 20	15.00%

Finance Structure	
Debt Percentage	75.00%
Equity Percentage	25.00%
Debt Interest Rate	4.00%
Return on Equity Rate	7.00%
WACC / Nominal Discount Rate	4.75%

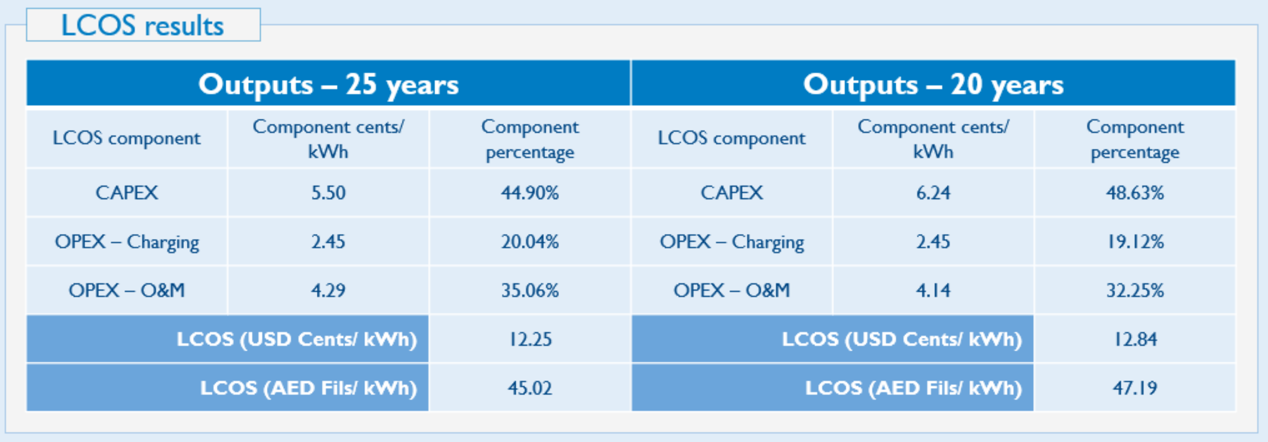






Source: F2M2 Financial Model by Fadi Maalouf

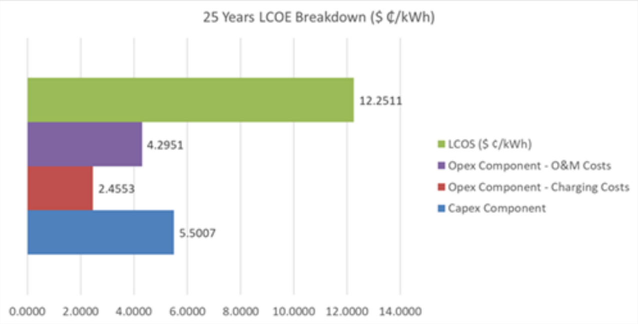
Exhibit -2: Results of LCOS analysis of a standalone battery energy storage system

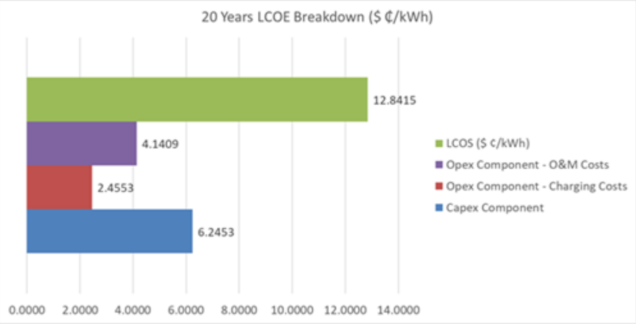


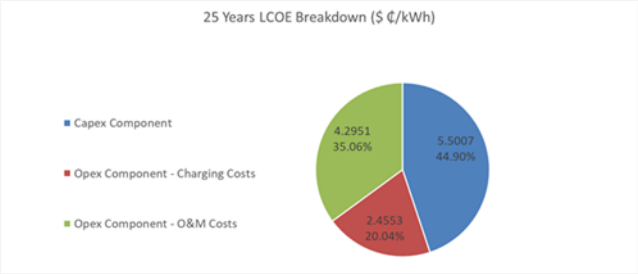
LCOS results

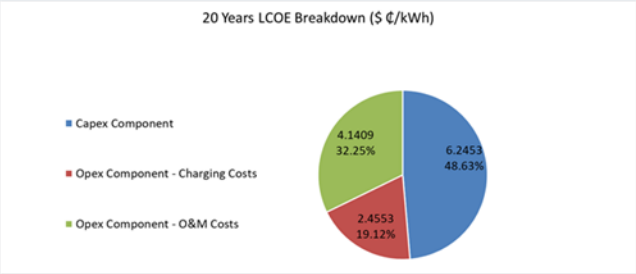
Outputs – 25 years			Outputs – 20 years		
LCOS component	Component cents/ kWh	Component percentage	LCOS component	Component cents/ kWh	Component percentage
CAPEX	5.50	44.90%	CAPEX	6.24	48.63%
OPEX – Charging	2.45	20.04%	OPEX – Charging	2.45	19.12%
OPEX – O&M	4.29	35.06%	OPEX – O&M	4.14	32.25%
LCOS (USD Cents/ kWh)		12.25	**LCOS (USD Cents/ kWh)**		12.84
LCOS (AED Fils/ kWh)		45.02	**LCOS (AED Fils/ kWh)**		47.19

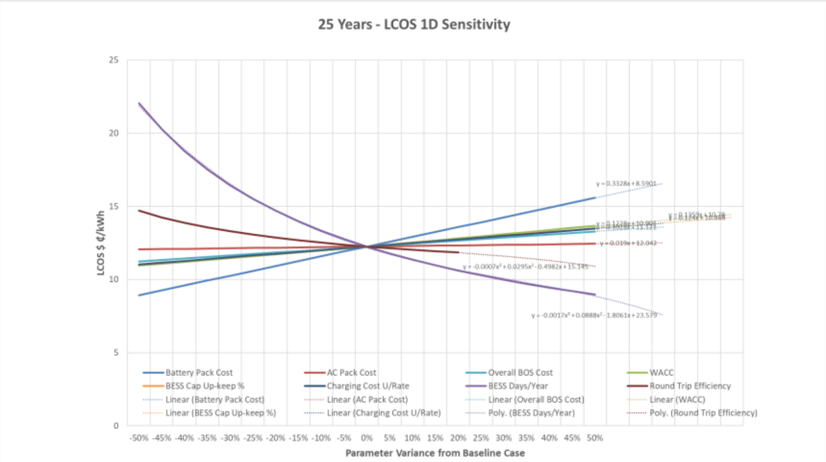
The LCOS calculations for the standalone system show that the BESS system under the assumptions of exhibit 1 achieves an LCOS of 12.25 $\text{USD}_{\text{cents/}}$ kWh for a 25 years project and 12.84 $\text{USD}_{\text{cents/}}$ kWh for a 20 years analysis period. Although promising, the BESS LCOS is still a bit more costly than the average LCOEs for most renewable energy sources (except for CSP) and standalone BESS will have to make some strides on the cost reduction front to be competitive with other sources as a standalone option. However, if additional revenue streams are added, e.g. grid services, then the same system LCOS/LCOE will go down significantly.











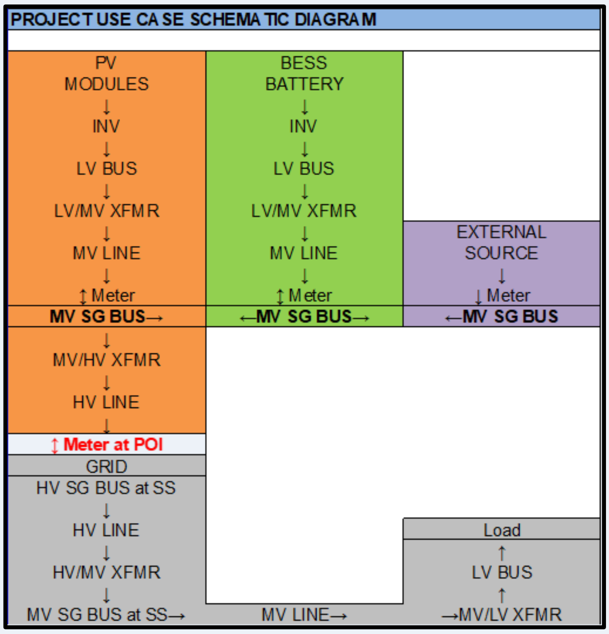
Source: F2M2 Financial Model by Fadi Maalouf

