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Housing Estate Energy Storage Feasibility for a 2050 Scenario

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***Abstract*—The further penetration of renewable sources in the grid requires the implementation of energy storages in order to smooth out the variability and intermittent nature of renewables. This paper looks at the possibilities for a storage solution to meet an unprecedented situation of having no power input from renewables or an outage from grid sources for five consecutive days in the highest demand period of the year. The study uses as test case a 1000 house estate in the year 2050 with each property using electrical heating and electrical vehicle charging. The magnitude of power and energy estimated, together with the practicalities is then used to assess current storage solutions suitability and the likely possibilities of new innovations in the storage environment.**

***Keywords*—renewable energy, energy storage, energy management**

I. INTRODUCTION

If the UK is to meet its 2050 climate obligations of an 80% reduction in CO2 on 1990 levels [1] then part of the strategy must be to create an effective means to reduce fossil fuel usage for the housing estates of the future. This may involve the installation of solar PV and/or wind turbines on site, together with a smart grid in combination with effective energy storage. Linked energy storage is critical to smooth out the variability and intermittent nature of renewable energy supply (i.e. if there is no wind or sun energy capture for consecutive days to charge storage) together with the variability of consumers usage.

To estimate the magnitude of the amount of energy that needs to be stored depends on the number of houses that need to be supplied together with the combined power usage of all the individual properties. This energy usage largely depends on the number of occupants and their habits in each property which varies considerably throughout the day. The following scope represents a typical large housing estate in the UK as it might look in 2050 which will be used as an example for this paper:

- A new large 1000 property housing estate;
- All housing will use primary electric heating;
- All housing will run one electric vehicle with a fast car charger (7 kW);
- The system will have a design life of 30 years;
- Storage will be required to hold energy for a relatively small period of time (days-weeks);
- Each of the 1000 properties might have individually linked battery storage or alternatively a centralised bulk storage unit feeding all properties.

II. ENERGY AND PEAK POWER REQUIRED PREDICTION

The amount of energy to be stored depends on how many days holdover backup is required as a whole. Demand for typical domestic consumption is not constant and peaks at points when electrical items are switched on as demonstrated in Fig. 1. Elexon load profiling can give a representation of averaging out patterns of electricity usage for customers in each one of the eight Profile Classes (Fig. 2) [3].

Future increases in power demand that will be considered in this paper are future uptake of electric cars, the transfer on mass from gas to electric heating and the increase of electrical

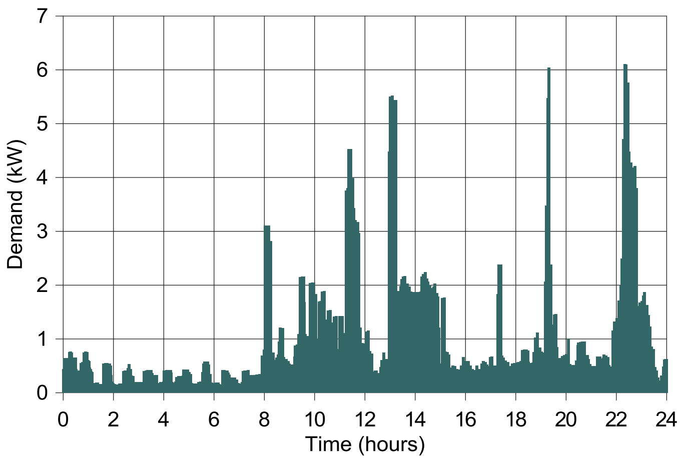

Fig. 1. Individual household electricity demand [2].

gadgets used in the home. For the latter this may be mitigated or even reduced as consumers swap over to more energy efficient household AAA+ rated appliances. If we look into the future, then houses in 2050 on the whole may be built to higher insulation standards requiring less heating input. This effect has not been considered in the calculations below as todays average electrical heating provides an accurate baseline and is being conservative in not considering future improvements, thus adding a factor a safety.

To future proof the energy storage capacity needed encompassing the 2050 carbon reduction targets, an approximate estimation of a worst case scenario of electricity storage must be estimated. This depends on many unknowns but this paper conservatively makes an approximate simple estimation.

A. Domestic Demand (Electric Heating)

If electric heating is used in domestic properties this, as could be predicted, dramatically alters both the shape and magnitude of the load profile. The night-time load for properties with electric domestic heating is dominated with night storage heaters with consumers taking advantage of specialist night-time discounted electricity tariffs (Economy 7).

