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Good practice principles for grid-scale battery storage

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Executive summary

This report provides an evidence base to inform Scottish policy in relation to the role that grid-scale battery storage could play in providing a resilient, affordable electricity network. In line with Scotland's Energy Strategy and Net Zero emission targets, the research considers the period to 2030 and 2045. It reviews current practice and experience, and current expectations for further developments.

Grid-scale battery storage is likely to be an important part of the evolution of the electricity system in the UK, including in Scotland, in the period to 2045. This is driven by several factors, in particular, the growth of variable renewables (wind, solar) and decarbonisation by electrification of heat supply and transport. This will be affected by further reductions in battery system costs and evolution of markets which reflect the value of services provided by energy storage. However, there are competitors for providing these services: principally demand-side management including EV charging, grid reinforcement, interconnectors to other systems, and flexible generation such as hydro or pumped storage.

Objectives

- To show how batteries bring value to electricity systems.
- To present evidence on sustainability, environmental and safety issues associated with grid-scale battery storage projects.
- To assess key spatial criteria associated with the siting of grid-scale battery storage projects.

The report focuses particularly on the first of these three aims.

Key findings

- In the Scottish context, battery storage is likely to be particularly useful in the longer term in supporting weaker parts of the electricity system, such as on islands and in more remote areas with high renewables penetration.
- The 'Grid-scale' sector is likely to grow. This also includes large battery installations 'behind the meter' on industrial and commercial sites.

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- Drawing on published scenarios, we estimate that grid-scale battery storage capacity in Scotland is likely to be in the range 1,800-2,700 MWh by 2030, and 6,800-10,500 MWh by 2045.
- The dominant battery technology at present is lithium-ion, in several different chemistries. Many other technologies are under development and may replace lithium-ion eventually.
- Globally, initial steps have been taken to improve overview of lithium-ion supply chains, to mitigate the social and environmental impacts, but much broader adoption and implementation is needed.
- The most critical raw materials in the global battery supply chain are identified as cobalt, lithium and graphite, based on the volumes likely to be required, and concerns over concentration of sources.
- The demand for critical raw materials associated with meeting an estimate of grid-scale battery storage capacity in Scotland up to 2030 and 2045 is equivalent to c. 0.2-1.4% of current global lithium production and 0.2-0.9% of current global cobalt production.
- While there are technical and economic challenges with effective lithium-ion battery recycling, the volume of batteries associated with the growth of the electric vehicle industry is likely to support the development of a global recycling and waste management chain.
- Few issues have been encountered so far in obtaining development consent for battery projects. The factor that most influences siting is proximity to an adequate grid connection.

Contents

Glossary

Active Network Management (ANM)	Control systems which manage load and generators as a solution to network constraints.
Aggregator	An energy service provider which dispatches a portfolio of flexibility assets to meet defined energy system/network needs.
Ancillary services	Functions that help grid operators maintain a reliable electricity system, managing imbalances in supply and demand. An example is frequency response.
Behind-the-meter (BTM)	Location behind a generating or consumption meter.
Black start	A process to restore power in the event of shutdown of the national electricity transmission system
Capacity Market	A policy mechanism which rewards electricity generators and consumers for being available during times of system stress.
Demand-side Management (DSM)	Flexibility provided by energy consumers – for instance smart charging of electric vehicles.
Frequency response	A service procured by system operators to help manage supply and demand on a second-by-second basis.
Grid-scale	Defined in this report as a project which is: • At least 1 MW electrical power output capacity; and • At least 1 MWh electrical energy storage capacity.
Lithium-ion (LI) battery (LIB)	A rechargeable battery using lithium-ions as a primary component
Lithium Manganese Cobalt Oxide (LMNC)	A lithium-ion battery chemistry commonly used in electric vehicles and for stationary storage
Lithium-ion Phosphate (LFP)	A lithium-ion battery chemistry particularly common amongst Chinese battery manufacturers.
MW	Megawatt
MWh	Megawatt-hour
Non-firm connection	A grid connection where an outage of a single element of the electricity system requires the output of a generator to be limited.
Power-to-gas	A technology converting electrical power to a gas fuel.
Voltage control	A service procured by system operators to manage voltage on their system

1. Introduction

This report was drafted by Everoze and commissioned by ClimateXChange on behalf of the Scottish Government. It is intended to inform energy policy development within Scotland on the roles that grid-scale battery storage could play in providing a resilient, affordable electricity network.

'Grid-scale' in this context has been defined by Everoze as:

- At least 1 MW electrical power output capacity; and
- At least 1 MWh electrical energy storage capacity.

This definition therefore covers projects which are directly connected to the public electricity system, and those which may be 'behind the meter' (BTM), i.e. within an industrial site, office building, hospital or similar.

The term 'battery storage' or 'battery' in this context includes the electrochemical cells, the modules and racks into which they are packaged, the power-electronic converters to convert DC to and from AC[1], the control and monitoring systems (Battery Management System, Energy Management System), and containers often including air-conditioning and fire suppression.

The report is structured around three objectives defined by ClimateXChange:

- Objective 1: To show how batteries bring value to electricity systems
- Objective 2: To present evidence on sustainability, environmental and safety issues associated with grid-scale battery storage projects.
- Objective 3: To assess key spatial criteria associated with the siting of grid-scale battery storage projects.

The work has been informed by published studies, a series of semi-structured interviews with relevant stakeholders[2], and experience gained by Everoze staff in providing technical and commercial consultancy advice to battery project developers, investors, equipment manufacturers, aggregators, and others.

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[1] Batteries store electricity as Direct Current. Electricity networks use Alternating Current. Conversion between AC and DC is achieved by power-electronic devices using transistors or other semiconductor technologies. For battery systems, the power-electronic devices are bi-directional, commonly called 'converters', though other terminology is sometimes used.

[2] Stakeholders interviewed are listed in Appendix 1.

The energy storage context

All energy supply systems rely on some form of storage, in order to match supply and demand: examples are coal stockpiles at mines, water in a reservoir, or gas at high pressure in gas fields and pipelines. Electricity supply has traditionally relied on long-term storage of fuel, and short-term energy storage in the high-pressure steam systems and rotating masses in the turbines of coal, gas, and nuclear power stations. These forms of storage are disappearing as coal and gas-fired thermal generators are displaced by variable renewables such as wind and solar; and, in addition, wind, and solar increase the variability of electricity supply. Therefore, electricity storage is becoming critical to decarbonisation of electricity supply.

In parallel, battery technology has advanced rapidly, driven in turn by new markets for mobile phones and laptops, power tools, and now electric vehicles. Batteries, and in particular lithium-ion technologies, are now very competitive with other forms of storage, opening new markets beyond those associated with wind and solar integration.

There are several different battery technologies commercially available:

The vast majority of grid-scale batteries use ***lithium-ion*** (LI) technology, of several different chemistries. The rapid advances and cost reductions of these technologies are largely due to their use in electric vehicles.

Lead-acid is a mature technology long used for reliable back-up power supply and also in petrol and diesel vehicles.

Flow batteries pump electrolyte through electrochemical cells; the storage capacity is limited only by the size of storage tanks. Flow batteries are therefore suited for longer storage duration, though at present appear unable to compete with LI for most common applications.

Many other battery technologies are under development, mostly driven by the EV market. This document does not describe or distinguish between battery technologies, except where necessary to explain specific points.

Other forms of electricity storage are also available or under development, against which battery storage must compete. Pumped hydro storage is a very mature technology, characterised by long operational life, large unit sizes, and long construction timescales. Others at varying stages of development include compressed air and liquefaction of air.

All forms of electricity storage also compete against other ways of matching supply and demand:

Demand-side management: reducing or increasing non-critical electrical loads. In the future, it is likely that electrification of heat and transport will provide more opportunities for demand-side management.

Greater ***interconnections*** to other electricity systems, to spread the variability of both electricity production and consumption. For example, east-west interconnections across Europe spread the diurnal variation in electricity demand due to working patterns, and north-south interconnections could provide smoothing between those areas dominated by wind generation, and those dominated by solar.

Flexible generation: in particular, gas turbines are now available with very short start times and wide operating ranges. When operating, the fuel cost and carbon emissions are high, but the capital cost is low, making them suitable for meeting peaks in electricity demand, or coping with unexpected events.

2. The role and value of grid-scale battery storage

2.1 Purpose

The aim of this Objective is to provide a summary and synthesis of how batteries bring value to the electricity system[3], to inform Scottish Government policy on the varied roles that batteries can play and to support appropriate, sustainable, applications of the technology which benefit the energy system as a whole.

The timescales under consideration are:

- To 2030, to match the Energy Strategy [1] and Climate Change Plan [2] target to provide the equivalent of 50% of the energy for Scotland's heat, transport, and electricity consumption from renewable sources.
- To 2045, to match the Net Zero target proposed for Scotland by the UK Committee on Climate Change [3] and now included in the Climate Change (Emission Reduction Targets) (Scotland) Act, passed on 25 September 2019 [4]. The Act also includes an interim target of 75% reduction by 2030, higher than the CCC Net Zero recommended interim target of 70%.

2.2 Roles for grid-scale battery storage

There are many ways of classifying roles for battery storage; there is no clear established taxonomy, and in some cases the same function is described or defined differently in different countries or circumstances, depending for example on the electricity regulatory regime. The roles covered here are chosen for relevance to Scotland:

- Smoothing electricity price peaks (arbitrage)
- Enabling increased renewables penetration, on several scales
- Deferring or avoiding network investment.
- Providing ancillary system services.

2.3 Energy arbitrage

Arbitrage is the process of charging the battery storage when electricity prices are low and discharging when prices are high. This would appear to be the obvious prime use of grid-scale battery storage, but in practice arbitrage alone has proven insufficient to make an economic project, in recent GB market conditions. The price differential between high price and low-price periods is insufficient to cover the energy losses (around 15% of the energy used to charge the battery is lost as heat) and to pay for the capital and operational costs. However, periods of very high and low spot prices[4] may well occur and provide a valuable source of revenue; in the last year, volatility in the Balancing Mechanism[5] has become sufficiently significant for a number of market actors to develop battery dispatch algorithms for this market – suggesting that the market is on the verge of becoming commercially viable for battery projects.