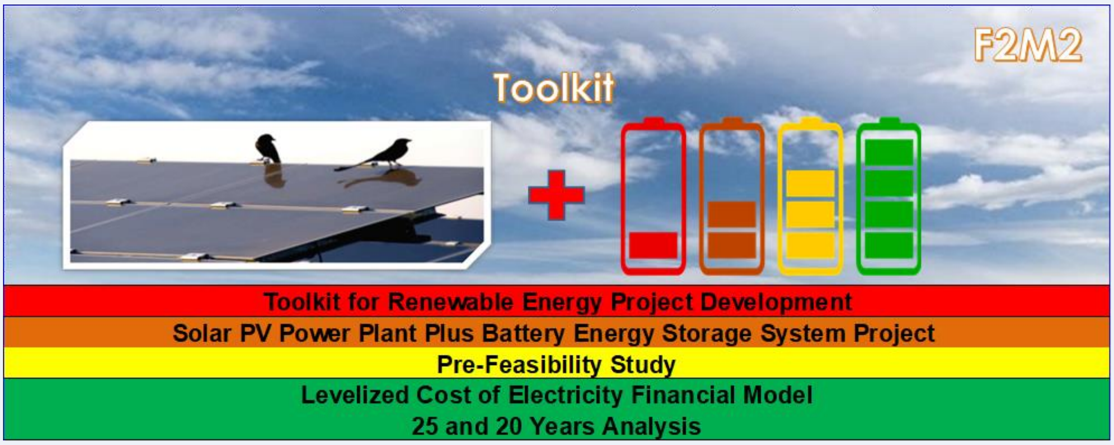
- LCOE study of a battery energy storage energy system ***coupled with a PV system***

For the second analysis, instead of having a standalone BESS, the system has a PV generator coupled to it and therefore, the metric that will be calculated is the LCOE. When you couple a BESS with a PV generation system, the charging costs can be reduced to zero as the PV system will be supplying energy to the BESS to store it for later use. This is a more realistic realization and it offers a more appealing business case as showing on exhibit 4.

PV + BESS Use-Case Description:

1. Purpose of report: rough estimation, benchmarking and research purposes.
2. The use -case is a solar PV plus BESS project:
    a. Solar PV: 192 MWp / 160 MWac.
    b. BESS: 100 MW / 400 MWh.
3. The costing is based on a long list of assumptions (input parameters).
4. The plant is connected at HV (see use case schematic page 7).
5. BESS is coupled at MV.
6. The model is built around “PU”, Per Unit, i.e.
    a. per unit of storage 1 kW / 4 kWh.
    b. coupled with 1.6 kWac / 1.92 KWp PV Plant.
    c. The estimated cost unit rates are based on utility scale (100+ MW).
7. General sizing estimate:
    a. if BESS AC capacity is “X”, and with 4 hours storage,
    b. then PV Plant AC capacity is “1.6X”,
    c. and PV Plant DC/AC ratio 1.2, and hence PV Plant DC capacity is “1.92X”.
8. Based on preliminary analysis, such setup is estimated to provide (90%-95% target period capacity factor):
    a. 6 hours firm “X” capacity form PV during day,
    b. and 3 hours firm “X” capacity from BESS during evening.
9. PV plant injects 71% of its production directly to gird.
10. PV plant supplies 29% of its production to BESS.
11. Overall Energy injection to grid percentage:
    a. PV: 76%.
    b. BESS: 24%.



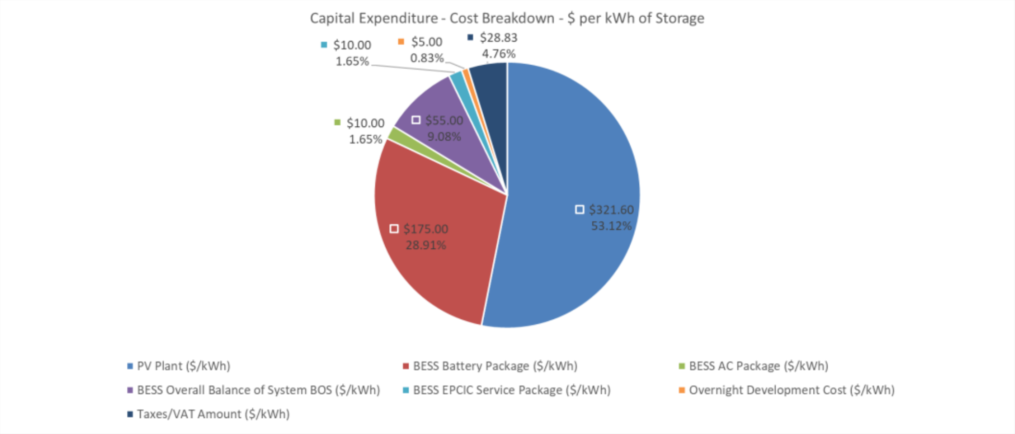


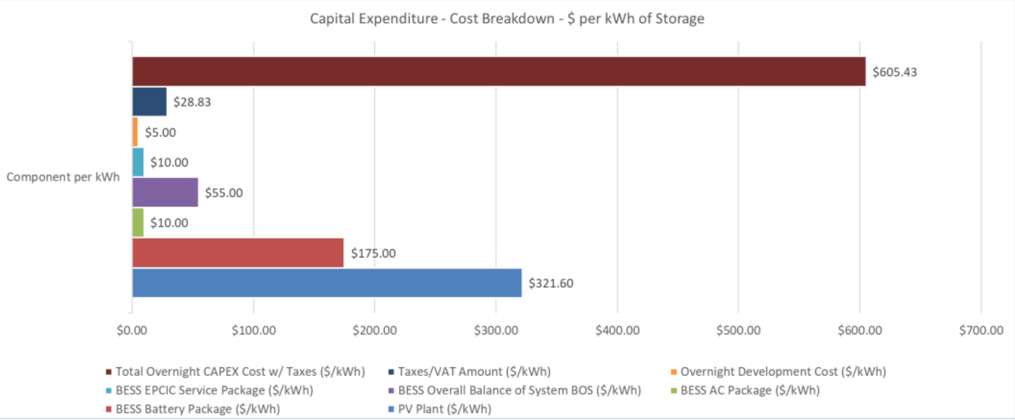
Source: F2M2 Financial Model by Fadi Maalouf

Exhibit -3: Key assumptions for the calculation of LCOE of a battery energy storage system + PV

System	
Project Use Case Schematic Diagram Number	1
PV	
PV Plant DC to AC Ratio	1.2
PV Plant Power Rating (kWp)	1.92
PV Plant Power Rating (kW AC)	1.60
PV Plant Annual Specific Energy Yield P50 (kWh/kWp)	2,567.77
PV Plant Installed Annual Energy Output (kWh)	4,930.11
PV Plant Annual Energy Degradation Yr1 (%/year)	0.00%
PV Plant Annual Energy Degradation Yr 2 to 25 (%/year)	0.00%
PV Plant Plant Annual Availability (%)	100.00%
PV Plant Net Annual Energy Output Yr1 (kWh)	4,930.11
PV Plant Net Annual Energy Output To Grid Yr1 (%)	71.34%
Other Losses (Auxiliary Loads, Curtailment, etc.) Yr1 (%)	2.10%
PV Plant Net Annual Energy Output To Storage Yr 1 (%)	26.56%
PV Plant Annual Energy Output To Grid Yr1 (kWh)	3,517.20
PV Plant Annual Energy Output To Other Losses Yr1 (kWh)	103.36
PV Plant Annual Energy Output To Storage Yr1 (kWh)	1,309.55
BESS	
BESS Plant Installed Power Rating (kW)	1.00
BESS Plant C-rate, Energy to Power Ratio (kWh/kW)	4.00
BESS Plant Installed Energy Capacity (kWh)	4.00
BESS Plant Usable Energy Capacity (kWh)	3.06
100% DoD of Usable Capacity - Cycles per Day	1.00
BESS Operating Days per Year	365.00
BESS Plant Usable Annual Energy Output (kWh/yr)	1,118.24
Usable Annual Energy Degradation Yr1 (%/year)	0.00%
Usable Annual Energy Degradation Yr2+ (%/year)	0.00%
BESS Plant Annual Availability (%)	100.00%
Net BESS Usable Annual Energy Output Yr1 (kWh/yr)	1,118.24
Charge/Discharge Roundtrip Efficiency (%)	86.00%
Self Discharge per Day (%)	0.13%
Auxiliary Power Load per Day (%)	0.50%
Required Annual Energy Input from PV Plant Yr1 (kWh/yr)	1,309.55
Net +Surplus/-Deficit Annual Energy Input Yr1 (%)	0.00%
Annual Energy Supply from External Source Yr1 (kWh/yr)	0.00
PV+BESS	
PV+BESS Annual Availability (%)	99.50%
PV+BESS Net Annual Energy Output Yr1 (kWh/yr)	4,612.26
PV Contribution (%)	75.88%
BESS Contribution (%)	24.12%
System Residual Value at End of Service Life	
Residual Value as % of EPC at Year 25	15.00%
Residual Value as % of EPC at Year 20	15.00%

