











installations in Figure 9. The top row shows two battery sizes for an installed capacity about equal to the nominal heat load, where the first bar is for a generation portfolio using only wind turbines, the 2<sup>nd</sup> bar has a mix of 0.5 pu installed wind capacity and 0.5 pu Solar PV. The third column has 0.25 pu wind and 0.75 pu PV where the annual wind production is about the same as the annual PV production, and the final column is for solar PV only. Figure 9a is for a storage size to store half a day's of operation, while Figure 9b is for a full day's operation. At low generation capacity, only just exceeding the nominal load, around 50% of the local generation can be used directly. Adding storage increases the utilisation of the generation significantly, with a clear increased contribution from 0.5 days to a full day's consumption. The smallest benefit is when storage is coupled to solar PV only. This can be explained by the very large seasonal variation between winter and summer. Even though wind energy also has a seasonal variation, this is much smaller compared to the variability across a day or a week. As a result, storage can facilitate the operation more easily. Most substantial benefits are by coupling storage to hybrid installations, where the two seasonal variations, more sun in the summer and more wind in the autumn and winter, complement each other.

The second row in Figure 9 shows the same information for the same battery choices but doubled renewable generation. Here, the directly used generation is much higher, leaving less opportunity for benefits from the battery. This also results in much smaller increase of the storage utilisation of the larger battery. While the hybrid installations in Figure 9d use the battery less than the wind-only installation, they achieve almost self-sufficiency, with only a few percent of the heat load to be supplied from other sources, such as grid electricity or a back-up generator.

This analysis clearly shows that the best choice of renewable generation and energy storage is a tightly interconnected problem, depending strongly on the nature of the local resource and the purpose of the installation, whether it is to maximise cost savings or self-sufficiency.

#### 4. Conclusion and Further Work

This analysis demonstrates that the combined use of onsite generation and local storage is beneficial for an energy intensive industrial site. However, it has become clear that the size of the local demand, installed generation capacity and storage capacity need to be carefully matched to realise that potential. If the generation is small compared to the onsite demand, then it provides a small reduction in load while any storage device will only be occasionally used. If, however the generation is very large, then the local benefit is dwarfed by the excess electricity generation which would need to be exported. This obviously relies on a strong grid connection and a contract which allows substantial exports. In this case, the local site would become a major generator alongside its original purpose. In this case, any storage device will be less useful to serve local needs, though it might become essential to balance the grid. This latter option, however, was not evaluated in detail here, where the

primary purpose was to serve local consumption while allowing some surplus to be exported.

In the intermediate range, where the local generation capacity is aligned with the demand, storage can indeed provide an effective benefit as long as it is large enough to manage a sizable fraction of a day's consumption. No benefit was observed for storage capacities exceeding a day's production. This might partly be due to the particular location of the system, based on an island off the west coast of Scotland with an excellent wind resource and even a good solar resource during the summer months, when the wind tends to be at its lowest.

Further work will need to go into more detail of finding guidelines for optimum sizing, not only in terms of electricity production but also setting of installation costs. Other further work will need to analyse the sensitivity of the results to interannual variability – at this stage, only one typical year's worth of resource data was used, and also to apply this methodology to other locations with different wind and solar climates.

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