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[3] The electricity transmission system in Scotland is an integral part of the GB electricity system (i.e. UK excluding Northern Ireland), contributing to and benefitting from its stability and economic operation as a result of scale. In the context of this report, where relevant we have noted how battery storage in Scotland can contribute to benefits at GB level. The electricity system of Northern Ireland forms part of the combined system for the island of Ireland.
[4] Spot prices: short-term buy and sell prices on the wholesale market.
[5] The Balancing Mechanism is run by National Grid as electricity system operator, to balance supply and demand in the very short term, i.e. not in wholesale energy markets. Generators and demand customers provide bids to adjust their planned production and consumption.

The arbitrage opportunity is a function of market arrangements; in jurisdictions where there is no capacity market[6], wholesale prices are likely to be more volatile[7]. The GB system has a capacity market [5], discussed further below. Depending on how the GB electricity market evolves in future, especially with high penetration of wind and solar, electricity wholesale prices may become more volatile.

Arbitrage income is subject to the risk of 'cannibalisation'; the more storage, deferrable demand or peaking generators are built to take advantage of spot price differentials, the smaller those differentials will become. Therefore, investors in storage projects dependent on arbitrage are subject to risks caused by actors outside their control.

2.4 Enabling increased renewables penetration

National or regional scale

The variability of wind, solar, wave and tidal on timescales of hours to years presents problems for electricity systems (shorter-term variability is averaged out over areas the size of national electricity systems)[8]. The combined electricity systems for the island of Ireland provide a good example: even though Ireland is achieving world-leading penetration of wind energy, with production regularly reaching 65% of instantaneous demand, the annual contribution from wind in 2018 was 29%. This is far from enough to achieve the separate decarbonisation targets for the Republic of Ireland and Northern Ireland. To reach those targets, a large over-capacity of wind will be needed, resulting in frequent and substantial overproduction, and high costs. The straightforward solution is to curtail wind production: currently 8% of wind production in Ireland is 'lost' in this way, and higher renewables penetration will increase this substantially faster than pro-rata.

Energy storage is one solution, competing with demand-side management (DSM; which may include a large element of electric vehicle charging in future) and greater interconnection to neighbouring electricity systems. The greatest challenge is long-term or seasonal storage. In the context of Scotland, there may well be a need to store surplus renewable generation throughout the year to meet the much higher energy demands in winter, particularly if decarbonisation of heat demand is to be achieved through electrification[9]. Although there is substantial uncertainty about the best ways to meet this challenge, battery storage costs are unlikely to fall enough to be economic[10] for seasonal storage of energy; other options such as hydrogen (Power to Gas), long-term heat storage, and interconnection to electricity systems with substantial hydro storage appear more hopeful.

Currently in GB there is no market mechanism specifically intended to reward grid-scale battery projects for enabling greater penetrations of variable renewables, or for minimising constraint losses[11]. Section 2.5 covers the related issue of network reinforcement.

Co-location with renewable generation

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[6] Capacity market: a market whereby electricity generators and consumers bid for long-term contracts to provide capacity (MW) rather than energy (MWh). This is one way of encouraging sufficient capacity to be built (or kept available) to ensure that peaks in demand can be met.

[7] An example is South Australia, a weakly-connected part of the Australian National Electricity Market: https://www.aer.gov.au/communication/aer-reports-on-high-wholesale-electricity-prices-in-victoria-and-south-australia-on-24-and-25-january-2019

[8] These challenges and their economic consequences have been probed in the report 'An analysis of electricity system flexibility for Great Britain', Nov 2016, authored by Imperial College London. The report assesses the impact of renewables variability and quantifies the value of flexibility in helping accommodate large proportions of renewables.

[9] Currently, UK gas demand is around twice as high in winter as in summer, and most of this variation is due to the gas demand for homes, which is about five times higher in winter. National Grid's 2019 Future Energy Scenarios http://fes.nationalgrid.com/media/1409/fes-2019.pdf shows peak electricity demand in winter increasing from 60 GW to over 80 GW by 2050, in the scenario which assumes highest use of EVs and domestic heat pumps.

[10] Seasonal energy storage has to be able to recover its costs over just one charge/discharge cycle per year.

[11] National Grid's Constraint Management Pathfinder project seeks to identify new solution to management of transmission constraints, especially flows from Scotland south. Other Pathfinder studies will also be relevant.

Using battery storage co-located with renewable generation to allow renewable electricity to be sold during higher-price periods currently appears to be insufficient on its own to justify investment in co-located battery storage. It appears to be used in conjunction with other income streams. An early example of co-located solar storage is the Clayhill project developed by Anesco in Milton Keynes, commissioned in 2017. The project combines 10MW solar with 6MW battery storage, seeking to provide frequency response and capacity market services.

A reason why co-location of storage with renewables has been limited has been due to investors and particularly lenders being eager not to risk income from renewables subsidy schemes, such as Feed-in Tariffs, Renewables Obligation or with current Contract for Difference contracts. In 2016-17 industry was held back by a lack of clear guidance on what constituted compliant metering arrangements for subsidy schemes; but today the barrier is more economic. Subsidy schemes fundamentally incentivise the maximisation of renewables export; and co-location of storage acts against this due to round-trip efficiency losses reducing export.

The picture will change in future – both as new subsidy-free projects come online, and as aging renewables projects meet the expiry dates of existing support payments, needing to establish a subsidy-free model for late-life operation. The output of wind and solar projects is the result of weather systems and is therefore correlated to some extent across the GB system; high production already has some correlation with low electricity prices. Therefore, this is likely to become a more important factor in the economic justification for co-located storage. It is likely that this will happen first with solar, as there is stronger geographical correlation.

Co-located storage may also provide value to renewable generators by reducing the grid connection capacity needed for a given generation capacity[12]. This will reduce the capital cost of the grid connection, and ongoing Use of System charges. It may also allow connection to a lower-voltage network, further reducing costs as well as time to build. It may also reduce visual impact of overhead lines.

Alternatively, the benefit could be taken by adding additional wind or solar to an existing project without upgrading the grid connection.

A further possible use of battery storage co-located with renewable generation, not yet seen in GB, is to mitigate the impacts of curtailment due to constraints within the electricity network. Renewable project developers often agree to a 'non-firm' grid connection[13], in order to reduce cost or achieve an earlier connection date. With a 'non-firm' grid connection, the risk of lost production is taken by the renewable generator. Under current market conditions the value of saving this lost production is usually too low to justify adding battery storage. This is expected to change in future. The opportunity for co-located storage is likely to be greatest in areas suffering constraint due to excessive solar export during the middle of the day, with grid operators offering new build solar plant flexible connections that might constrain export around 11am-2pm in summer. In this context, co-located storage can assist a developer by time-shifting solar generation to export later in the day.

From the above it is clear that there are several potential drivers for co-location. It is fair to say that all are under discussion, but it is not clear which mix of these may predominate in Scotland in future.

The term 'co-location' in this context means that the battery storage is located within or closely adjacent to the wind or solar project. It is not necessary for the battery storage to be owned by the same entity, or to be connected behind a single set of meters, though for some of the issues discussed above it is necessary to share the same grid connection.

[12] Because for most of the time, wind and solar generators are producing less than their nominal capacity. Storage could be used to smooth the output over periods of hours, reducing the maximum output.

[13] Non-firm: where a planned or unplanned outage of a single element of the electricity system (for example a transformer, a section of underground cable, or an overhead line) will require the output of the renewable generator to be limited, usually to zero. Depending on the situation, this could continue for days or weeks. A 'firm' connection has at least two separate paths, so that the loss of any one element has no impact.

Industrial and commercial sites

Renewable generation, usually rooftop solar, is being installed behind the meter on industrial sites and large commercial buildings such as offices, warehouses, and shopping centres. When used to offset the site electricity demand, the renewable production is valued at the electricity import cost; when there is surplus generation, the excess is exported to the grid at substantially lower value. This often means that the economic optimum size for the solar array is relatively small, sized to cover just the site's minimum electricity demand, resulting in a relatively small reduction in electricity consumption and carbon footprint.

Behind-the-meter battery storage can allow a larger solar array to be installed, by storing the generated electricity for when the site is using more electricity. The financial case for this does not yet appear good enough for this to be standard practice, though where organisations have strong carbon-reduction strategies this can be justified. However, with reducing costs for batteries and solar, this may become more prevalent, especially on sites where the storage can also provide other benefits, such as reducing charges for use of the electricity system: see Section 2.7.

Islands

Similar to the industrial sites discussed above, electricity connections to islands can limit the wind capacity which it is economic or technically possible to install. So far, only relatively small batteries have been installed on Scottish islands[14]; greater use has been made of Active Network Management schemes to constrain generation when necessary (e.g. Orkney), and forms of demand-side management (using surplus energy to produce heat or hydrogen on Shetland). On both Orkney and Shetland, these actions have so far largely been driven by innovation funding.

The actions which can be taken on island systems are strongly affected by principles of electricity regulation. This is discussed further in the following section.

2.5 Deferring or avoiding network investment

Electricity networks in Europe, both for transmission and distribution[15], are designed to be extremely robust, i.e. to be able to continue uninterrupted operation despite credible combinations of events and equipment failures. The main philosophy has been to build an extensive interconnected network with multiple paths between generators and consumers. However, this principle is under strain for several reasons:

- The shift to renewable generation means there are more small generators, often connected to the distribution system. Unlike larger thermal power stations, these renewable generation projects can be proposed, consented and constructed faster than the transmission and distribution systems can be expanded to accommodate them.
- Wind and solar generation makes less use of the network: for the same transmission capacity (in MW), over the year there is less energy transmitted (in MWh). The capital costs of networks are largely a function of capacity, rather than energy transmitted.
- There is growing public opposition to the visual impact of substations and overhead lines.

Further, it is possible in future that rapid growth in EVs and possible electrification of heat could lead to large local increases in electricity demand, again faster than new network capacity can be constructed. This could particularly affect rural areas; for example, longer delays in network reinforcement could mean rural customers are more likely to face constrained EV charging times.