Capital Expenditure	
Costs per kW of Storage or kWh of Storage	Note
PV Plant ($/kWp)	$670.00
PV Plant ($)	$1,286.40
PV Plant ($/kW)	$1,286.40
PV Plant ($/kWh)	$321.60
BESS Battery Package ($/kWh)	$175.00
BESS Battery Package ($/kW)	$700.00
BESS AC Package ($/kW)	$40.00
BESS AC Package ($/kWh)	$10.00
BESS Overall Balance of System BOS ($/kWh)	$55.00
BESS Overall Balance of System BOS ($/kW)	$220.00
BESS EPCIC Service Package ($/kWh)	$10.00
BESS EPCIC Service Package ($/kW)	$40.00
Overnight EPC Cost ($/kW)	$2,286.40
Overnight EPC Cost ($/kWh)	$571.60
Overnight Development Cost ($/kW)	$20.00
Overnight Development Cost ($/kWh)	$5.00
Total Overnight CAPEX Cost ($/kW)	$2,306.40
Total Overnight CAPEX Cost ($/kWh)	$576.60
Taxes & VAT Rate During Construction (%)	5.00%
Taxes/VAT Amount ($/kW)	$115.32
Taxes/VAT Amount ($/kWh)	$28.83
Total Overnight CAPEX Cost w/ Taxes ($/kW)	$2,421.72
Total Overnight CAPEX Cost w/ Taxes ($/kWh)	$605.43
O&M Expenditure	
Taxes/VAT Rate During Operation (%)	5.00%
External Energy Supply Cost Unit Rate ($/kWh)	$0.0000
External Energy Supply Cost Annual Escalation Yr2+ (%)	0.00%
External Energy Supply Cost Yr1 ($/yr)	$0.00
Gen. O&M PV/Batt/AC/BOS as % of EPC (%)	1.20%
Gen. O&M PV/Batt/AC/BOS Annual Escalation Yr2+ (%)	1.50%
Gen. O&M PV/Batt/AC/BOS Cost Yr1 ($/yr)	$28.81
Extended Warranty Battery Package as % of Cost, Yr3+	1.50%
Extended Warranty Battery Package Cost, Yr3+, ($/yr)	$11.03
Extended Warranty AC Package as % of Cost, Yr3+	1.50%
Extended Warranty AC Package Cost, Yr3+, ($/yr)	$0.63
BESS Capacity Up-Keep/Augment as % of Cost (%)	3.50%
BESS Capacity Up-Keep/Augment Cost, Yr1+ ($/yr)	$35.28
PV 0.55% Capacity Up-Keep/Augment as % of Cost, Yr2+ ($/yr)	80.00%
PV 0.55% Capacity Up-Keep/Augment Cost, Yr2+ ($/yr)	$5.94
Finance Structure	
Debt Percentage	75.00%
Equity Percentage	25.00%
Debt Interest Rate	4.00%
Return on Equity Rate	7.00%
WACC / Nominal Discount Rate	4.75%





Source: F2M2 Financial Model by Fadi Maalouf

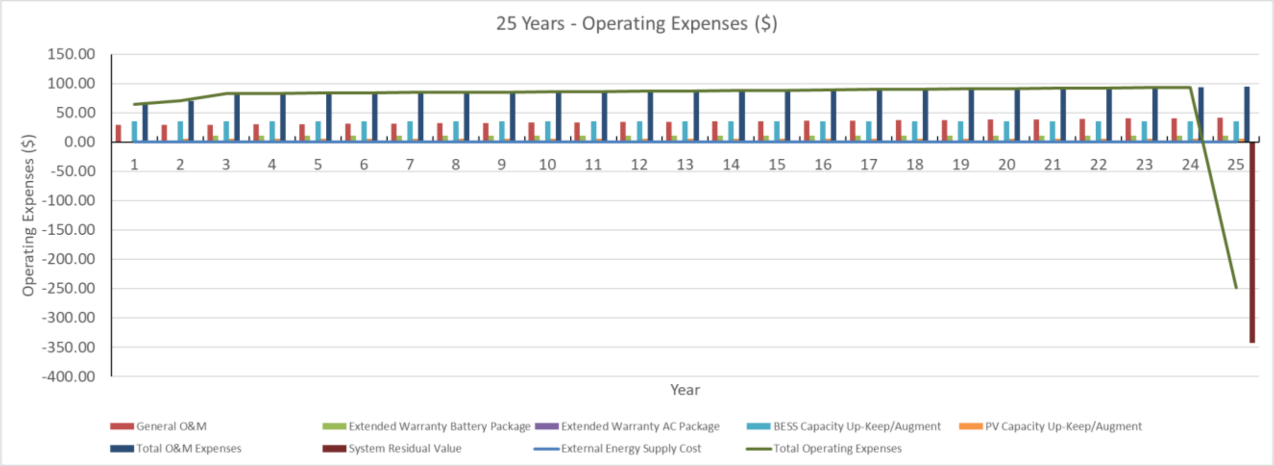
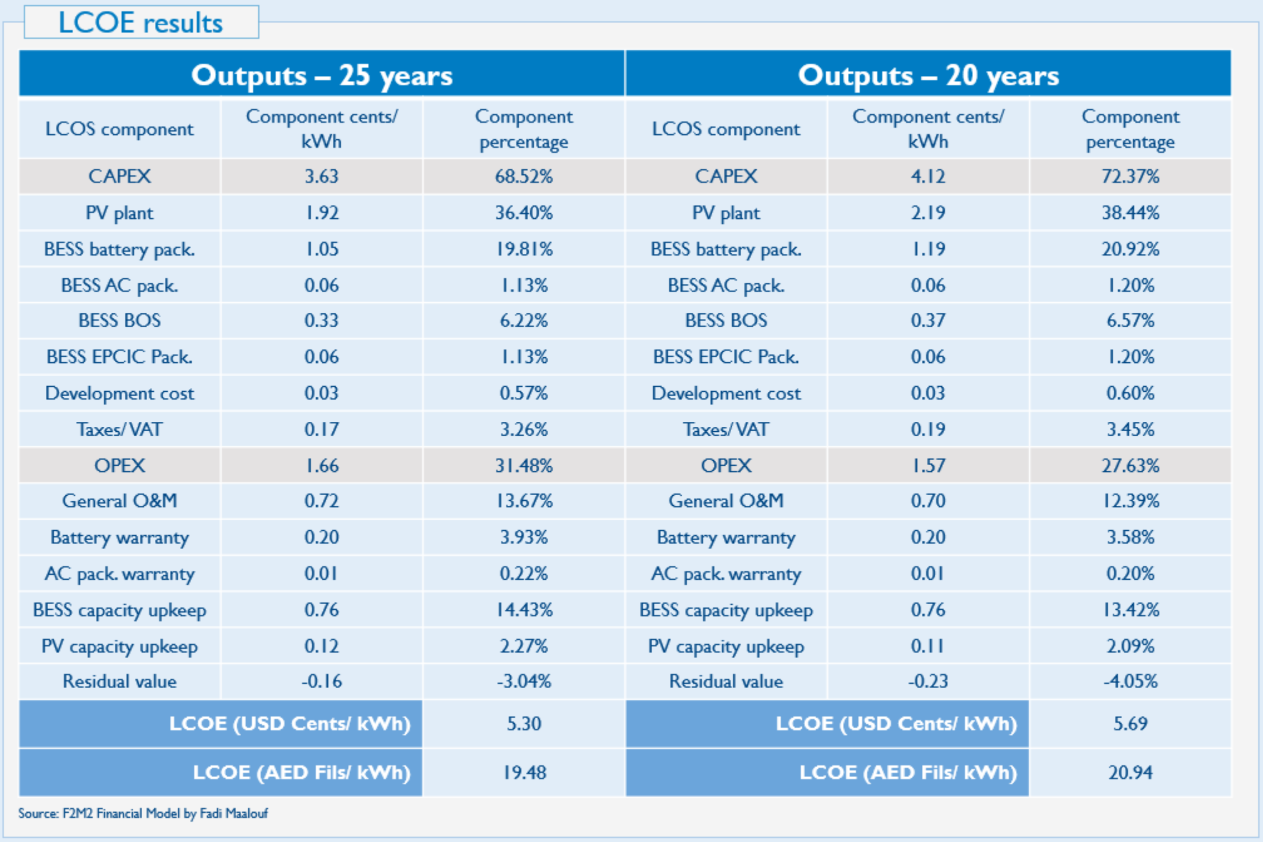


