STORAGE, RENEWABLES, RELIABILITY AND COST

In this section, it is shown how storage can be used as a tool to allow one to integrate higher levels of variable renewables while maintaining system reliability and keeping costs down.

To show how these variables—renewables penetration, reliability, storage and cost—interact, a model of an electricity system that starts as a pure fossil-fueled system, to which we add varying amounts of renewables and storage, is used. Key model outputs are reliability and costs. In other words, it is shown how increased use of renewables can be combined with storage to maintain reliability and show the overall cost impacts of doing so.

The HOMER modeling system, which is emerging as the international standard for modeling of smaller and distributed renewable electricity systems, is used.

HOMER is an electricity system design tool that chooses an optimal mix of generation resources from a user-defined set of choices and provides as outputs capital and operating expenses. A free version of HOMER software can be downloaded at ***www.homerenergy.com.*** The software is relatively easy to use and well-supported via an active and engaged online community. The results shown here are for a typical, or representative, small island electricity system.

However, these results may not be applicable to *all such systems*.

Costs, insolation (sunlight) levels, electricity demand, load shape and other variables vary across systems, and their values affect how renewables and storage interact and perform. Fortunately, it is not too difficult to do a comparable analysis for any system. The process of getting started is illustrated at the end of this section.

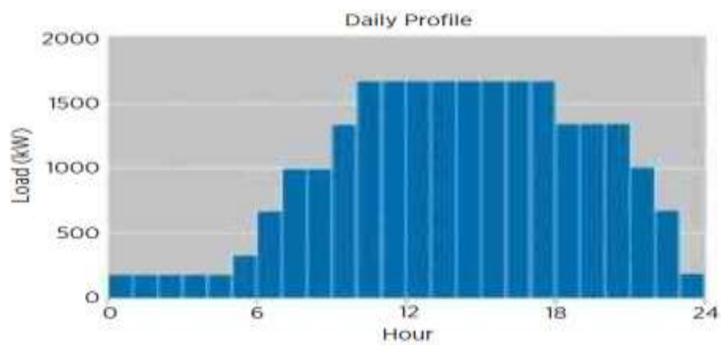

Figure 6: Assumed daily load shape

The Model Island and the Base Case: Diesel Generator Only

For this analysis, we created a fictional island located in the Caribbean, near Puerto Rico. The electricity system on this island serves 1,000 households, each with an average electricity demand of 500 watts, totaling 500 kW residential average demand. The island also has a comparably sized commercial and industrial average demand of 500 kW. The load factor is 0.37, meaning that the total *peak* demand is 2.7 MW.[8] The daily load shape follows typical working hours with a midday peak (Figure 6). For a base case, it is assumed that a single diesel generator serves the island, with a peak rated output of 3.5 MW.

Such oversizing is quite common, motivated in part by a desire to provide reliable electricity even if demand exceeds predicted levels and to accommodate future demand growth. However, as shown below, such oversizing has a significant penalty in the form of high diesel consumption.

It is assumed that this diesel generator costs $250/ kW, or $875,000 (first cost only). Furthermore, it is assumed that diesel fuel is available at a price of $1/litre. (All prices and costs in this report are in U.S. dollars, unless noted otherwise). The efficiency (defined as the percentage of energy in the consumed fuel that is converted into electricity) of this diesel generator rises sharply with load, which is typical of diesel generators.

The final critical assumption is that electricity supply always equals or exceeds demand. In other words, there is a requirement that there is always sufficient capacity to meet demand. It is important to note, however, that since transmission and distribution (T&D) issues, such as downed power lines, are a significant cause of outages, this requirement does not translate into 100% reliability.

The costs and other performance characteristics of this base case system are summarized in Table 12. Note that the levelised cost of electricity, which accounts for both the first cost of the diesel generator and the ongoing costs of the diesel fuel, is 53.9¢/kWh. (This assumes a 6% real interest rate and reflects only generation costs; it does not include T&D, operations or other electricity system costs.)

Table 12: Base case: diesel generator only

Indicator/measure	Value	Units
Initial (first) cost	875,000	US$
Diesel consumption	4,016,700	Liters/year
Levelised cost of electricity	53.9	¢/kWh

Adding Storage and Renewables to the Model Island

To demonstrate the potential roles of storage and re-newables, the island is then modeled with several alternative electricity generation scenarios:

- Generator plus storage;
- Generator plus PV;
- Generator plus PV plus storage; and
- PV plus storage (100% renewables).

The results of these scenarios are summarized in Table 13.