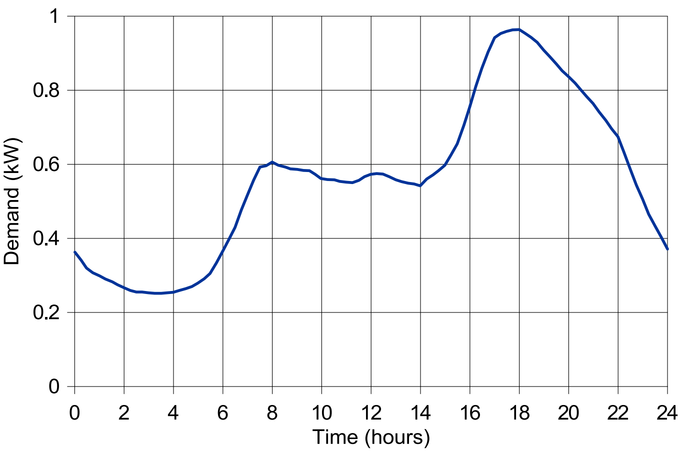

Fig. 2. Example of a load profile for the average Profile Class 1 (domestic unrestricted) customer in a typical winter weekday [3].

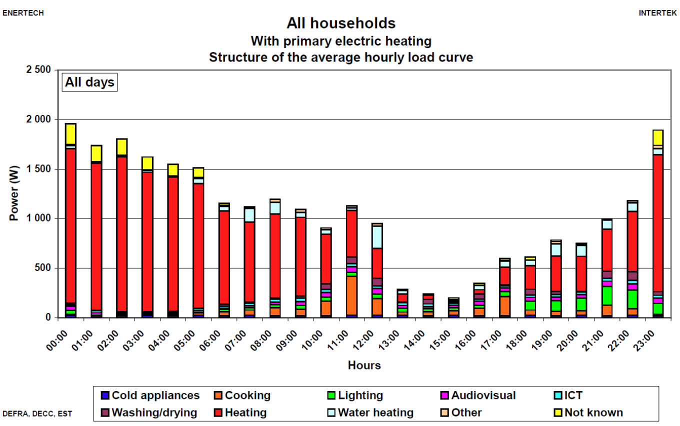

Fig. 3. Structure of the average hourly load curve [4].

Fig. 3 shows an average of households' energy profile with electric heating broken down into constitute parts. The load profile is skewed towards early morning to take account of overnight (Economy 7) cheap rate electricity. In our scenario, it would be spread out as and when required by the home owner as there would be no fixed overnight cheap electricity from the microgrid, instead the periods of low electricity prices would be variable depending on when abundant renewable energy is available. The overall energy profile for the day however would be of a different shape but approximately the same daily magnitude. It should be noted that the sample size for this study was relatively small.

The load curve in Fig. 3 is an average for a total year which includes large seasonal variations that need to be adjusted to gain peak values. This will have the effect which would greatly skew for increased usage in the winter time months as shown in Fig. 4 [4].

Data in this paper uses a current base load for Economy 7 users (Load profile 2) from Elexon [3]. From analysis of winter energy usage for average households using electric heating the highest winter daily usage is a Sunday at 20 kWh/day, winter Saturdays average 19.4 kWh/day and winter week days come in at 19 kWh/day. From this average there will be a spread of higher and lower usage in individual houses but given a sample size of 1000 houses this average will be sutable.

The worst case winter load scenario over 5 days, E_{max}, is a Saturday, Sunday and 3 weekdays.

$$E_{house/property} = 20 + 19.4 + (19 \times 3) = 96.4 \text{ kWh}$$

B. Domestic Demand (Electric Vehicle Charging)

There has been some speculation in the popular media that the rollout of electric cars will increase overall emissions [5], however Fig. 5 [6] indicates this to be incorrect and overall there will be a significant cut in overall CO2 emissions with the role out of electrical vehicles. The effect on the domestic demand load profile of using an electrical vehicle for a German property is shown in Fig. 6 [7]. On the other hand, it is predicted that the total energy demand from a household by electric vehicle will be slightly reduced in the future due to the