Exhibit -4: Results of LCOE analysis of a PV+ battery energy storage system



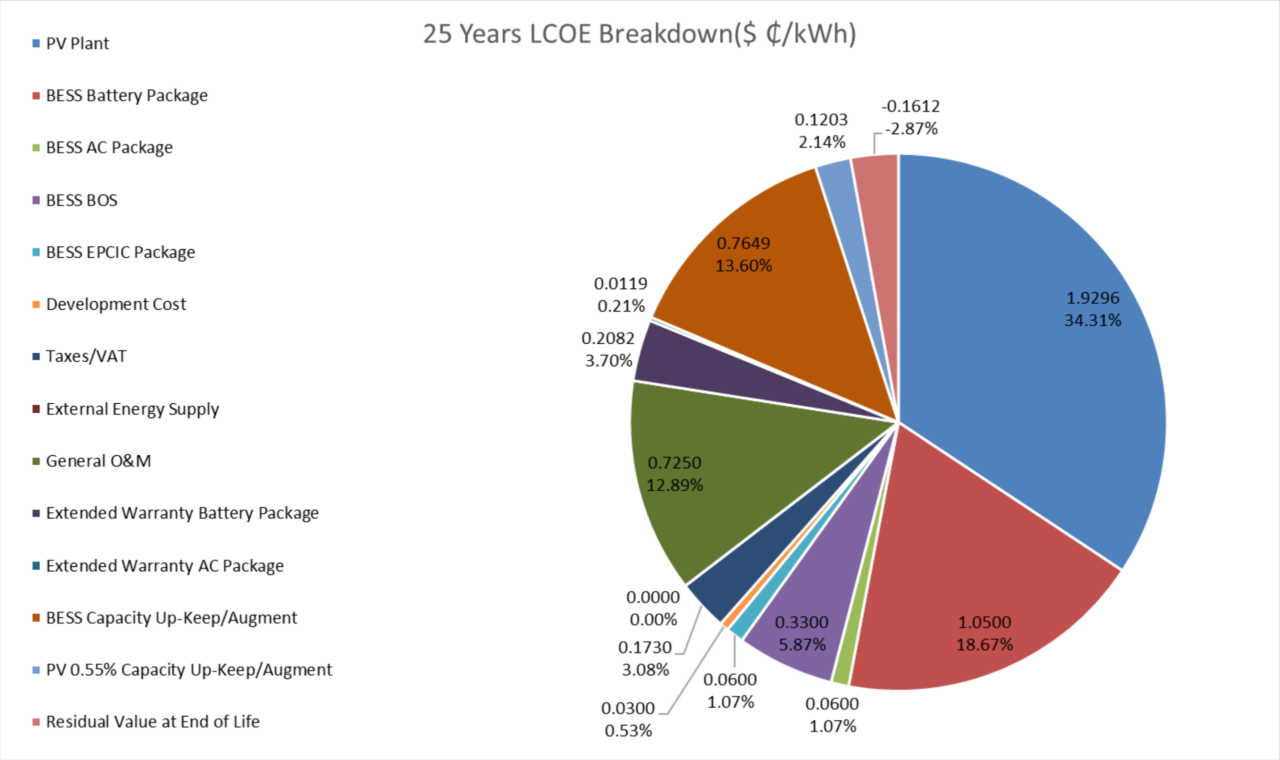
LCOE results

Outputs – 25 years			Outputs – 20 years		
LCOS component	Component cents/ kWh	Component percentage	LCOS component	Component cents/ kWh	Component percentage
CAPEX	3.63	68.52%	CAPEX	4.12	72.37%
PV plant	1.92	36.40%	PV plant	2.19	38.44%
BESS battery pack.	1.05	19.81%	BESS battery pack.	1.19	20.92%
BESS AC pack.	0.06	1.13%	BESS AC pack.	0.06	1.20%
BESS BOS	0.33	6.22%	BESS BOS	0.37	6.57%
BESS EPCIC Pack.	0.06	1.13%	BESS EPCIC Pack.	0.06	1.20%
Development cost	0.03	0.57%	Development cost	0.03	0.60%
Taxes/ VAT	0.17	3.26%	Taxes/ VAT	0.19	3.45%
OPEX	1.66	31.48%	OPEX	1.57	27.63%
General O&M	0.72	13.67%	General O&M	0.70	12.39%
Battery warranty	0.20	3.93%	Battery warranty	0.20	3.58%
AC pack. warranty	0.01	0.22%	AC pack. warranty	0.01	0.20%
BESS capacity upkeep	0.76	14.43%	BESS capacity upkeep	0.76	13.42%
PV capacity upkeep	0.12	2.27%	PV capacity upkeep	0.11	2.09%
Residual value	-0.16	-3.04%	Residual value	-0.23	-4.05%
LCOE (USD Cents/ kWh)		5.30	**LCOE (USD Cents/ kWh)**		5.69
LCOE (AED Fils/ kWh)		19.48	**LCOE (AED Fils/ kWh)**		20.94

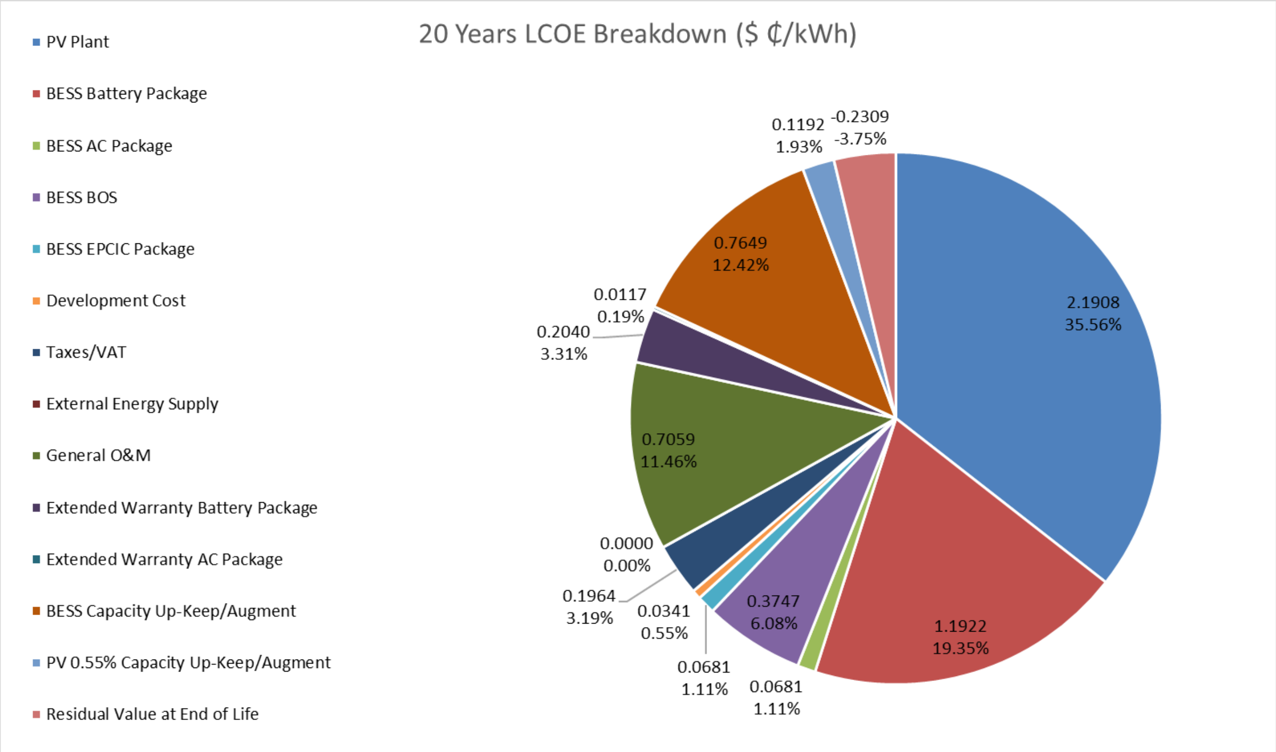
Source: F2M2 Financial Model by Fadi Maalouf

The LCOE calculations for the BESS+PV system show that the BESS system under the assumptions of exhibit 3 achieves an LCOE of 5.30 USD$_{\text{cents/}}$ kWh for a 25 years project and 5.69 USD$_{\text{cents/}}$ kWh for a 20 years analysis period. LCOE/ LCOS calculations for renewables + storage show that a viable business case can be obtained, which makes the adoption of energy storage seem like inevitable in the near future.