[14] For example, a 1 MW lead-acid battery on Shetland as part of the NINES project, and a 2 MW LI battery on Orkney.
[15] Transmission systems are intended for bulk long-distance transfer of energy at the highest voltages (132 kV and above in Scotland). Distribution systems operate at lower voltage levels and supply energy to consumers; traditionally this energy came from the transmission system but increasing amounts of 'embedded' generation are now connected to distribution systems, particularly wind and solar. In some cases (for example, the GB transmission system) there is a split between the 'owner' (responsible for financing, construction, maintenance) and the 'operator' (responsible for safe and economic operation of the electricity system).

Battery storage is an alternative to network expansion or can be used to defer expansion. It acts to smooth out the daily peaks and troughs of power flows; electricity network capacity requirements are very strongly driven by the peak flows. Therefore, it is particularly suited for:

- Temporary situations, for example to cope with network failures, or to cover a gap until new network can be constructed. It is relevant that standby diesel hire companies now also offer transportable battery storage; particularly useful for short-term needs where noise and fumes are an issue, such as close to housing.
- Where the electricity flows are particularly 'peaky', i.e. high occasional use, low average use. Sports stadia are an extreme example.
- Where there is considerable uncertainty: in particular, it can allow network owners the time to build a strong case for network investment to present to the regulator, based on operational data.

Islands present a particularly extreme version of this situation, especially with renewable generation as noted in the previous section. This is because there is often no 'gradual' or incremental option for reinforcing island connections or building new ones. The most sparsely populated rural areas face the same issues.

However, there is a fundamental regulatory problem: storage is treated as a generator, and network operators are prevented from operating generators[16]. In principle, there are four possible solutions to enable battery storage to deliver network benefits:

- Treat as 'innovation'; all batteries operated by network owners in the UK so far have been treated as innovation projects in some way. This is a short-term solution only.
- Allow network owners to invest in and own storage assets, but strictly regulate the way in which the assets are used. In practice this is very hard to define: it also limits the economic benefits which the storage asset can provide.
- Network owners could invest in and own storage assets and contract the operation to an independent operator. The independent operator must operate the asset to achieve the desired effect but can use any spare capacity at any time to earn income from other sources.
- The network owner contracts for services from storage, and a storage provider builds, owns, and operates the asset. This is the direction of travel in GB, with distribution system operators such as Western Power Distribution and UK Power Networks developing technology-agnostic flexibility markets to help manage local constraints.

As an example, the system operator in South Australia financed the construction of a large battery on a weak part of their system, and contracted operation to an electricity supplier and generator [6]. The contractor earns income from providing other services, as in the following section, and the lease payments are understood to be sufficient to pay back the system operator's capital investment in 12 years. This is a shorter payback time than is usually the case for traditional network investments.

2.6 Ancillary services

Electricity system operators need several forms of 'services' in order to be able to operate their network reliably. Traditionally, these services have largely come from large fossil, nuclear or hydro generators. As this traditional generation capacity reduces, other suppliers of these services are needed. This is prompting major efforts by system operators, including National Grid, to define what they need.

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[16] In the UK and many other countries, there is a strict limitation on electricity network owners and operators also owning generating plant. This is to prevent the monopoly electricity operator from having an unfair advantage in the competitive wholesale energy market, and ancillary services markets.

Initially this attempted to directly replicate the services from the large generators, including some that previously were not explicitly defined or even recognised as services. More recently, the aim is to define what is needed in a 'technology-agnostic' way. This process is further driven by regulators' realisation that this opens up new opportunities for cost reductions by obtaining these services through market mechanisms rather than mandatory provision through Grid Codes, or by regulated prices. Payment for provision of these services is weighted towards payments for availability rather than for use. This recognises that often the costs of providing the service are driven by capital cost, rather than use.

The international picture is complex, especially as different jurisdictions use different terminology and define services differently. The situation for the GB system is well defined by National Grid, particularly through the Operability Strategy framework [7]. In summary, the services relevant to battery storage can be summarised as follows:

- Frequency Response and Reserve

This is the ability to increase or reduce output power quickly in order to balance supply and demand, thus maintaining the system frequency close to 50 Hz. 'Response' means automatic action on short timescales, sub-second to tens of seconds, and 'Reserve' means manual or automatic actions on timescales of minutes or longer.

Battery storage is proving very competitive in these markets: all winners of National Grid's 2016 tender process for Enhanced Frequency Response were battery projects. Demand-side management can achieve the same effects and may become a strong competitor to battery storage. On the longer timescales of Reserve services, it is notable that there is considerable interest in the US on using battery storage with durations of several hours to replace thermal generators currently in 'peaking' operation, i.e. generating only during the daily peak in demand.

Enhanced Frequency Response and subsequent auctions for Firm Frequency Response have been the main sources of revenue for grid-scale battery projects in the UK. However, prices have fallen significantly recently, demonstrating that this is a relatively small market which saturates quickly. The same may be true of other ancillary services markets.

- Capacity

Capacity markets are intended to ensure that sufficient generation capacity is built or retained to provide a secure electricity supply during peak demand periods. This may be more economically efficient and successful than relying on high wholesale prices during peaks. Battery storage can compete in GB capacity market auctions, though with a substantial 'de-rating factor' for short storage durations. The de-rating factors are applied to competing bids in the Capacity Market auction and provide a good indication of National Grid and Ofgem's current views on the capacity needs of the GB system to meet demand peaks. A combined-cycle gas turbine has a derating factor of 89%; storage of 4 hours duration and longer fares better with a de-rating factor of 95%, but this declines sharply for shorter storage durations, reaching 17.5% for a duration of 30 minutes [27].

- Voltage control

Voltages across transmission and distribution networks must be kept within statutory limits. This can be difficult on weak networks, especially as more generation is added to those networks. Battery storage devices all have power-electronic converters, to convert between the Direct Current in the batteries and AC. These converters can be controlled to produce or consume reactive power, which can control voltage on the nearby network, in response to signals from the network operator. This has almost insignificant capital or operational costs. Innovation projects are under way in the UK, and we can expect markets for voltage control services to emerge, particularly on distribution networks.

- Black start

'Black start' is the term used for the process of re-starting an electricity network after a complete failure. Generators can earn income for having the capability to contribute to this process, and there appear to be no regulatory barriers to prevent battery storage doing the same.

2.7 Services or benefits for industrial and commercial sites

Section 2.4 noted the benefits of battery storage in enabling greater use of behind-the-meter renewables. Battery storage can also provide benefits in other ways:

- Several elements of ***network charges*** are a function of peak demand. Battery storage can be used to reduce peak demand, or to shift it to periods when the charges are reduced. Some of these elements are currently under review [8]. However, some element of peak demand charge is expected to remain.
- Some elements relate to the contracted ***connection capacity***. Battery storage can reduce the required connection capacity, though this is more likely to be useful in avoiding the need to increase connection capacity if electricity demand on the site increases.
- Behind-the-meter battery storage can provide ***ancillary services*** as described in Section 2.6. Response and reserve services are the most likely. There are many business models for this: the site's electricity supplier may offer to manage this, or a third party ('aggregator' or energy services company), or large organisations can take this on internally. Energy suppliers and aggregators may offer to finance the battery storage, with the site owner merely providing space and a grid connection.
- Battery storage can provide ***secure supply***, in the same way as a standby diesel generator.

At present, these benefits are not yet sufficient to create a substantial market in the UK, based on economics alone. As battery costs fall and awareness grows, niche markets are likely to appear. As an example, a battery system with two hours of storage capacity is being trialled in a hotel in Edinburgh [9] – see the case study below.

Case study: Premier Inn, Edinburgh Park

Image: Whitbread

Whitbread operates around 800 hotels across the UK and is investing across its properties in order to reduce environmental impact and energy costs. They have chosen the Premier Inn at Edinburgh Park to investigate and demonstrate benefits of battery storage 'behind the meter'. A 100-kW battery with 2 hours duration was installed in 2018, with the aims of:

- Reducing peak demand charges
- Purchasing electricity in low-price periods
- Earning revenue from provision of ancillary services: typically, these can include frequency response, reserve and reactive power.

Experience to date with the first two of these aims has been good. Revenue from ancillary services markets in 2019 has been volatile, and Whitbread is of the view that stability in these revenue streams would be beneficial in establishing the business case for future battery installations.

The battery is owned by Whitbread, and is operated by E.On, from its control centre in Glasgow.

Whitbread is particularly interested in the case for batteries in hotels with onsite PV generation, as this will help to match PV production with the hotel demand, which is concentrated in early mornings and evenings.

The Edinburgh Park battery is a retrofit, consisting of containerised equipment located in a service yard. For new-build hotels, especially in congested city-centre locations, there would be advantages in locating the battery in a basement. There could also be advantages in more closely integrating the battery with the hotel electrical system at the design stage, to optimise provision of power for essential loads.

2.8 Battery storage capacity required

This section estimates the total capacity of grid scale battery storage likely to be required in Scotland by 2030 and 2045.

Battery storage capacity in GB is predicted to increase significantly in the coming years under most commonly modelled scenarios. The many roles that battery storage can play, as described in previous sections, represent crucial needs of the GB electricity system that must be met if Scottish Energy Strategy and Climate Change Plan targets are to be met.

Yet, while there is little doubt that the capacity of battery energy storage in GB and Scotland will increase in the future, there is significant uncertainty as to the rate and scale of this growth. The use of different scenarios for the evolution of the GB energy system can be used to help illustrate the range of possibilities.

Methodology

This analysis is based on estimates provided by National Grid, Scottish Power Energy Networks (SPEN) and Scottish & Southern Energy Networks (SSEN). In each case, the two most ambitious scenarios for carbon emissions reduction are chosen. These are the 'Two Degrees' and 'Community Renewables' scenarios used by National Grid[17] and SPEN, and the roughly equivalent 'Proactive Decarbonisation' and 'Local Optimisation' scenarios used by SSEN.

National Grid Future Energy Scenarios (FES) data has acted as a reference point for this analysis. However, these data alone are not sufficient: they do not provide a clear breakdown of its projections by geographical area, only for the whole of Great Britain.

SPEN projections are taken from their 'Central and Southern Scotland Electricity Scenarios 2018' report [33], and SSEN projections are taken from their 'North of Scotland Future Energy Scenarios' report [34], also published in 2018.

The following methodology was used to generate the results:

Both SPEN and SSEN figures were adjusted upwards to put them in line with 2019 projections. The adjustment made is proportional to the difference in National Grid's FES projections for each scenario between the 2018 and 2019 FES publications.