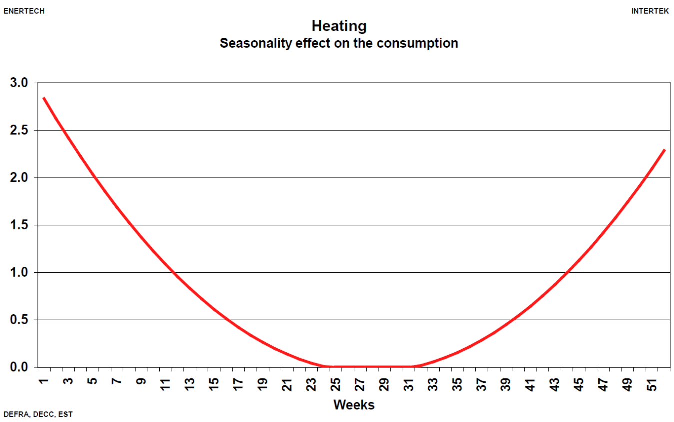

Fig. 4. Seasonality effect for water and space heating [4].

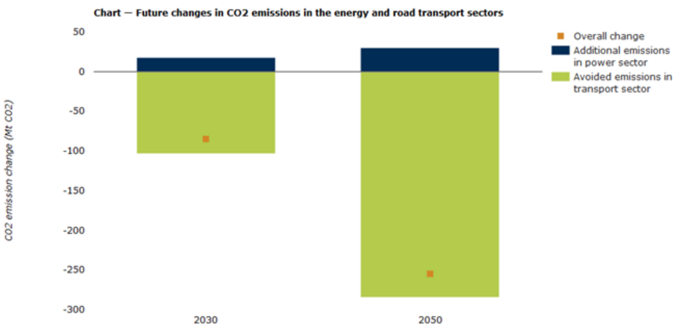

Fig. 5. Future changes in CO2 emissions in the energy and road transport sectors in 2030 and 2050 (80% peroration) [6].

significant increase of charging stations and points in public areas i.e. parking lots in the workplace or shopping centres [8].

This paper assumes average UK electrical vehicle demand per household would be not dissimilar to Germany. Refining this graph with the price of possible cheap electricity at night is demonstrated in Fig. 7 [7]. In this case the load profile shape is altered, however the magnitude of the overall energy used over a 24 hour period would be similar i.e. whenever a car is charged it will take the same magnitude of energy.

Assuming that in 2050 every property will have an average of 1 electric vehicle, with an average capacity of 30 kW then we could assume that 50% may wish to be charged every day. Average additional daily load due to electrical vehicles/ household over 5-day period $E_{car} = 5 \times 30 \times 0.5 = 75$ kWh.

Total worse case 2050 five-day demand per house $E_{max} = E_{house} + E_{car} = 96 + 75 = 171$ kWh capacity needed per property (average 34.2 kWh/property/day). Energy storage needed for a 1000 property housing estate equates to 171 kWh × 1000 houses = 171 MWh + storage losses.

C. *Peak Power Rating Prediction*

According to Elexon [3], the highest peak load for Economy 7 users is 1am-1.30am on a winter Saturday where an average of 2.32 kW is used. Even though there may not be the artificial peak when Economy 7 cheap overnight electricity is taken away, there may be other times where cheap renewable energy is available. Smart storage heaters and appliances would replicate this peak power demand i.e. they may switch on automatically when energy hits a pre-determined cheap rate if there is abundant renewable energy in the system.

Rapid car changing can take up to 43 kW, however fast charging takes 7-22 kW and slow 3 kW. If each property is fitted with a fast (7 kW) chargers and 50% of property owners use them at once this will create a power load of 50% × 7 kW = 3.5 kW.

Peak Power = 2.32 kW + 3.5 kW = 5.83 kW/property

Simple 5 day worse-case housing estate totals:

- Peak Power = 5.82 MW (no factor of safety)
- Storage required for 5 consecutive days is 171 MWh + storage losses.