PV+BESS LCOE Breakdown



PV+BESS LCOE Breakdown



Source: F2M2 Financial Model by Fadi Maalouf

4. Local regulation decisive in giving the boost to battery deployment

To date, much of the development in battery technology has been driven by the consumer device and, recently automotive industries. However, the evolution of the energy market is rapidly escalating needs for storage technologies, meaning the power sector is likely to become a catalyst for cost reduction and technology development. Energy-market evolution calls for more flexibility in the network, which batteries can provide. The drivers for battery use in the power sector are discussed in more detail in the following section.

Fundamental drivers of battery storage

We have seen in the previous section that batteries can be used in various applications and by a broad range of market players.

The flexibility offered by batteries becomes even more valuable as renewable energies develop and constrain system operation and planning. But renewable penetration is not the only parameter driving the business case for storage in particular markets. Table 2 summarizes the key drivers for storage deployment and the applications they directly address

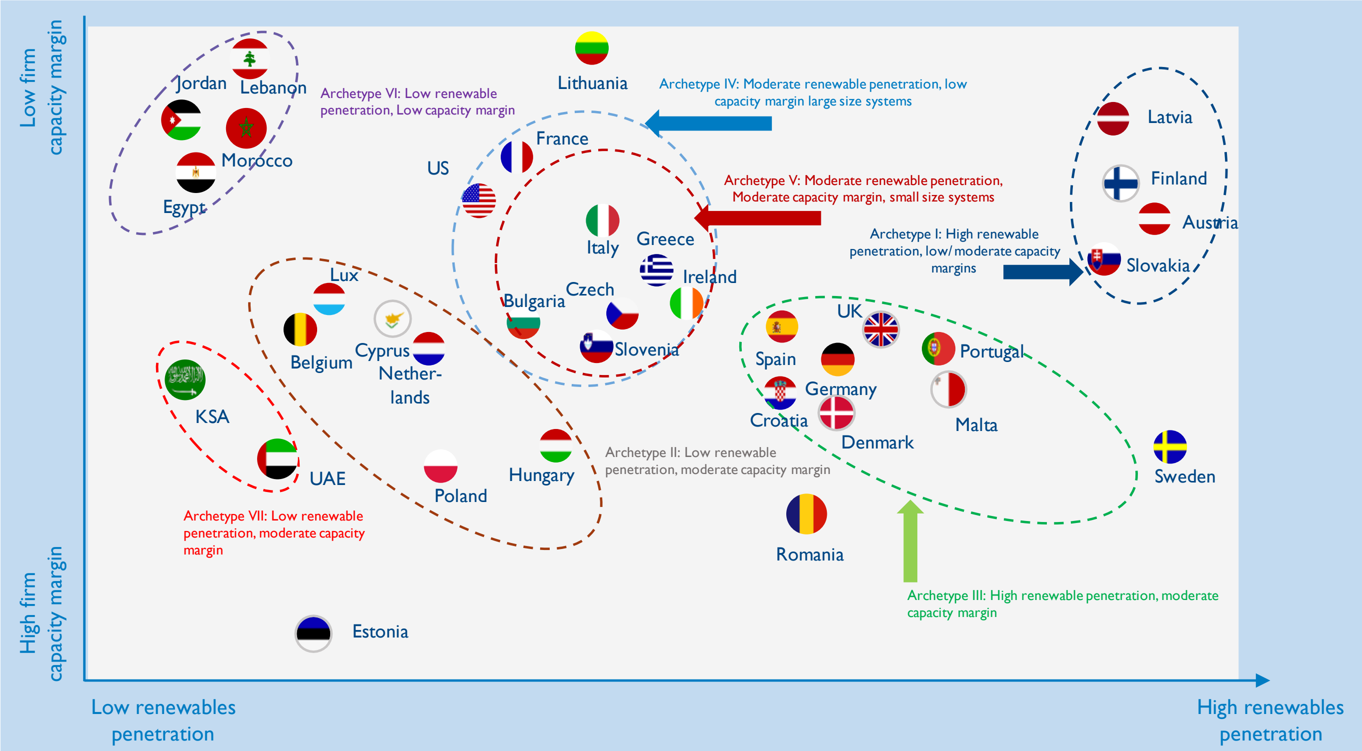
Table 2: Drivers of battery storage

	Drivers	Rationale	Key applications
1	**High grid-renewables penetration**	■ Need for further flexible generation to step in/out at short notice due to fluctuating, unpredictable power generation in the network ■ Tends to increase price differentials in the market through introduction of low marginal generation costs (see Driver 5)	■ Frequency response ■ Frequency regulation ■ Stable output
2	**Degree of physical decentralization of renewable generation assets**	■ Pressure on the distribution network to accommodate new and unpredictable generation capacity in the network	■ Frequency response ■ Frequency regulation ■ Stable output ■ Voltage stability ■ Congestion avoidance
3	**Low flexible capacity margin**	■ Reflects low flexibility in the system to accommodate intermittent renewables ■ Tends to go along with expensive generation at the margin, leading to high prices at peak periods (Driver 5) and high retail electricity prices (Driver 6)	■ Frequency response ■ Frequency regulation ■ Stable output ■ Peak shaving
4	**Poor security of supply**	■ Provision of enhanced security of supply with battery systems (coupled or not with renewables) at all times or during network outages	■ Self-supply & TOU
	Enablers		
5	**High peak/base-load price spread**	■ Benefits the battery-storage business case by increasing revenues from charging/ buying electricity during low price periods and selling/discharging during high price periods ■ Price spread is closely related to the generation mix, including renewable share and capacity margin	■ Arbitrage
6	**High electricity retail prices**	■ Incentives for optimized self-production through a combination of self- generation (from PV, for example) and storage (e.g. store surplus for later usage)	■ Self-supply & TOU

High renewable penetration (grid and distributed) and tight flexible-capacity margin have been identified as key drivers, conveying an indication of both flexibility needs and the underlying economics (e.g. price spread and retail prices).

A selection of countries has been mapped against these two drivers, allowing identification of high-potential countries for battery deployment, on Figure 9.

Figure 9: Countries mapped against key drivers of battery deployment[23]



Renewables penetration is the ratio of renewable energy generation to the total electricity produced in the country. The countries with the most appealing case are the countries that have a high renewable penetration as a higher renewables' penetration suggests that energy storage is inevitable. For instance, Germany is famous for developing a lot of renewables projects, but the penetration is still relatively lower. Germany is an interesting case for energy storage, and although the most interesting cases for energy storage are the ones with lower capacity margins and high renewable penetration, Germany is an exception to this rule

This framework highlights groups of countries that face similar constraints, representing potential for battery deployment.

Among these high-potential groups are countries at the forefront of storage development and deployment, such as Italy, the United States, the United Kingdom and Germany. On the other hand, other markets under similar conditions have, until now, only seen very limited development of batteries. This could be explained by:

The development of alternative storage technologies (hydro- storage and pump-storage plants, CAES, flywheels, power to gas) and/or alternative business models, providing indirectly similar flexibility services (e.g. interconnection, distributed conventional generators, DSR) as well as cross border flexibility as is the case for Germany. Despite high costs, key competitive advantages of battery storage compared to alternative storage technologies and business models are rapid deployment[31] (versus the development of connections, interconnections and hydro-storage) and reliability (versus demand-side management);

Lack of strong political involvement to clarify the regulatory framework and market mechanisms and lack of willingness to bring down the major cost barriers left today. Examples of levers include clarifying the role of TSOs and DSOs related to storage, reviewing the

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[23] Firm capacity margin evaluated based on installed intermittent capacity, incl. interconnection on peak demand; renewable penetration evaluated based on intermittent renewable installed capacity at peak demand

procurement of system services (eligibility and combination of services) and reconsidering taxes and fees on storage to avoid double charging (load and generation).

In the Middle East, the main drivers for the deployment of battery energy storage systems will be the adoption of renewable energy sources in countries with low capacity margins and high dependence on energy imports to meet their energy demands. The battery storage systems are starting to be deployed for the purposes of output stabilization and are mainly deployed at the generation side of the network.

Several Middle Eastern governments are putting in place policies to facilitate the adoption of renewable energy sources to be able to meet their energy needs and break away from the dependence on imports of energy. As an example, Lebanon relies on the imports of energy from Syria and Egypt through the interconnected grid. However, the instability in Syria and increase in the demand for energy in Lebanon led to serious issues with securing stable energy supply which is negatively impacting the economy of the country. This has led the country to adopt the resolution of increasing the supply of energy from renewable sources and rely on storage to ensure stability of output. Lebanon is planning on building 3 photovoltaic plants of 100 MW capacity each coupled with battery storage system of a minimum of 70 MWh each amounting to a total capacity of 300 MW with a storage capacity of 210 MWh. Lebanon battery storage tender is the largest in the region. The country sought the help of the European Bank of Reconstruction and Development to manage the tendering process for the construction projects and received 75 Letters of Interest in 2018.