- SPEN's report provided projections only for the years 2030 and 2040. It was considered reasonable to extrapolate to 2045.
- SSEN provide projections only up to 2030. It has been assumed that the battery storage capacity within northern Scotland doubles between 2030 and 2045.
- SPEN's projections for 2030 include estimations for the proportion of capacity that is made up of behind-the-meter installations. This capacity is very small (well below 10%) and was removed from the projections in order to provide a clear figure for 'grid-scale' capacity. A similar proportion of capacity was removed from SPEN projections for 2045, and both SSEN projections.

Results

The grid scale battery energy storage capacity in Scotland is predicted to increase significantly between 2030 and 2045 – see Figure 1.

[17] The FES also includes a 1.5 degree Net Zero sensitivity study, in less detail than the main scenarios; this was considered and it was found that the implications for storage capacity fell within the range of the Two Degrees and Community Renewables scenarios.

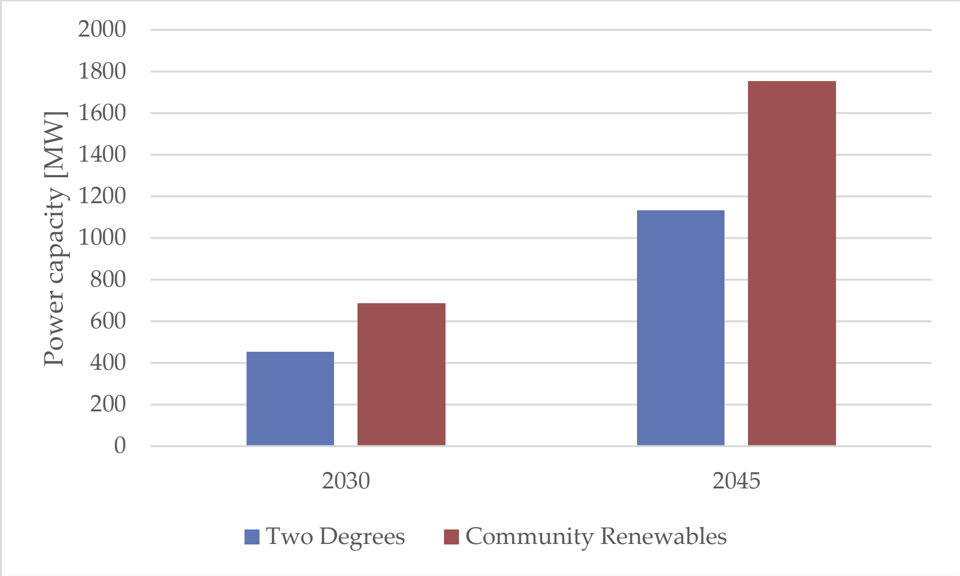

Figure 1: Forecasts of battery storage capacity in Scotland by power rating

Across the two scenarios modelled, the Community Renewables scenario predicts greater volumes of battery storage, with an increase from 687 MW in 2030 to 1,754 MW in 2045. Under the Two Degrees scenario, 455 MW of grid scale battery storage capacity is anticipated in 2030, rising to 1,134 MW in 2045. These figures represent just a fraction of the energy storage capacity connected to the entire GB electricity network. National Grid project a GB energy storage capacity of 11,746 MW and 12,300 MW in 2030 for the Two Degrees and Community Renewables scenarios, respectively. These numbers rise sharply to 18,502 MW and 27,362 MW in 2045. It should be noted that these figures include pumped hydro storage capacity[18] that is excluded from the Scotland-only battery storage results presented here.

For comparison with Figure 1, FES estimates that grid-connected battery storage capacity for all of GB in 2018 was 840 MW. Virtually all of this was installed in at most the last 3 years, giving an installation rate for GB of around 300 MW/y. The estimates in Figure 1 imply a long-term installation rate for Scotland of no more than 70 MW/y, which appears readily achievable with a stable policy background.

Energy storage capacity (MWh) is not defined in the source data, though Everoze believes it is credible to assume an average storage duration of 4h around 2030, and 6h in 2045[19]. These assumptions have been applied in Figure 2.

[18] Current pumped hydro capacity on the GB system is 2.7 GW. FES predicts this to rise to 5.8 GW by 2045 in the Two Degrees scenario, and to 5.1 GW in the Community Renewables scenario. Both represent substantial rises in storage capacity, but very significantly less than the increase in battery storage capacity.

[19] This is based on current experience, which shows the storage duration of new battery projects gradually increasing, as battery prices drop and more markets for battery services emerge at longer durations. Everoze does not expect battery storage durations to extend beyond a few hours by 2045, because it is expected there will still be a strong daily cycle in electricity demand.

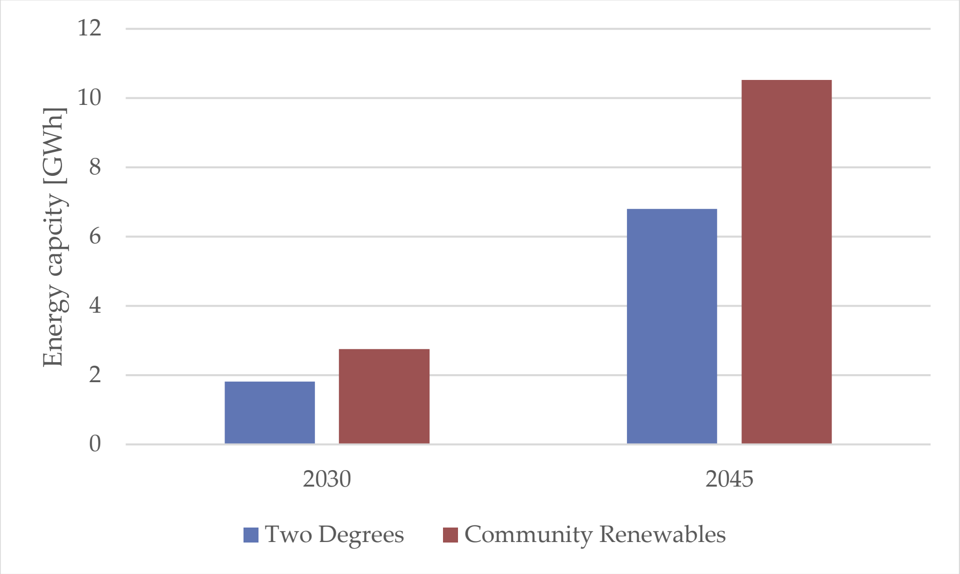

Figure 2: Forecasts of battery storage capacity in Scotland by energy capacity

2.9 Roles and value: summary for Scotland

The discussion in previous sections is summarised in the following table. Note that there may be significant overlap between some of the future roles.

The table uses a traffic-light system to highlight roles which may be most significant. Green indicates significant growth, or relevance for policy development; amber indicates less significance; and red indicates no or very little impact.

Table 1: Grid-scale battery storage roles and value relevant to Scotland

Role	Short term	2030	2045
Energy arbitrage	On the verge of economic viability for Balancing Mechanism and intra-day markets, albeit with high revenue risk.	Possibly significant role: depends on electricity market design. Capital-intensive investment; value likely to go mainly to investors rather than location.	As 2030.
Managing renewables: national scale	Negligible: capital costs and losses of battery storage are too high	Likely significant role managing variable renewables. Faces competition from DSM (especially EV charging), thermal storage and Power-to-Gas. Possibly also competition from new pumped-storage projects if these become investable. Potentially high value to Scotland, by reducing costs of variable renewables.	Role as 2030. Potentially higher need, therefore greater value to Scotland.
Co-location with renewables	Already happening in GB, though only in conjunction with other sources of revenue. In the short term, this is affected by development of electricity network charging principles.	Likely to become standard practice, especially with solar, assuming network charging principles are cost reflective. Potentially high value to Scotland, by reducing costs of variable renewables.	Role as 2030. If Scotland continues to have a greater fraction of variable renewables than the rest of the UK and continental Europe by 2045, then the high value to Scotland will remain.
Industrial and commercial sites	Depends on electricity markets and network charging principles; Ofgem's Targeted Charging Review currently makes this model challenging.	Likely to become standard practice on sites with time-varying electricity demand, assuming network charging principles are cost-reflective. No particular benefit to Scotland compared to the rest of the UK or to other countries.	As 2030.

Deferring or avoiding network investment	Likely to move from exploratory or innovation-funded activities by network operators, to 'business as usual'.	Battery storage is likely to have a role as one of the standard approaches to electricity network expansion and reinforcement. The ownership issue is likely to become less significant, as business models for third-party provision develop, either as infrastructure, or as a 'congestion management service' or similar. Likely to be more valuable to Scotland than to the rest of the UK, because of the proportionally larger number of customers on weak grids in rural areas and on islands. These areas may face major difficulties if decarbonisation strategies for heat and transport result in large increases in electricity demand.	As 2030.
Ancillary services	Currently the major source of revenue for UK battery storage projects. More ancillary services likely to be defined by network operators. However, experience so far is that these markets are small and easily saturated, leading to low prices.	Battery storage is likely to have a very substantial role in providing a wide range of ancillary services, including services not yet defined. Significant competition is possible from other options such as DSM and pumped hydro. Most ancillary services are not location-specific, so no particular benefit to Scotland compared to the rest of the UK or to other countries. A few such as voltage control and black-start capability may have particular value to Scotland.	As 2030 but higher volumes.
Islands	Potential benefits in facilitating large-scale wind on island groups. Significant regulatory barriers in using battery storage: may need political will to remove barriers to major investments.	Costs of battery storage are likely to fall relative to costs of island connections. If heat and transport decarbonisation strategies are successful, electricity demand on the islands is likely to increase very significantly, making battery storage attractive instead of increased connection capacity. On the other hand, if the heat decarbonisation strategy leads to significant heat storage in centralised networks or in buildings, this may be a better use of surplus renewable electricity. EV charging could have a similar effect but smaller in scale. Potentially a significant value to Scotland in minimising the costs of decarbonisation strategies on the islands.	As 2030 but higher volumes.

2.10 Business models

This section considers the business models which may best support the deployment of grid scale battery storage in Scotland today, and how this might this change in the future.