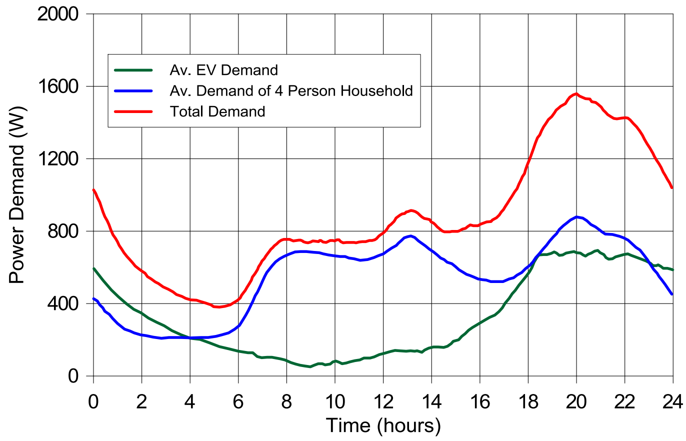

Fig. 6. Load profile (user-driven charging) of electric vehicle charging, private household and both aggregated (Germany) [7].

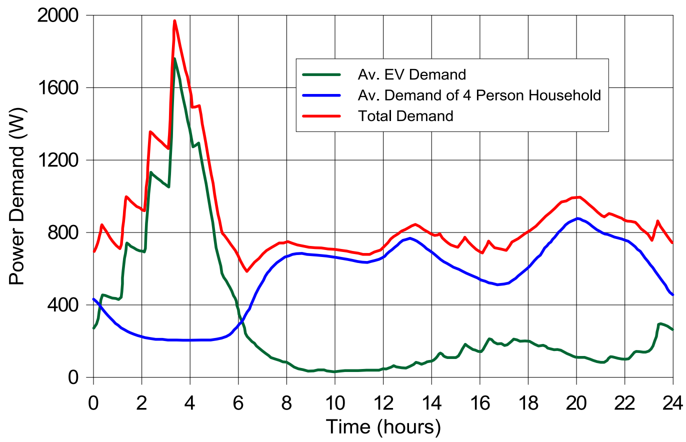

Fig. 7. A comparison (cost oriented charging) of electric vehicle charging private household and both aggregated (Germany) [7].

III. Choices of Storage Considerations

The most efficient choice of energy storage for any situation depends upon:

- Practicality for the location/environment (Safety, Noise, Size);
- Cost;
- Reliability;
- The depth of discharge profile in regular use. (DOD);
- How long the energy needs to be stored for;
- The magnitude of energy that needs to be stored.
- The power vs. energy demand profile;
- The life expectancy of the storage required;
- Efficiency within the specific environment and usage criterion;
- Voltage stabilization and frequency control.

There are many ways to store energy in both thermal and electrical form that may be suitable for this scheme including:

- Electrochemical battery technologies;
- Hydro Pumped storage;
- Compressed Air Energy Storage (CAES);
- Gravity Power Modules (GPMs);

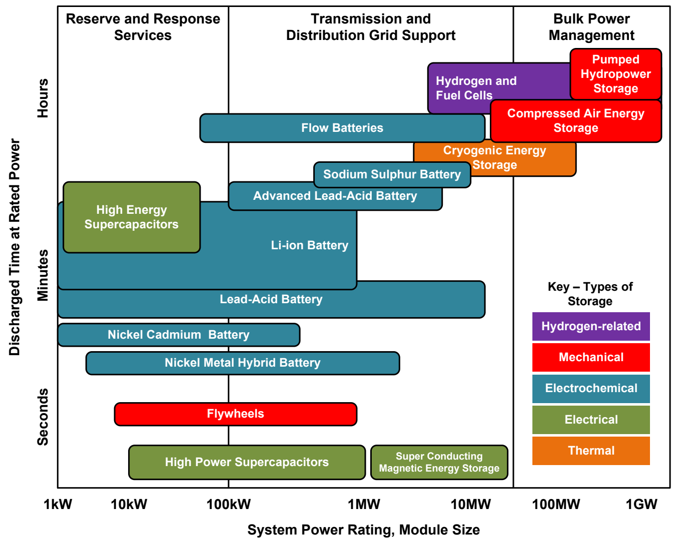

Fig. 8. Applicable power ranges and discharge power duration of different energy storage technologies [9].