Jordan is another Middle Eastern country that is expected to undertake several renewable energy projects that will lead to growth in the adoption of battery storage systems. Jordan’s growth in the use of renewable energy is motivated by the country’s desire to break away from the dependence on imported fuel for energy generation and therefore, the country has been working on the development of renewable energy plants. The country’s strong push for the adoption of renewable energy led to two projects; One project coupling photovoltaic generation with Li-ion battery energy systems of a storage capacity of 12.6 MWh and a second project as standalone battery plant of storage capacity of 60 MWh.

Another example of progressive policies in the MENA region, is the case of Morocco that has worked with Abu Dhabi based consortium Masdar to provide electricity through a rooftop photovoltaic panel coupled with a battery system to 19,000 rural homes.

Deployment status, enablers and alternative

Archetype I: High renewable penetration, low/ moderate capacity margin

Austria

Austria is one of the leading countries in the development of renewable energy, with 33.5% of its total energy consumption and 72% of its gross electricity consumption generated from a renewable energy source. The country is a strong developer of pumped hydro storage, being one of the earliest countries in the EU to build PHS plants. Its plants date back to 1890s. Its efforts carry on till today, being heavily invested in the development of battery energy storage capacity. In 2017, the government amended its Green Electricity Act, introducing additional subsidies for PV systems and energy storage amongst others. For the combined PV and energy storage category, the government allocated 15 million Euros for 2018 and 2019, of which 40% can be directed towards energy storage. This does not only apply to greenfield energy storage projects, but also expansions of existing ones. Upon the launch of this program, OeMAG, The Clearing Agency for Green Electricity, received 3,000 applications in the first 5 minutes, compared to receiving the same volume in 10 minutes the previous year, signaling an increase in demand one year after the other. The increase in demand is expected though given the target that was set by Austria’s government to generate 100% of its electricity from renewable sources by 2030.

For instance, the funding in Austria offers a subsidy of EUR 500 per kWh of storage capacity with a maximum subsidy amount of 45% of the investment costs. The country has cut the sun tax that was mandating that consumers of solar energy pay if they consume beyond a certain amount of energy from solar, and the newly elected government has agreed to put aside €36 million per year from next year to 2022 to fund solar and energy storage as part of the green electricity package

The Austrian energy storage market, driven by high renewable penetration, is already at a relatively advanced stage and considering the countries targets, and the current market dynamics, the energy storage market will continue to grow in the coming years. As per Bavarian battery developer Sonnen, the orders for batteries in the Austrian market is growing and the expectation is that this growth will be sustained over the next years

Archetype II: High renewable penetration, moderate capacity margin

The United Kingdom is one of the key battery markets in Europe:

- Changes to the policy and regulatory landscape are ongoing to further support the deployment of batteries. The launch of a call for evidence was announced for summer 2016 to investigate ways to facilitate use of flexibility before a reform is proposed by Spring 2017.
- National Grid foresees 1 GW of non-pumped storage by 2020, providing regulatory barriers are removed.
- In response to the flexibility challenges already faced today in the UK, National Grid ran the Enhanced Frequency Response auction during summer 2016, which resulted in 200 MW battery storage clearing the auction, with April 2017 as the earliest start date.
- In the Irish Single Electricity Market, where the share of renewables is higher than in the UK, AES recently commissioned a 10 MW battery to provide fast-response ancillary services and initiated the first step of a planned 100 MW battery project.

On the other hand, the deployment of battery storage at the residential level remains limited in the UK: residential PV is less developed, battery prices are too high, and subsidies are insufficient compared to the retail price.

Battery storage competes with other flexibility tools on the market such as interconnectors, flexible generation and demand-side management. Distributed conventional generators, in particular diesel generation, have lately had significant success with current grid challenges in the UK. Responding to market signals, distributed conventional generators are regaining interest with VIUs, generators and merchant players to generate revenues from capacity mechanism and ancillary services and reduced network charges (TRIADS).

About 1.1 GW small-scale distribution connected generators cleared the capacity mechanism auctions, hoping to capture revenues not only from the capacity mechanism, but also through embedded benefits that include the avoidance of transmission network charges. Stand-alone batteries today did not succeed in clearing the CM auctions, and hybrid renewables/batteries so far have not been allowed to participate in it.

The UK government, through National Grid, is also supporting demand-side response as a tool to provide flexibility to the grid. In fact, demand-side response is increasingly seen as a potential contributor to frequency response through the intermediary of aggregators (more details in ADL’s Viewpoint on Demand Side Management - Untapped Multi-Billion Market for Grid Companies, Aggregators, Utilities and Industrials?).

The business model consisting of incentivizing end consumers to reduce their consumption or switch to behind-the-meter generators to respond to grid requirements has been widely tested and enabled through regulatory changes. But the extent to which operators could rely entirely on third-party response and substitute assets, providing flexibility with DSR, has not been fully proven yet.

Demand-side management is not necessarily competing with storage applications and can be complementary to storage. In fact, batteries could be used as a complement to behind-the- meter generators (e.g. hybrid generators) and activated through demand-side response.

In conclusion the market development of energy storage in the U.K. will have to be closely monitored in the future as conflicting evidence suggests that within the U.K. certain trends suggest that there will be space for grid stability in the U.K. but the threat from substitutes such as generators might impede the development of the energy storage market.

Battery deployment in Spain remains very limited despite a high share of renewables in the network. The government started cutting back on subsidies for renewables in the past five years, and the new self-consumption law adopted at the end of 2015 is expected to adversely impact residential battery storage. Under this new law, hybrid battery-storage owners will not be able to decrease their maximum connection capacity and therefore benefit from lower network charges. So, although market fundamentals (e.g. high deployment of PV panels, relatively high retail prices) are present in Spain for the widespread development of residential battery storage for self-consumption, the absence of incentives slows down the deployment of battery storage. Especially, considering that serious alternatives exist for Spanish households when it comes to clean energy sources. Spain’s adoption of battery storage will not be driven by subsidies only, but also, market designs and an update in the regulatory framework will facilitate deployment when the country decides to move in that direction.

The German power system is characterized by moderate (as a percentage of total generation) penetration of distributed (PV) and centralized (wind) renewable generation, and a residential storage market on the rise. Policy measures have been promoting hybrid distributed systems (PV + batteries) for more than 4 years now, in order to accommodate distributed renewable penetration in the grid. The KfW programme 275, for example, provided a 30 % investment grant for equipment purchased with low-interest loans until the end of 2015 to residential customers who could see their on-site consumption increased with batteries. While high retail prices also facilitate the business case for residential batteries, incentives are playing a key role in a market where the average state of charge of batteries approaches is low over the first three months of the year. Potential savings achieved with residential battery storage for self-consumption are fundamentally lower in Germany than in other markets, such as California, which benefits from favorable irradiation all through the year.

Compared to the residential sector, the industrial and commercial (I&C) sectors have so far lagged behind. And still, retail prices are high, capacity margin is decreasing with the closing of nuclear plants, and I&C-owned renewables are ever growing. But the incentives for German I&C are not there: network charges and tax regimes do not promote I&C storage. Furthermore, Germany’s high interconnectedness with neighboring markets means that excess supply is better sold to neighboring countries than stored and kept for self-consumption or for later hours in the day. In a nutshell, integrated power grids via interconnections lead to a smoothing impact on power-price spreads and volatility, which goes against part of the battery-storage business case.

In Germany we can see how market rules can inhibit business cases. According to the renewable energy act (EEG) curtailed power from renewables is payed to the operator. Otherwise, this would be a positive business case.

Archetype III: Moderate renewable penetration, low capacity margin, large size systems

USA

In the U.S. market Activity in the battery storage market is highly dependent on the state. California is one of the states with the highest renewable capacity (wind and solar), and a leader in battery storage deployment.

Its 30% penetration rate of renewables and 70%–30% split of solar capacity between utility-scale solar and distributed PV has driven the deployment of battery storage at both grid and residential levels.

Beyond favorable fundamentals, the deployment of battery storage is supported by relatively high residential tariffs and strong regulatory signals, with California’s Public Utilities Commission setting clear targets that require utilities to build energy-storage capacity and clarifying the market rules for behind-the-meter battery aggregation. Southern California Edison (SCE) acted as first mover and bought 261 MW of energy storage by the end of 2014, 100 MW of which were from AES and 85 MW from Stem (both battery storage). Stem also recently won close to 1MW capacity in the demand-side response (DSR) auction held this summer by Con Edison for the state of New York, testifying to the complementarity of battery storage and DSR.

The state of New York is also one of the early adopters of battery storage, and currently clarifying market rules for enabling battery storage to access the market. In the PJM (Regional Transmission Operator, part of the Eastern Interconnection grid), the creation of fast regulation reserve combined with pay-for-performance framework introduced by the Federal Energy Regulatory Commission have promoted the development of battery storage with about 250 MW energy storage (flywheel and battery storage) installed to date. However, the decrease in clearing prices, namely due to falling oil prices, have raised concerns on the economics of battery storage.