The main source of income at present is contracts for providing frequency response, either National Grid's Enhanced Frequency Response[20] auction launched in 2016, or the more recent Firm Frequency Response. It is understood that all projects which provide this service also gain, or intended to gain, income from other sources of revenue; so-called 'revenue stacking'. Revenue stacking is likely to continue in future, though the mix of services provided will change, as new services are defined and tendered for by National Grid and distribution network operators.

Note that revenue stacking has always been commonplace for thermal generators; however, the vast majority of their income has been electricity sales. This highlights the problem for storage projects: they do not have a single long-term source of income which is dependable or at least reasonably forecastable. This is a major difficulty when financing storage projects, and is one reason why new pumped-hydro projects in Scotland have not yet proceeded: their construction period is so long that construction has to start with no certainty of the sources of revenue once in operation.

Therefore, some argue that the best business model to support deployment of grid scale battery storage, and indeed all capital-intensive or infrastructure-type projects, is with long-term contracts to cover at least a portion of their income. Current GB regulatory practice prefers auctions for relatively short periods, because of the rapid evolution of technologies and business models: there is a reluctance to get tied into long-term contracts when better alternatives may emerge in the near future.

Regulators can however take actions to assist:

- Allow the longest contract duration compatible with the regulatory principles;
- Aim for clarity in requirements, including particularly definitions of the tests to prove compliance[21];
- Promote the development of liquid, well-functioning markets within a stable policy regime, so that industry feels more comfortable to take a view on long-term market pricing.

Another model is emerging: 'aggregators' who operate a portfolio of assets providing ancillary services to the electricity system, trading electricity, and providing other energy services to industrial, commercial and residential customers. They may own the assets, lease them, or simply operate them[22]. This approach attempts to deal with the revenue uncertainty issue through a portfolio effect, so the risk of a particular asset type such as battery storage failing to earn sufficient revenue does not have such severe consequences as it would for a stand-alone battery storage project. The case of residential battery storage in Germany is relevant: many householders[23] have installed residential-scale batteries in order to maximise their internal use of their rooftop solar panels [31]. The financial case for this is poor but is driven by other factors. Even in this situation of multiple very small units, it has proven economic for companies such as electricity suppliers and

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[20] Or in the case of the Broxburn project in West Lothian, an exploratory precursor to EFR developed under a bilateral contract, i.e. not an open tender process (image in Section 4.3).

[21] Compliance testing is very important, to ensure system operators get the performance they need, perhaps in critical situations.

[22] In the case where aggregators only operate the asset, the asset owner still faces substantial risk unless the owner too has a portfolio of assets.

[23] Currently around 150,000 households in Germany, with total storage capacity around 400 MW and 1 GWh. Around half of all new residential solar installations incorporate a battery.

PV suppliers to offer to control these batteries, providing ancillary services and running 'markets' to allow householders to trade solar-generated electricity amongst themselves.

An important part of any business case for battery storage are the assumptions about lifetime, and what happens at End of Life (EoL). Standard practice has not yet emerged here, as few projects have operated for long enough. Assumptions are made about the cost of decommissioning, and even whether an EoL battery is actually a liability or an asset – if a method is found to cost-effectively recycle them. In some cases battery suppliers have undertaken to take back the active parts of the batteries, but even without such specific agreements the battery supplier will have certain responsibilities at end of life under 'producer responsibility' rules, see [10]. It is possible or indeed likely that battery project lifetimes will be extended by adding new battery capacity, similar to life-extension actions for a wind farm. The useful life of the battery cells is almost certainly less than the useful life of the other equipment on site (power conversion systems and electrical / civil Balance of Plant) and so replacing the batteries is likely to be a financially attractive option compared to building a new battery site, as long as land access and planning conditions allow. Business cases for grid-scale battery assets may typically consider a useful life of 15-20 years but that is likely to include at least one occasion when the batteries are augmented or replaced.

2.11 Possible actions: views of stakeholders

Interviews were held with the stakeholders listed in Appendix 1 in order to gather views from a range of organisations with interests and experience in battery storage. During the interviews, some stakeholders expressed opinions on possible actions which may provide value to Scotland's electricity system. These are summarised below.

Electricity system operation

In the case of Scotland and the wider GB system, there was general agreement amongst interviewees who expressed an opinion that the benefits for electricity system operation are principally:

- Aiding integration of high levels of variable renewables, principally wind and solar, driven by decarbonisation objectives. Achieving these objectives is discussed separately below.
- Contributing to security of electricity supply.
- Replacing ancillary services previously provided by large thermal generators; itself a result of the growth of wind and solar.
- Providing other options to reinforcing electricity networks, as demand grows. Demand may grow rapidly as a result of policies to decarbonise heat and transport.

It is therefore likely that Scotland will see continuing growth in grid-scale battery storage, of similar sizes to those seen so far in the UK [24], and similar technologies, at least in the short term[25]. Actions which interviewees suggested could facilitate this are:

- The planning system should not create unnecessary barriers to battery storage. This is largely a matter of familiarisation and capacity-building and is discussed further in Section 4.
- Promoting the development of local markets by distribution system operators (DSOs), to manage constraints on their networks. Tender processes should be managed in order to allow sufficient time for potential bidders to be able to talk to, for example, existing customers in the area who could benefit from hosting battery storage. Currently, timescales can be too short.

[24] In the range 1-50 MW, and storage duration 30 minutes to 2 hours, likely increasing towards 4 hours as battery prices drop, and markets develop.

[25] At several points in this document it is noted that there are competitors to battery storage, principally demand-side management, interconnectors to other electricity systems, and other forms of storage. In Scotland, the large pumped-hydro projects are potentially major competitors. Battery storage has advantages of speed of deployment and small unit size.

- Ensuring that ancillary services contracts drafted by the DSOs or National Grid avoid 'exclusivity' clauses (i.e. barriers to providing other services from the same battery capacity at other times) unless truly necessary.

Meeting decarbonisation targets

To provide some context, it is important to note that battery storage is not of itself 'green' in any way: it uses substantial quantities of materials (see Section 3), and around 15% of the energy imported is wasted as heat[26]. Battery storage only assists in meeting decarbonisation targets to the extent that it allows fossil generators to operate more efficiently, or to reduce the costs of integrating variable renewables (wind, solar) in the electricity system.

The experience from other regions which have achieved high renewables penetration (Ireland, South Australia, Texas[27]) is that battery storage is not so far essential[28], but it is useful. As penetration increases, the need for storage increases.

The need for long-term storage for months or seasons only appears at very high penetrations; battery storage is unsuitable for this.

Suggestions from interviewees in this area are:

- It is important that electricity markets provide clear signals to low-carbon generation owners and developers about the time value of electricity, and also operate at the shortest feasible timescales. For example, intra-day markets allow forecasts of renewables production to be significantly more accurate than day-ahead markets.
- Energy policy for Scotland, if based on assumptions of high contributions from wind and other variable renewables in the medium and long term, should address the issue of seasonal storage for which batteries are unsuitable [32]. In particular, decarbonisation of heat is a significantly different issue for Scotland than for the UK generally, with different challenges and opportunities for energy storage and renewables.

[26] A generic figure, typical of manufacturers' published data. Depends on usage.
[27] All these have substantial solar or wind penetration and are only very weakly interconnected to other electricity systems.
[28] I.e. other solutions are available (demand management, greater interconnection, flexible generation, and other forms of energy storage as already discussed). However, some of these alternatives run counter to decarbonisation objectives: diesel or gas-fired peaking generation, or storage technologies with substantially poorer round-trip efficiency.

3. Sustainability, environmental and safety issues

3.1 Purpose

The aim of this section is to provide evidence and analysis to inform government policy on sustainability, environmental and safety issues relevant to the deployment, decommissioning and end-of-life (EOL) treatment of battery storage projects and component parts.

3.2 Sustainable supply

Batteries for grid-scale storage

Stationary energy storage system applications predominantly use lithium-ion batteries (LI). There are various different 'chemistries' of LI batteries, of which Nickel Manganese Cobalt (NMC) and Lithium Iron Phosphate (LFP) are the most common for grid-scale battery storage. This section concentrates on NMC, where the sustainability concerns are greater.

A major reason for the dominance of LI in stationary storage is that electric vehicles currently also rely on LI, as do a wide range of portable electronic devices. Many manufacturers therefore produce LI batteries for both EVs and stationary storage. Currently, the EV market is far greater than that for stationary storage, and this is expected to continue.

Lithium-sulphur is an example of a potential emerging battery chemistry that may provide an alternative to lithium-ion for some applications. Flow batteries may also find a market for longer-duration storage. These use vanadium; however global supply of vanadium is not seen as a risk as it is already used in substantial volumes in the steel industry.

Table 2 – Materials typically used in NMC LI batteries

Anode and current collector	Graphite and copper foil
Cathode and current collector	Layered transition metal oxide (e.g. nickel, manganese, and cobalt) and aluminium foil
Separator	Polymer / ceramic composites
Electrolyte	Lithium salt in organic solvent
Container	Aluminium

Sourcing LI battery materials

The materials required for production of lithium-ion batteries are part of complex global supply chains. Through the stages of extraction, processing, production of component parts, cell manufacture and battery pack assembly, materials initially sourced in South America, Africa or Australia will typically be transported to one or more locations in Asia, and to a lesser extent in North America and Europe, and then onwards for further assembly or final product sale.

The top producing countries' estimated global resources reserves and annual production capacity for lithium, cobalt, nickel, manganese, copper and graphite as of 2018 are summarised in **Appendix 2**. Batteries make up only a small fraction of the end-use market for nickel, manganese, and copper, whereas significant proportions of lithium and cobalt are used for battery manufacture.

Factors affecting supply

As well as resources, reserves and production capacities, aspects to consider when assessing whether a sustainable supply of LI materials will be possible also include:

- Recycling rates (and therefore reduction in primary demand)
- Substitutability of materials and development of new battery technologies
- Supply risks such as geographical concentration of supply and political stability
- Demand on materials from other sectors.

In a study of materials important for batteries, **copper** (which is difficult to substitute) and **lithium** (which currently has low levels of recycling) have been highlighted as posing the greatest challenges to reducing total demand through substitution or advances in battery material efficiency and recycling [12].