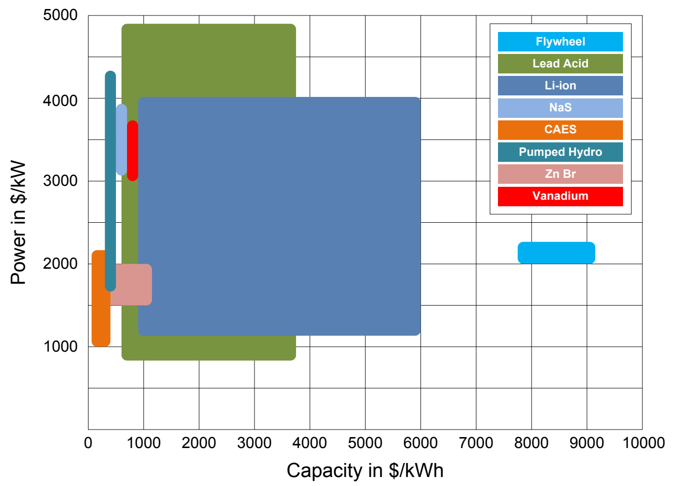

Fig 9. Comparison of different storage technologies regarding the investment costs for power and capacity [10].

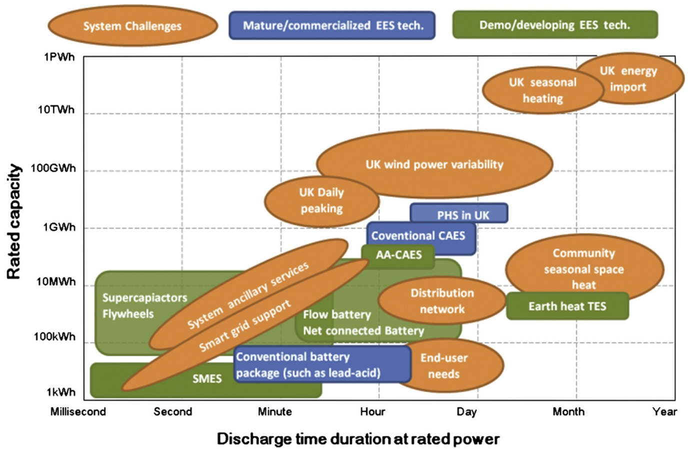

Fig. 10. Electrical energy storage technologies with challenges to the UK energy systems [11].

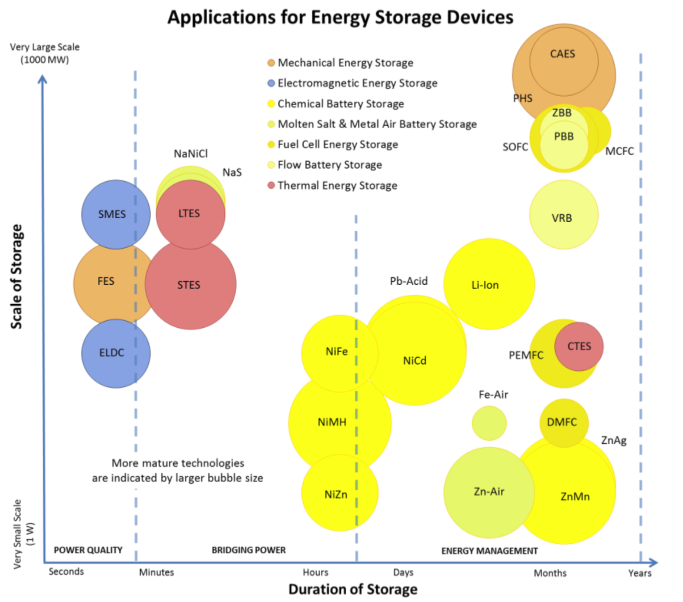

Fig. 11. Application of energy storage [12].

- ARES energy storage technology;
- Flow-batteries;
- Hydrogen energy storage and Fuel Cells (FC);
- Flywheels;
- Super capacitors;
- Superconducting Magnetic Energy Storage (SMES);
- Liquid air energy storage;
- Liquid metal batteries;
- Pumped Thermal Electricity Storage (PTES);
- Pumped hydro electrical storage.

This paper looks at a review of existing research and applies this to find the best solution for this situation. There have been many studies of energy storage comparisons for various scenarios looking into suitability, cost and a myriad of other factors for example Fig. 8 [9], Fig. 9 [10], Fig. 10 [11], and Fig. 11 [12].

IV Possible Solutions

From this review the technologies considered for this situation of storage are:

A. Large Scale Compressed Air Energy Storage (CAES)

Large scale CAES offers a power rating and rated capacity range of up to 1000 MW [13] and energy storage of < 1000 MWh [14] respectively which is suitable for the purposes of this paper. Cycle Efficiency's range from 42 to 54 [15] but can be as high as 70% [16]. Predicted lifetime is slightly less than HPS ranging from 20-40 years [16].