Other parts of the United States, such as the Northwest, will likely be later adopters given their significant hydro-resources and the flexibility provided by hydroelectric and pump storage, which are enough to manage current levels of renewables.

Archetype IV: Moderate renewable penetration, moderate capacity margin, small-size systems

Island markets have seen a lot of activity in battery storage. The unique challenges faced improve the business case for battery storage: networks are more quickly saturated given their smaller grid size and higher generation costs driven by more expensive generation mixes (e.g. diesel generators). Battery storage is an opportunity for these markets to support the development of renewable energies, support decarbonization of markets often heavily reliant on oil-fired generation, decrease exposure to oil prices and potentially reduce costs. Island markets also have fewer available alternatives to add flexibility to their systems: pump-storage plants are often not an option, and interconnection is weak if existent. So, it is with no surprise that most countries have concentrated their pilots on these islands when possible: La Gomera and La Aldea de San Nicolas (Canary Islands) in Spain, Azores (Graciosa Island) in Portugal, Tilos in Greece, La Réunion in France, Sardinia and Sicily in Italy, and Hawaii.

Pilots have so far focused on grid-scale batteries within hybrid configurations or stand-alone providing support to the grid to enable renewables integration.

In Hawaii, where about 90% of solar capacity is distributed PV, HECO recently announced it would finance and deploy residential storage to resolve grid congestion and enable more distributed PV to connect to the grid. This is one of the few examples where utilities are paying for and remotely operating residential storage. A couple of grid-scale hybrid configurations have also been announced: Ambri battery storage next to a wind farm on Oahu’s North Shore, and SolarCity’s solar PV battery project on Kaua’i.

Archetype V: Low renewable penetration, high capacity margins, need for energy mix shift

The UAE and KSA are two Middle Eastern countries with considerable potential for the adoption of renewable energy and battery storage systems. Both countries have expressed strong interest in breaking away from the generation of electricity from fossil fuels and the adoption of renewable sources to meet energy demands and environmental targets

The Dubai Electricity and Water Authority (DEWA) has been constructing the largest solar park in the world in Dubai under the name of Mohamed Bin Rashid Al Maktoum Solar Park as a five-phase project amounting to a total value of 5 GW generation capacity from solar sources (Photovoltaic and Concentrated Solar Power).

The fourth phase of the solar park has achieved many world records. It will have the world’s tallest solar tower, at 260 meters, and the largest thermal energy storage capacity in the world of 15 hours, which allows for energy generation round the clock. It also achieved the lowest Levelized Cost of Electricity (LCOE) of 2.4 US cents per kilowatt-hour (kW/h) for the 250 MW photovoltaic solar panels technology and USD 7.3 cents per kW/h for the 700 MW CSP technology, the lowest worldwide. DEWA has trialed the installation of a network attached storage battery system of a 7.2 MWh capacity built by NGK insulators. The battery system was connected to the first section of the solar park to stabilize fluctuations in the solar output, plus other grid applications (e.g. energy time shifting and frequency control)

In Abu Dhabi, the department of energy (formerly Abu Dhabi Electricity and Water Authority) has inaugurated a 108 MW/ 648 MWh Sodium-Sulfur (NaS) battery plant which is the largest battery plant in the world with a size 5-times that of the Lithium-ion plant installed by Tesla in Australia.

The ambitious targets of the UAE to produce 60% of its electricity demands from clean energy will be a major driver for the adoption of renewable energy sources. But also, the emergence of new players like Enerwhere in the country with innovative business models in terms of providing photovoltaic panels coupled with batteries and diesel generators will accelerate the adoption of such systems for off-grid applications such as construction sites.

Similarly, KSA set out very ambitious renewable energy targets and had signed a memorandum of understanding with Japanese investment firm Softbank to finance the development of 200 GW worth of renewable energy projects to boost the KSA economy and limit the dependence on fossil fuels. French EDF was expected to build 10 GW worth of battery storage system but project was called off.

Despite halting the project in KSA, experts anticipate that several projects will emerge in KSA and that battery energy storage systems adoption will grow as a result. In KSA as well as in the UAE, the increase in the penetration of renewable energy sources (e.g. the country has increased its renewable energy targets from 9.5 GW in 2022 to 27.5 GW by 2040) at the generation side will turn out to be the main driver for the increase in demand for energy storage systems.

Archetype VI: Low renewable penetration, low capacity margin, dependence on energy imports

Lebanon Jordan Morocco Egypt

Lebanon has been facing serious issues with balancing its electricity supply and demand. With a total generating capacity of 2 GW and a recorded demand peak of 3.4 GW, experts estimate that Lebanon's supply-demand gap is on average as high as one 1 GW. The discrepancy in supply and demand along with the fact that Lebanon relies heavily on imports for its energy suppliers made the country adopt the resolution of launching ambitious renewable energy projects. Lebanon is planning to boost its energy supply capacity with a handful of renewable energy projects to improve the reliability of its energy supply and respond to the increasing demand in the country.

Lebanon is planning on building 3 photovoltaic plants of 100 MW capacity each coupled with battery storage system of a minimum of 70 MWh each amounting to a total capacity of 300 MW with a storage capacity of 210 MWh. Lebanon battery storage tender is the largest in the region. The country sought the help of the European Bank of Reconstruction and Development to manage the tendering process for the construction projects and received 75 Letters of Interest in 2018.

Therefore, opportunities in Lebanon in the battery storage market are mainly driven by the unreliability of the energy supply leading up an increase in the adoption of renewable energy that are coupled with battery storage systems to ensure a 24/7 energy supply in the country.

With low renewable energy penetration, Jordan and Morocco rely on energy imports (fuel) to meet their energy demands. The countries respective governments have ambitions to increase their share of renewable energy in the generation mix and strong projects have been undertaken.

Jordan is expecting that 20% of its total electricity requirements will be produced from renewable energy by 2025. The country has been closing in on its targets and by 2018, Jordan was producing 1.13 GW (accounting for 11% of its total electricity requirements) from renewable energy sources and announced that this amount will double by 2021.

The country's strong push for the adoption of renewable energy led to two projects; One project coupling photovoltaic generation with Li-ion battery energy systems of a storage capacity of 12.6 MWh and a second project as standalone battery plant of storage capacity of 60 MWh. The increasing adoption of renewable energy will have a positive impact on the installation of battery energy storage systems for generation stabilization and peak shelving purposes.

Morocco, with a total electricity capacity in 2017 of 9.0 GW, has ambitious renewable energy targets of generating 42% of its energy from renewable sources by 2020 and 52% by 2030. The country has seen important developments in the adoption of renewable energy with its solar complex in Ouarzazate, Agadir. The solar complex relies mainly on concentrated solar power (CSP) mirrors and uses thermal energy storage. Additionally, the country built a concentrated photovoltaic plant coupled with a battery storage system with the help of Japanese company Sumitomo Electric Industries.

Another driver in Morocco is the implementation of home rooftop projects coupled with battery storage system in rural areas where connections to the grid are challenging to establish. In a project, in collaboration with Masdar, the national office for electricity and water has implemented a project for 19,000 homes supplying them with rooftop photovoltaic panels and battery storage systems.

Although Egypt's reliance on energy imports is not as significant as Jordan's and Morocco's, Egypt's renewable energy targets of increasing generation from 3% in 2016 to 20% by 2022 is an ambitious target that is expected to boost the development of renewable energy projects in the country. The country started work on a new PV plant coupled with battery energy storage for a capacity of 30 MW through a contract with the Japanese government of a value of USD 89mn and it is anticipated that other projects will follow

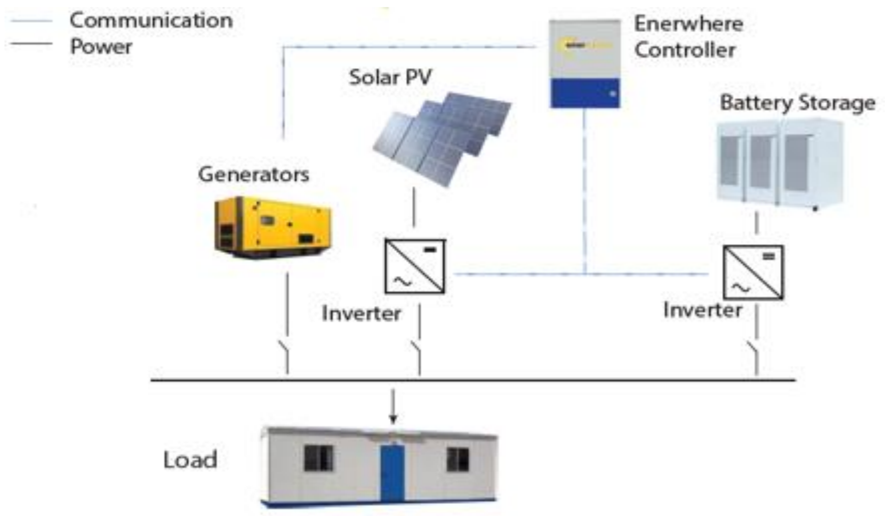
Other drivers for adoption of battery systems in Egypt will be the installation of PV panels coupled with battery storage systems on rooftops of homes where grid connections are challenging to establish. Masdar led a project in Egypt to supply 7,000 homes in Egypt with clean energy.