Although derived using different criteria and methodologies, four 'criticality of supply' rankings[29] for LI materials are summarised in **Table 3**. This highlights higher risks for **cobalt**, **lithium,** and **graphite**, than nickel, manganese and copper. The highly concentrated sourcing of cobalt, lithium and graphite is also illustrated in a European Commission report of 2018 [12].

Table 3 – Summary of four material supply criticality assessments

Element	EU Critical Raw Materials List (2017) [13]	US Dept of Interior Critical Minerals List (2018) [14]	British Geological Survey Relative Supply Risk Index (2015) [15]	Royal Society of Chemistry Relative Supply Risk [16]
Cobalt	✓	✓	8.1	7.6
Lithium		✓	7.6	6.7
Graphite (natural)	✓	✓	7.4	8.1
Nickel			5.7	6.2
Manganese		✓	5.7	5.7
Iron (for steel)			5.2	5.2
Aluminium		✓	4.8	4.8
Copper			4.8	4.3

Note: higher scores identify greater risk

Determining what the future demand for grid-scale battery materials is likely to be is a complex undertaking, not least as it requires projections for how battery technologies will develop, the rate of expansion of the EV market and potential changes in other sectors that use the same materials.

There are multiple predictions however for a large growth in demand for **lithium** and **cobalt**: for example, the World Bank expects demand for both to grow >1,000% from 2017 to 2050 in a 2-degree climate scenario [17]. Similarly, the World Bank anticipates this demand could be difficult to meet: for example under a scenario of 100% renewable energy and transport by 2050, cumulative cobalt demand would reach 423% of reserves or 120% of resource levels[30], and for lithium 280% of reserves and 85% of resource levels.

[29] I.e. risks of inadequate supply
[30] Definitions of 'Resource' and 'Reserve' are provided in Appendix 2.

Using the results of Section 2.8, we estimate LI batteries for Scottish grid-scale storage scenarios to require the quantities of cobalt and lithium shown in Table 4. This is based on current material intensity values derived from [11] and assumes predominantly NMC technology. There are major assumptions in this estimation process, and the results should be treated as indicative only.

The figures are also presented as a fraction of 2018 global production, in order to give a sense of scale. For clarity, the quantities estimated here are ***total*** material consumption for the storage capacities installed by 2030 and 2045, and therefore comparison with 2018 annual production should be treated with care.

Table 4 –Estimated lithium and cobalt material requirements for Scottish grid-scale storage

Scenario	Storage battery capacity (assumed)	Storage capacity	Total requirement (113 t/GWh)	Fraction of global production 2018 (85,000t)	Total requirement (124t/GWh)	Fraction of global production 2018 (140,000t)
			Lithium		Cobalt	
2030 Community Renewables (687 MW)	4h	2.75 GWh	311 t	0.4%	341 t	0.2%
2030 Two Degrees (455 MW)	4h	1.82 GWh	206 t	0.2%	226 t	0.2%
2045 Community Renewables (1,754 MW)	6h	10.52 GWh	1,189 t	1.4%	1,304 t	0.9%
2045 Two Degrees (1,134 MW)	6h	6.80 GWh	768 t	0.9%	843 t	0.6%

Social & environmental sourcing issues

In addition to the physical availability of LI materials, the sustainability of supply also depends on important social and environmental factors. Awareness of environmental and human rights issues in relation to mineral sourcing has increased over the last decade, with several recent campaigns directed specifically towards batteries and renewable energy: for example, Earthworks' *'Making Clean Energy Clean, Just and Equitable'* [18].

Appendix 3 provides a summary of reported social and environmental issues related to the sourcing of cobalt, lithium, and graphite: the materials with higher supply risks highlighted above and/or a significant proportion of end-use going towards battery manufacture. These issues include the effect on communities and individuals of reduced water availability, water, soil and air pollution, a wide range of health issues, child and forced labour, dangerous working conditions, and links to conflict.

Addressing social & environmental sourcing issues

As awareness of the environmental and social issues linked to the supply of materials such as cobalt and lithium has increased, so have the number of tools and initiatives seeking to address these issues. **Appendix 4** provides a summary of these and includes UN guiding principles, country-specific legislation and reporting requirements, assessments and benchmarking of various companies, mining industry good practice and standards, due diligence guidance and independent verification and certification schemes.

However, some of these are in their early stages (e.g. benchmarking/assessments that have started by focussing on certain companies or sectors), have low levels of adoption (e.g. UN

Guiding Principles Reporting Framework [19]) or are based on voluntary participation rather than legally binding obligations to conduct supply chain due diligence. An example of the first of these is the Know The Chain benchmarks for companies in the ICT, food and beverage and apparel and footwear sectors [20].
According to Transitions Mineral Tracker, of the top 15 companies mining copper, cobalt, and lithium, only nine have human rights policies in place [21]. Some recent progress by a small number of battery manufacturers in identifying their mineral suppliers has been noted [22], but it is currently difficult to determine the overall proportion of LI battery materials that could be considered as sustainably sourced. Although presently likely to be low, greater adoption and standardisation of tools such as those listed in Appendix 4 could positively impact this.

The EV market is thought to have made less progress than the technology sector in adopting robust supply chain due diligence [23] but the consumer-facing nature of EV brands, recent publicity and challenges issued will hopefully also lead to significant improvements in the sourcing of materials for all LI batteries: for example, in March 2019 Amnesty International issued a challenge to the EV industry to produce the world's first completely ethical battery by 2024 [24].

It is worth noting that recent developments in lithium-ion battery technology are producing cells with greatly reduced amounts of cobalt, or indeed cobalt-free. In addition, the existing mature Lithium Iron Phosphate (LFP) technology has lower specific energy capacity (kWh per kg) than chemistries which include cobalt, but this is not a critical issue for stationary grid-scale batteries. Therefore, cobalt supply chain issues may be less important than previously thought, especially for stationary storage.

Influencing procurement

A Scottish Government policy position on social and environmental issues in supply chains for raw materials generally could, through planning policy, influence battery projects to demonstrate compatibility with the policy. This may be achieved through a requirement or preference for project developers to demonstrate how they are addressing social and environmental risks in their business and their supply chain. This could include demonstration of independent review of the supply chain. Currently, the planning system has no such legislative powers to require that type of procurement by developers, so this would be a major change of approach.

Factors for evaluation could include:

- Due diligence undertaken following the UN Guiding Principles of Business and Human Rights
- Sourcing practices are aligned with OECD Due Diligence Guidelines
- Smelters/refiners within the supply chain being compliant with the Responsible Mineral Process Assurance Standards
- Voluntary participation in initiatives or use of tools, e.g. smaller companies filing Modern Slavery statements to demonstrate their due diligence and use of the Corporate Human Rights Benchmark core indicators.

3.3 Decommissioning and recycling

There is little practical experience of decommissioning of battery technologies relevant to grid-scale batteries in Scotland. Project developers and owners interviewed during this work were confident that decommissioning would not be an issue. The major parts of the installation are standard civil works and electrical equipment. The only 'new' issues are to do with disposal of the battery cells and other components of modules. Battery producers[31] retain the responsibility for disposal [10].

Currently LI battery recycling and disposal costs more than the value of the recovered materials. Cobalt and nickel have the highest value, whereas lithium and manganese are less likely to be recovered [29]. The economics of recycling are strongly dependent on volumes and standardisation, and currently volumes are low.

At present, batteries of all technologies are handled at recycling facilities in the UK and Europe[32], as part of the waste stream arising from the Waste Electrical and Electronic Equipment and the Batteries Directives. Figures for collection and recycling rates in Europe, for all waste batteries are given in [30]. However, it is not clear how much of the LI battery waste stream is currently processed in Europe, or merely sorted and transferred to Asia for recycling. There may be opportunities for the establishment of battery recycling facilities to address this increasing waste stream and reduce primary demand for materials[33].

In the future, it is expected that LI battery recycling will be driven by the volumes of batteries coming from the EV industry. Vehicle manufacturers are likely to retain the responsibility for recycling, or re-use in 'second-life' applications. There is much discussion about the possibilities for using EV batteries in second-life static applications once they have degraded such that they are no longer good enough for EV use. Such second life re-purposing has been proven technically but it is still very uncertain whether this will be able to compete with the use of new batteries, especially given the likely fall in the price of batteries in the short to medium term.

For other battery technologies, such as flow batteries, recycling paths are less mature, though suppliers state that all materials can be recycled or safely disposed of[34].

The general conclusion is that, while there are technical and financial issues with effective recycling, the sheer scale of LI batteries needing to be recycled, and the legal obligation of producers within Europe to dispose of batteries at end of life, is likely to produce a competent recycling and waste management chain. This is most likely to be driven by the EV manufacturers.

3.4 Factors relevant for development consent

This section considers issues that could be relevant when considering planning applications for grid-scale battery storage, and any mitigating actions.

Construction stage

Most of the factors are relevant for any construction project, and so are not discussed here.

There is a specific risk for those battery technologies which involve transport and installation of materials which could leak. For LI and other technologies constructed in modules, the worst leak will be small. For flow batteries, large quantities of liquids could be released, though mitigation is straightforward.

Operation stage

There will be **noise** from the operation of electrical equipment, particularly transformers and power-electronic converters. Noise from cooling fans and pumps may also be an issue. This is very

[31] Or importers if the manufacturer has no legal entity in the importing country. Under current regulations (https://www.gov.uk/guidance/waste-batteries-producer-responsibility#industrial-battery-producer-register) it is not necessarily the original producer or importer: other producers of similar batteries can also be responsible for disposal.
[32] Widespread within Europe, though information on relative volumes and specialisation in specific battery types is not immediately available. See for example https://www.environmental-expert.com/waste-recycling/battery-recycling/companies/location-europe
[33] One commentator on a draft of this report noted that there was no reason why a major recycling plant could not be located within Scotland, and indeed the low carbon intensity of electricity generation in Scotland could allow such a plant to produce recycled materials with very low embodied carbon.
[34] At least one flow battery supplier offers to retain ownership of the active chemicals and effectively lease them to the customer.

similar to the characteristics of electricity substations, and normal procedures for estimating noise emissions will be satisfactory.

For flow batteries, **leaks** are a possible issue, resolved by suitable design of containment.