Large scale CAES offers the advantages of low maintenance costs of 0.003 $/kWh [13] and can have a relatively low (compared with other storage technologies) energy capital cost of 2-50 $/kWh [17] this variance depends on there being a naturally occurring holding storage vessel i.e. cavern system being available or not [18]. Storage duration, discharge time, daily self-discharge and response time are all suitable for this application.

B. Hydro Pumped Storage

Power ratings can range between 100-500 MW with a rated capacity range of 500-8000 MWh which make it suitable for a wide range of large grid level applications [17].

A pumped storage hydro station would be ideal if the natural topography of the land was favourable [19] and was suitable in terms of size but this geographical situation would be rare. HPS is in teams of capital cost (depending on location) can be economically sensible with an energy capital cost of 5-100 $/kWh [17] There is a considerable variance in these values due to the suitability of location and build cost indicated above. HPS has the advantages of a long life (40-60 years) [17] and low maintenance costs of 0.004 $/kWh [13]. Storage duration, discharge time, daily self-discharge, response time and cycle efficiencies of 70-85% [17] are also favourable to this application. Dinorwig electric mountain large pumped storage PowerStation holds about 9,100 MWh [20] and would keep approx. 68,000 houses in energy at the 5-day worst case scenario in this paper.

This would be an ideal solution for multiple housing estates and cities/county level, close to a natural source of water at two elevations and could be used for balancing into the wider grid with other load shifting measures. Although HPS relative (to other storage) is favourable, it should be noted it is very expensive compared with current direct grid price electricity.

Smaller scale hydro GPMs (Gravity Power Modules) are available but are in a testing/evaluation phase at time of writing. These however rely on the construction of as large tube with piston under the ground which would, in the authors view, be expensive to construct.

C. Cryogenic/Liquid Air Energy Storage

Liquid air storage has a current rated energy capacity maximum of 2.5 MWh [21] however there are larger ones planed up to 15 MW [22] which is too small, being in a demonstration phase, to be considered for this application but has potential to one day be suitable with innovation.

D. Hydrogen energy storage and Fuel Cells (*FC*)

Fuel cells life span is between 5-15 years [18] with a rated energy capacity of 0.312 MWh max [23] which makes them unsuitable for this application, however much research is taking place [24] and this may become viable in the future if the longevity, efficiency and scalability can be improved.

E. Advanced Rail Energy Storage (*ARES*)

A new technology which at time of writing has had approved a first commercial scale (50 MW) plant in Nevada USA. This project consists 7 trains of total mass 9,280 tonnes traveling up and down a 7% grade for 5.5 miles at an average of 18 mph [25]. ARES relies on proven rail technology and in the authors opinion has much potential. It has no need for water or storage vessels however it does rely on there being a hill or large change of elevation and long strip of land to lay rails on for installation.

The 50 MW proposed planned scheme is claimed to have a round trip efficiency of 80%, a storage capacity of 12.5 MWh (which is easily scalable). The time taken from 0 to Full Charge Power is 10 seconds and 0 to Full Discharge Power is 15 seconds [25]. Where natural topography is suitable, i.e. a long natural grade with large elevation difference, this may prove to be a future viable proposition.

F. Electrochemical Battery Technologies

Tesla and other manufacturers are gaining attention and have overcome many obstacles, investing heavily in the Li-ion battery technology [26]. However, the costs, life span and practicalities [18] involved would prohibit use in this application needing 10 Powerwall 2s, or a Tesla power pack in every other house.

V. Conclusion

It is difficult to ascertain accurate LCOE (Levelised Cost of Energy) costs or other attributes of some energy storage methods because the capital cost to construct plants varies significantly with topographical and geological location (as with HPS and CAES). Many storage technologies are in development and may see significant improvements in key areas over the coming years with game changing breakthroughs possible. However what is clear from the review is that it is wildly expensive, considering not including the renewables to charge any storage, for the 1000 housing estate scenario with the technology of today to progress with any such storage scheme.

The storage technology of today however is viable and indeed essential for load shifting and smaller (time) outages of grid energy together with the ability to smooth out peaks and troughs in future renewable production and user demand [27]. It is considerably financially better for home owners to have grid back up to cover for high load/low renewables production periods than go completely off grid.

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