5. Concrete use cases for battery applications in MENA

A. Battery energy storage projects in UAE

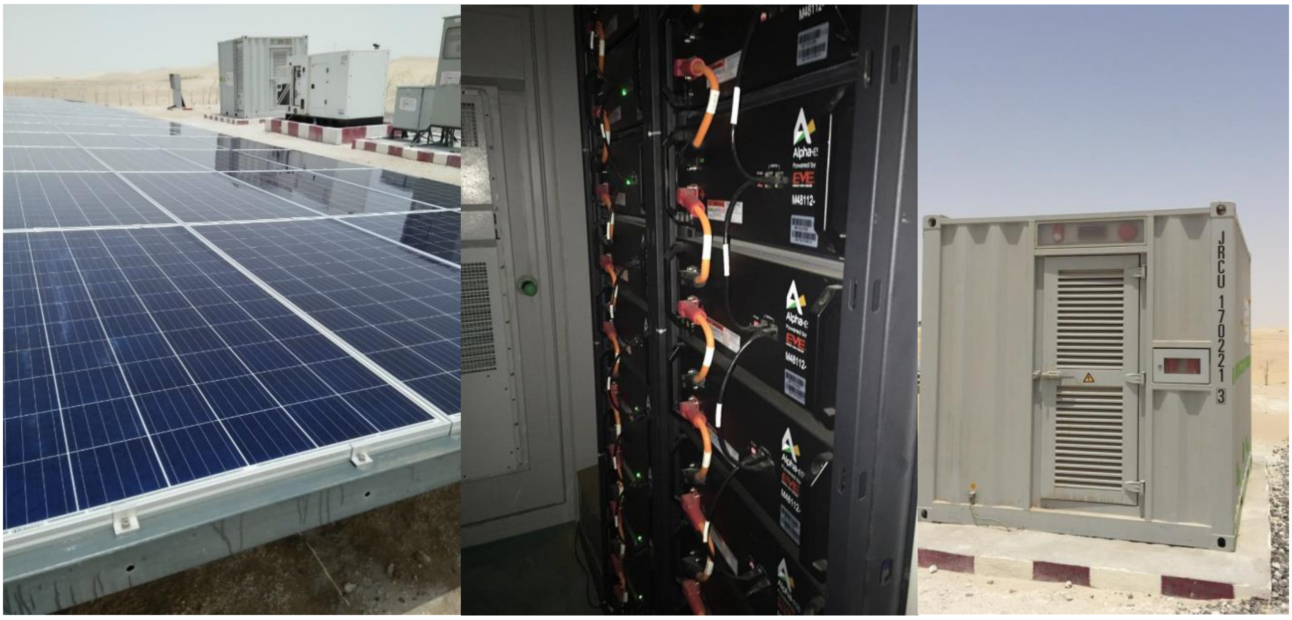
1. First Tesla Powerpack in the Middle East

Enerwhere, an SME based in Dubai, UAE, set up the first Tesla Powerpack in the Middle East in 2017 as part of a microgrid for a construction contractor in DIFC, Dubai. The system comprised of 40 kWp solar, 250 kVA of generators and 100 kW, 190 kWh of storage. An outline of the system and some pictures are shown below



2. Lithium Iron Phosphate (LFP) ESS installation in Abu Dhabi

The first LFP based energy storage system in Abu Dhabi was installed for a waste management facility. The end client for this solution is Tadweer. This system comprised of 150 kWp of solar and 100 kW, 200 kWh storage system. This solution reduces the dependency on diesel by 80% in the summer and in winter it runs ~98% on solar energy only. This is also the first LFP based energy storage system in the UAE. Below are some pictures.



3. Abu Dhabi home to world’s largest ‘virtual battery plant’

Region’s first grid scale battery deployment and the world’s largest virtual battery plant with a capacity of 108 MW distributed over 10 sites has been setup across Abu Dhabi. Although the battery units have been fitted across 10 different locations, the department of energy in Abu Dhabi can control it virtually from a single location.

The 108 MW/648 MWh sodium-sulfur battery plant opened in January 2019 and is about five times the size of the Tesla battery system installed in Hornsdale, Australia in 2017.

The Abu Dhabi department of energy opted for NGK NaS batteries for this system considering NaS batteries’ long discharge time as well as their capacity to withstand high temperatures (Up to 300 degrees Celsius) which makes them ideal for operation in the Arabian desert.

B. Energy storage installation in Jordan

A 3MW/12.6 MWh lithium ion energy storage system has been setup near Mafraq, in northern Jordan, at the 23 MWp solar PV park of Philadelphia Solar. It was commissioned in February 2019. The customer Philadelphia Solar quotes:
"The new power plant's purpose is to enhance the grid by power peak shaving and power shifting to increase the stability of the grid and support the grid at peak load hours. Additionally, it will also enhance the availability of energy during daytime hours and the remaining Energy will support the grid during nighttime Hours."

6. Conclusions: fast move for some, wait for others – shape for all

Battery storage is expected to play an important role in responding to the current challenges posed by the deployment of renewables. However, today there are a number of barriers to its implementation, such as regulatory uncertainty, commercial models, maturity of technology and associated costs.

In the short term, the deployment of battery storage in specific markets will depend not only on market characteristics (e.g. renewables penetration, interconnection rate, generation mix, network topology and system size), but also on the regulatory framework, incentives and commercial models:

1. Grid-scale storage for frequency regulation and stable output applications are seen as the most promising applications today.
2. It has significantly developed in countries such as Japan, the US (California) and Germany, residential battery storage finds positive business cases only with strong public support.
3. Combination of applications is essential today to stack revenue streams and build a positive business case; current market design (definition of ancillary services, access to grid services and the possibility of stack services) often doesn’t support this, hence the business case will continue to be challenging in the short to medium term to provide individual grid-support services
4. System operators have so far been very cautious regarding the integration of batteries in their portfolios and limited themselves to pilots. In most countries system operators are restrained from developing battery storage solutions beyond pilots because of the regulatory definition of battery storage and its interference with energy market mechanisms.
5. Opportunities for TSO/ DSO are more promising in MENA countries considering that distribution and transmission for the most part is performed by the utilities themselves, so they can exploit the full spectrum of applications from generation to transmission and distribution.
6. Combined ownership is considered the most likely, economically viable solution for system operators.
7. For residential hybrid PV/storage, current commercial developments show that the opportunity is now where incentives are in place. In leading markets such as California, VIUs are entering the battery storage market to broaden their commercial offers. Also, the role of aggregators continues to expand to cover battery storage, either as software providers or technology operators, though somewhat slowed down by the regulatory framework, access to ancillary services and energy market.
8. Deployment of battery storage by industrial and commercial customers is likely to remain limited in the short term given the current challenging economics, except for the telecom industry presented with challenges related to accessibility and security of supply.
9. For grid-scale applications, it is time for early adopters. Power utilities are stepping into the market and a series of large-scale commercial battery storage contracts have been announced over the last year, providing flexibility services (e.g. frequency response, frequency regulation) to the grid and benefit from arbitrage. Island markets, under the initiative of system operators, have been leading the market in terms of grid-scale battery deployment (combined with renewables to stabilize output or for frequency regulation) by power utilities and, in some particular cases, directly by system operators.
10. Vertically integrated utilities (VIUs) in the MENA region will be able to integrate energy storage with their renewable projects as vertical integration offers more room for utilities to deploy energy storage with various applications (e.g. frequency response, peak demand response, or output stabilization). It is anticipated that the adoption of renewables in the MENA region will play major role in facilitating the deployment of battery storage.

So, is it too early for battery storage?
“Battery storage is a fast move today for some actors in the value chain and a wait for others. But all actors can shape the market and must develop their strategy now if they don’t want to turn up late at the party.

Dii shareholders:

ACWA Power is a developer, investor, co-owner and operator of a portfolio of power generation and desalinated water production plants currently with presence in 12 countries including in the Middle East and North Africa, Turkey, Southern Africa and South East Asia regions.

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