For LI batteries, and some other storage technologies still at research or development stages, the electrolyte is flammable, and there is a risk of overheating leading to **fire.** This is an active area of research and policy development [25] [28]. The fire is likely to be confined to the site or to the battery container, but there could be release of smoke and potentially toxic gases. Approaches vary from 'let it burn out' to extensive fire detection and extinguishing systems, and fire separation walls between containers. The Scottish Fire and Rescue Service refer to guidance published by the Energy Institute [28] and consider fire safety for battery installations to be within the scope of the Health and Safety Executive. The HSE have stated that currently they have not published any battery-specific guidance. Owners and operator are responsible for ensuring that they have a fire safety plan for the installation, and that this is regularly reviewed and updated, as necessary.

Decommissioning stage

As discussed in the previous section, no specific issues are expected, provided obligations are placed on project owners to remove and dispose of active materials from the site. Grid-scale battery project developers will expect to be required to produce a decommissioning plan. The same may not be true of industrial and commercial operators installing behind-the-meter batteries.

4. Key spatial criteria

This section addresses several issues related to spatial planning for grid-scale battery projects. Further information on battery storage planning has been published by energy institute [35].

4.1 Criteria for siting

This section reviews the criteria which are likely to be important for identifying sites for battery storage units, and whether these should be universal, or dependant on location: specifically, urban, rural, coastal, or island. It is concluded that, with the exception of islands, there are no differences between these location classes; other locational factors are more important.

Proximity to grid connection

From the stakeholder interviews, it is clear that the main criterion for location is proximity to a grid connection. Grid connection is a significant part of storage project cost and obtaining a grid connection is subject to considerable uncertainty, at least in the early stages of project development. Except for renewables and BTM cases covered below, there is no other factor driving storage project location.

Location adjacent to existing grid substations will often mean a brown-field site, but this is not universal; a field adjacent to a substation may technically be ‘green-field’, but in terms of visual impact, vehicle access, and noise emissions it is more logically considered as a brown-field location.

The interviewees noted that other issues such as flood risk, access, ground conditions and topography were less of a constraint on their decisions on location.

For battery storage to be built by or for distribution network operators, it is possible that they may create a new substation on an existing network, to locate the battery where it can have the greatest impact on the problem it is intended to solve.

The grid connection point has also historically been a major revenue-driver for battery storage projects, influencing revenue that can be secured during winter months through ‘triad-chasing’ to help support the network during peak usage periods. This has historically favoured projects in southern GB but is undergoing reform.

Co-location with renewables

Clearly in this case, siting is driven by the siting considerations of the renewable generation project. In particular, the battery storage will almost certainly be located at the site’s substation.

For offshore wind projects, and potentially also for wave and tidal, the battery storage would be located at the onshore substation.

Behind the meter

Location will be on the industrial or commercial site; again, preferably at the grid connection point, though space may be more of a constraint on these sites.

For commercial buildings, there will be more incentive to locate the battery storage inside the building. This removes spatial planning issues, but requires interaction with architects, other building users, the fire service, and the building control authorities.

Islands

Islands are a special case, as the justifications for adding storage may well be very location-specific; for example, as part of local electricity supply reinforcement. Locations may also be constrained, and in extreme cases transport constraints may apply.

An example of the complexity of island installations is the proposed Reflex project on Orkney [26], which seeks to make the best use of Orkney’s strong renewable resources despite the very limited cable connection to the mainland. A large range of technologies are being considered for this project, including battery storage.

4.2 Benefits to local communities

This section evaluates opportunities to maximise the benefit to local communities. The following potential benefits have been identified, including some points raised during stakeholder interviews.

Local employment

Local employment during construction and operation is low; the construction period is shorter than for a wind farm, for example (a few weeks), followed by a commissioning period with only a few people on site, and operation is essentially unmanned. Nevertheless, one renewables and storage project developer who makes specific efforts to encourage local suppliers, estimated the local spend as £1.5M during development, construction, and commissioning.

Some battery development and manufacturing companies are established in Scotland; currently most are suppliers to niche markets.

Increased renewable energy development locally

If a constraint on the electricity system can be reduced by battery storage, whether constructed by the renewable developer or by the network operator, and leads to new renewable generation locally, this will cause increased local economic activity and employment.

This is particularly relevant for islands, due both to network constraints and limited alternative employment options.

Improved electricity network

Apart from the opportunity for increased renewable generation, a more robust electricity network can improve reliability and quality of supply for local residents. In principle, electricity network owners have obligations to achieve a minimum standard of supply for all customers, so no location in Scotland should have unacceptable reliability of supply. Any such benefit will therefore be small and very localised.

If EV numbers grow rapidly, particularly in rural areas or on islands, where fuel is expensive, there is a risk that network constraints will constrain EV adoption. This may possibly affect rural and island areas more than urban areas. Battery storage, possibly transportable, may be used to cover the gap until the network can be reinforced.

For those few remote communities currently without a connection to a public distribution network, batteries may offer opportunities to operate diesel generators more efficiently, make more use of local renewable resources, decrease costs, and increase quality of supply.

Lower energy costs

Battery storage could allow local industrial and commercial (I&C) businesses to generate more of their electricity demand from onsite or nearby renewables. This could reduce costs, and for some businesses the reduced carbon footprint will help meet company environmental targets and could be a strong branding benefit. At present, such projects are generally not economically viable, due to Ofgem's Targeted Charging Review eroding the value that can be accrued from time shifting. In addition, anecdotally the complexity of revenue stacking and risk allocation has led to some projects failing to be approved by I&C management teams. Nonetheless, some I&C actors are pursuing battery projects for other reasons; for instance, as regulated entities, multiple GB water utilities have been probing battery storage opportunities in response to stakeholder feedback and regulatory incentives.

Further, battery storage could help businesses to reduce Use of System costs, specifically grid charges related to peak demand.

For islands, battery storage may form part of larger efforts to develop integrated energy systems making maximum use of local renewables and including heat and transport energy as well as electricity: the Reflex project noted earlier is an example.

Avoiding grid reinforcement

Grid reinforcement in scenic areas can be controversial: battery storage may yet become an alternative.

Contribution to decarbonisation

Grid-scale battery storage offers several opportunities for increasing deployment of renewables, as noted throughout this report. As well as the direct local benefits this provides, it also allows local communities to contribute to national decarbonisation targets, reducing the effort and cost that may be required in other areas and sectors of the economy.

4.3 Grid-scale vs. distributed small-scale batteries

The costs of modular batteries such as LI are not very sensitive to scale; however, project-specific costs such as development effort and grid connection are. Therefore grid-scale batteries are likely to be significantly lower cost than multiple smaller batteries.

However, batteries small enough to be suitable for residential applications in effect become consumer products, subject to benefits of mass production and mass marketing. Further, householders may have other reasons to purchase (self-consumption of rooftop solar as seen in Germany, stand-alone supply in event of grid failure), and be more relaxed about financial returns. In addition, they offer a local solution to addressing expected future local grid constraints brought from electrification of heat and transport.

Therefore, we may see growth of residential battery systems such as the Tesla Powerwall, particularly if packaged as part of rooftop solar, or with energy supply services including EV charging.[35]

If residential batteries become popular, the direction of travel is for them to be operated and controlled by aggregators or electricity suppliers to provide ancillary services, particularly frequency response – and also to time shift usage to lower import price periods. This may be part of management of the demand of all the household's electricity loads, including EV charging.

The growth of residential-scale battery installations can be influenced via policy on housing, regulation of energy supply propositions, and product standards. Small-scale batteries may compete with grid-scale battery storage to provide ancillary services, just as demand-side management will do; they may also act to reduce price volatility, thereby reducing the opportunities for arbitrage.

In addition to residential-scale batteries, there may also be a role for grid-connected batteries smaller than the 1 MW limit defined as 'grid-scale' for the purposes of this study. These could be used by distribution system operators to manage constraints on their low-voltage, 11 and 33 kV systems, incentivised via new local flexibility markets. As discussed in Section 2.5, this concept could be attractive in specific cases, particularly to provide the ability to respond to rapid growth in heat pumps or EV ownership in specific areas. However, application is likely to be constrained by suitable sites: existing substations are likely to be attractive. In rural areas, pole-mounted equipment may be feasible.

[35] Residential LI batteries may create a fire risk. Consumer products need to meet product safety standards, but in use the level of care, inspection and maintenance may be less than on a larger commercial battery.

Figure 3: Broxburn 20 MW battery storage project, West Lothian, constructed in 2018 to provide sub-second balancing services to National Grid (image RES Ltd/Keith Arkins)

5. Conclusions

The role and value of grid-scale battery storage

Grid-scale battery storage provides benefits to electricity systems, particularly as in Scotland where there are increasing levels of variable renewable generation such as wind. Electrification of heat supply and transport is also likely to place strains on the electricity system, which battery storage can mitigate. However, there are competitors for providing these functions: principally demand-side management including EV charging, grid reinforcement, interconnectors to other systems, and flexible generation such as hydro or pumped storage.

Existing battery storage projects in the UK earn their income from a range of services: 'revenue stacking'. These income streams are considerably less certain than the income streams for conventional generators. So far, frequency response has been a major revenue source. The range of 'ancillary services' required by electricity system operators is expected to change and grow, as a result of regulatory pressure.

'Grid scale' in this report is taken also to mean large battery installations 'behind the meter' on industrial and commercial sites, such as offices, warehouses, and shopping centres. This sector can be expected to grow, mainly because it can limit capacity-related grid charges, and enable significantly greater use of on-site renewables, particularly solar.

The islands of Scotland will not influence the 'big picture' issues much, but battery storage could provide significant local benefits, for greater use of local renewables and dealing with electrification of heat and transport. This could minimise the costs of decarbonisation strategies on the islands.

Sustainability, environmental and safety issues

The dominant battery technology at present is lithium-ion, in several different chemistries. Many other technologies are under development and may replace lithium-ion eventually. The most critical raw materials in the global battery supply chain are identified as cobalt, lithium and graphite, based on the volumes likely to be required, and concerns over concentration of sources.

This report includes estimates of the grid-scale battery storage capacity which may be installed in Scotland in 2030 and 2045. These estimates are very uncertain but show that Scotland's requirement for the critical materials likely to be needed is a very small part of current global supply. Therefore, any objectives to influence supply chains are likely to be most effective as part of international efforts.

Initial steps have been taken to improve due-diligence practices of lithium-ion supply chains in line with international standards, and therefore mitigate the social and environmental impacts, but much broader adoption and implementation is needed.

While there are technical and financial issues with effective recycling, the sheer scale of LI batteries needing to be recycled is likely to produce a competent global recycling and waste management chain, most likely driven by the EV manufacturers.

Key spatial criteria

Few issues have been encountered so far in obtaining development consent for battery projects. The most important issue for siting is proximity to an adequate grid connection. The planning system need not create unnecessary barriers. This is largely a matter of familiarisation and capacity-building: there are few 'new' issues to be addressed.

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Appendix 1: Stakeholder interviews

Everoze is grateful to the following organisations for participating in semi-structured interviews by phone and face-to-face.

Organisation type	**Organisation**	**Contact**
Environmental analysist for global energy infrastructure investor	Green Investment Group	Adrian Barnes
Battery Developer	RES	Tracy Scott
Battery Developer	Pivot Power	Matthew Boulton
Battery OEM	MEP Technologies Ltd	Stuart Morrison
Battery OEM	RedT	Joe Worthington
Renewables developers – tidal/wave	Simec-Atlantis	Anna Dunbar
Renewables developers – tidal/wave	Nova Innovation	Gavin McPherson
Renewables developers – onshore wind	Muirhall Energy	Alistair Yule
Planning officials	Workshop session	Arranged by Dan Barlow
Battery recycling	Faraday Institution/Birmingham U.	Tony Hartwell
Regulator	SEPA	Anna Gaffney
NGO	Business and Human Rights Resource Centre	Eniko Horvath
EVs	Urban Foresight	Kate Palmer

Appendix 2: Summary of sourcing information for key LIB materials

	Top Producers (2018)	Typical Methods of Extraction	Estimated Resources (2018) [Note 2] Metric tons of material content	Estimated Reserves (2018) [Note 3] Metric tons of material content	Annual Production (2018) Metric tons of material content	Estimated % of Material Used for Battery Industry
Lithium	Australia, Chile, China, Argentina, Zimbabwe	Brine extraction from salar deposits and hard rock extraction.	62,000,000	14,000,000	85,000	56%
Cobalt	DRC, Russia, Cuba, Australia, Philippines	Predominantly a co-product of nickel and copper mining.	25,000,000 (terrestrial)	6,900,000	140,000	42% [Note 4]
Nickel	Indonesia, Philippines, New Caledonia, Russia, Australia	Open-pit, hard rock ore extraction	130,000,000	89,000,000	2,300,000	3% [Note 5]
Manganese	South Africa, Australia, Gabon, China, Brazil	Open-pit, hard rock ore extraction	Land-based manganese resources are large but irregularly distributed	760,000,000	18,000,000	<2% [Note 6]
Copper	Chile, Peru, China, USA, DRC	Open-pit and underground hard rock ore extraction	2,100,000,000	830,000,000	21,000,000	Batteries distributed across multiple reported categories of copper use
Graphite (Natural)	China, Brazil, Canada, India, Mozambique	Open-pit and underground mining	>800,000,000	300,000,000	930,000	Estimate not found

Notes:

1. Producer, resource, reserve and annual production data taken from U.S. Geological Survey, 2019, *Mineral Commodity summaries 2019* https://doi.org/10.3133/70202434
2. Resources defined as 'A concentration of naturally occurring solid, liquid, or gaseous material in or on the Earth's crust in such form and amount that economic extraction of a commodity from the concentration is currently or potentially feasible' (USGS)
3. Reserves defined as 'That part of the reserve base which could be economically extracted or produced at the time of determination. The term reserves need not signify that extraction facilities are in place and operative. Reserves include only recoverable materials; thus, terms such as 'extractable reserves' and 'recoverable reserves' are redundant and are not a part of this classification system' (USGS)
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7. For example those highlighted in the World Copper Factbook 2018, International Copper Study Group https://www.icsg.org/index.php/component/jdownloads/finish/170/2876

Appendix 3: Selection of reported social and environmental issues around sourcing of cobalt, lithium and graphite

	Water Use	Water Pollution	Soil Pollution	Air Pollution	Health Issues	Child / Forced Labour	Poor Working Conditions	Link to Conflict
COBALT	High water consumption of smelters	Discharge of pollutants from mines and smelters – heavy metal contamination	Discharge of pollutants from mines and smelters – heavy metal contamination	Discharge of pollutants from mines and smelters – heavy metal contamination	Respiratory diseases from cobalt dust, chronic illnesses	Significant proportion sourced via 'artisanal' mining, including from children	Dangerous mine conditions. Lack of basic protective equipment.	Majority of cobalt is sourced from the Democratic Republic of Congo
	Resources: *Time to Recharge*, Amnesty International, 2017 https://www.amnesty.org/download/Documents/AFR6273952017ENGLISH.PDF *This is What We Die For*, Amnesty International, 2016 https://www.amnesty.org/download/Documents/AFR6231832016ENGLISH.PDF *Sustainability of artisanal mining of Cobalt in DR Congo*, 2018 doi: 10.1038/s41893-018-0139-4 / https://www.ncbi.nlm.nih.gov/pmc/articles/PMC6166862/ *Glencore mine collapse kills 43 miners in the Congo*, Good Electronics, 2019 https://goodelectronics.org/glencore-mine-collapse-kills-43-miners-in-the-congo/ *The Cobalt Pipeline*, The Washington Post, Sept 2016 https://www.washingtonpost.com/graphics/business/batteries/congo-cobalt-mining-for-lithium-ion-battery/ *The Hidden Costs of Cobalt Mining*, The Washington Post, Feb 2018 https://www.washingtonpost.com/news/in-sight/wp/2018/02/28/the-cost-of-cobalt/							
LITHIUM	High water consumption in arid areas	Pollution from chemicals used in extraction process	Pollution from chemicals used in extraction process	Pollution from chemicals used in extraction process	High levels of lead in blood			
	Resources: *Lithium Fact Sheet*, Friends of the Earth https://www.foeeurope.org/sites/default/files/publications/13_factsheet-lithium-gb.pdf *Lithium extraction in Argentina*, Good Electronics, 2019 https://goodelectronics.org/wpcontent/uploads/sites/3/2019/05/DOC_LITHIUM_ENGLISH.pdf *Indigenous people's livelihoods at risk in scramble for lithium, the new white gold*, 2019 http://www.ethicalcorp.com/indigenous-peoples-livelihoods-risk-scramble-lithium-new-white-gold							
GRAPHITE		Discharge of water used in production, graphite dust	Graphite dust from production process	Graphite dust from production process	Respiratory and heart problems			
	Resources: *In Your Phone, in The Air,* Washington Post, 2016 https://www.washingtonpost.com/graphics/business/batteries/graphite-mining-pollution-in-china/tid=batteriesseriesbox							

Appendix 4: Towards addressing the social & environmental impact of mineral supply chains

1) Principles (duties and requirements for states and companies), **reporting framework, database**	**UN Guiding Principles on Business and Human Rights** (2011) Outlines the duty of states to protect and companies to respect human rights, including in their supply chains. Requires companies to undertake human rights due diligence. https://www.ohchr.org/Documents/Publications/GuidingPrinciplesBusinessHR_EN.pdf Reporting Framework and Database (2015) https://www.ungpreporting.org/
2) Legislation – modern slavery reporting requirement for large companies	**Modern Slavery Legislation, e.g. UK Modern Slavery Act 2015 Section 54 – Transparency in Supply Chains** Requires large commercial organisations carrying out business in the UK with to publish an annual slavery and human trafficking statement in order to confirm the steps they have in place to combat modern slavery in their business and in their supply chains. https://services.parliament.uk/bills/2014-15/modernslavery.html
3) Register and database of UK modern slavery reporting	**Transparency in Supply Chains Register** (2016) Independent civil society register for filing annual modern slavery statements and database of supply chain transparency information. ttps://tiscreport.org/
4) Guidance - framework for respecting human rights and avoiding contributing to conflict	**OECD Due Diligence Guidance for Responsible Supply Chains of Minerals from Conflict-Affected and High-Risk Areas (**2011, 3rd Edition 2016) 5-step framework for respecting human rights and avoiding contributing to conflict. Endorsed by states and widely accepted as international standard for mineral supply chains in conflict and high-risk areas. https://www.oecd.org/corporate/mne/mining.htm **OECD Due Diligence Guidance for Responsible Business Conduct** (2018) https://mneguidelines.oecd.org/OECD-Due-Diligence-Guidance-for-Responsible-Business-Conduct.pdf
5) Tracking of human rights practices for certain companies	**Transitions Minerals Tracker** Seeks to improve the human rights practices of companies that produce the minerals vital to the renewable energy and electric vehicles sectors. Information currently available on 37 companies involved in production of cobalt, copper, lithium, manganese, nickel, and zinc. https://transitionminerals-tracker.business-humanrights.org/
6) Benchmarking of certain companies for forced labour risks within supply chains	**Know the Chain Benchmarks** Resource to help understand and address forced labour risks within supply chains. In 2018, 121 of the largest global companies in the three sectors of ICT, food and beverages and apparel and footwear were assessed. https://knowthechain.org/benchmarks/
7) Assessment of certain companies based on a set of human rights indicators	**Corporate Human Rights Benchmark** (2018 / pilot 2017) 101 of the largest publicly traded companies in the world in 3 sectors (agricultural products, apparel, and extractives) assessed on a set of human rights indicators https://www.corporatebenchmark.org/ **Responsible Minerals Initiative** (2008)

8) Independent audit against responsible sourcing standards **9) Verification and certification** of environmental and social responsibility good practice 10) Voluntary **industry initiatives**	Responsible Mineral Assurance Process Standards provide an independent audit of smelters/refiners against responsible sourcing standards (including OECD Guidelines). 380 companies/associations have participated. http://www.responsiblemineralsinitiative.org/ https://responsiblemining.net/what-we-do/standard/ **Initiative for Responsible Mining Assurance** (2006) Third party verification / certification of good practice for responsible mining, in areas of business integrity, planning for legacy, social responsibility and environmental responsibility. **Responsible Cobalt Initiative** http://www.respect.international/responsible-cobalt-initiative-rci/ **Global Battery Alliance** https://www.weforum.org/projects/global-battery-alliance

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