Note: "Renewables fraction" is defined as the fraction of annual electricity consumption that is provided by renewable sources. Storage is 7.6 kWh capacity lead-acid batteries, $2,000 each. The storage cost estimate includes balance-of-system costs.

There are several interesting implications of these results. These are best explained by discussing each scenario individually.

Generator + Storage. Adding storage increases the first cost significantly (i.e. an additional $2 million in this example). However, it also allows for a 25% reduction in diesel use. It does so largely by allowing the diesel generator to operate at higher loads (and thus higher efficiencies) and to switch off entirely when loads are low. In this scenario, the generator was able to reduce its run time from 8,760 hours/year (24 hours/day, 365 days/year) to 5,568 hours/year (an average of about 15 hours/day). Note that the levelised cost of electricity for this scenario is quite a bit lower than for the base case because the diesel savings more than outweigh the additional first cost of storage.

Generator + PV. This relatively small PV system did reduce generator run time, but mostly during midday, when demand was high, thus aggravating the ineffi-cient-at-part-load problem with diesel generators. Diesel savings were modest and levelised cost increased. PV as a supplement to a diesel generator without accompanying storage is unlikely to be a financially attractive choice although it may be worth considering as an interim step to become familiar with the PV technology.

Table 13. Costs and other characteristics of alternative system designs

Scenario	Generator (kW)	PV (kW)	Storage (kW)	First cost ($1000)	Diesel use (mill. liters/yr)	Levelised elec. cost (¢/kWh)	Re-newables fraction
Gen Only	3,500	0	0	875	4.0	53.9	0
Gen+Strg	3,500	0	1,000	2,875	3.0	42.6	0
Gen+PV	3,500	500	0	3,375	3.9	55.0	0.10
Gen+PV+Strg	3,500	2,000	2,000	14,875	2.0	42.4	0.28
PV+Strg	0	7,000	12,000	59,000	0.0	68.4	1.00

Generator + PV + Storage. This scenario has a very high first cost, but it cut diesel consumption by 50% and thus had the lowest levelised electricity cost. This is because the PV and the storage were able to work together such that the generator operated either at high output levels or shut off entirely. This is a technologically complex system, as it would require a sophisticated controller and software to optimize operation of the PC and storage. Nevertheless, as shown in Table 13, it can be cost-effective from a long-term financial perspective.

PV + Storage. This system has both the highest first cost *and* the highest levelised cost. This is because a very large PV system (7 MW) and storage system (12 MW) is required to ensure system reliability. (Relaxing the reliability requirement would allow for a smaller PV system and thus lower costs.) This nicely points out the challenges in going to a 100% renewable system. One needs to oversize the system significantly or allow for the possibility of occasional generation shortfall.

Implications for Renewable Energy Generation and Storage

The results summarized above lead to several key find-ings:

- Diesel generators have very low first costs but high operating costs. Although alternative systems using storage and/or renewables can have lower levelised costs, as discussed above, implementing these systems requires finding the up-front capital to cover the higher first costs.

- Storage should be considered as a supplement to pure diesel systems, even without renewables. As discussed above, storage can allow diesel generators to operate at much higher efficiencies and to switch off entirely when appropriate. The higher first costs of the storage can be more than outweighed by the diesel savings. It also prepares the system for integrating renewables later.
- Small amounts of renewables added to diesel-based systems are generally not a cost-effective option. This is because some renewables, notably PV, aggravate the low-load inefficiency of diesel generators.
- Combining diesel generators, renewables and storage can be the lowest cost option, based on levelised cost. However, such systems are complex and technologically sophisticated. It is suggested to add new technologies one at a time, rather than all at once.
- Pure renewable systems, particularly based on PV, can be very expensive, and they will need to be oversized to meet electrical needs throughout the year.

When to Add Storage

Use of the HOMER modeling system is strongly recommend to assess the feasibility and economic attractiveness of storage and renewables for a given electricity system. This modeling system:

- Helps to model a wide range of storage technologies, including hydrogen, batteries, flow batteries, flywheels and more.

- Uses a chronological analysis, which is critical for understanding the impacts of adding storage to a system. Without this sort of analysis, one must rely on rules of thumb to select storage, which can be inaccurate.
- Allows one to do sensitivity analyses and answer questions, such as: Which system is least expensive if the cost of fuel doubles? How much can be paid for PV panels and still cost-effectively add them to the system? If electricity demand goes up, will the system be able to supply enough electricity? If so, how much would it cost?
- Includes tools to do a quick PV analysis by specifying the location. It connects to an online database of solar radiation worldwide to determine how much electricity can be expected from the PV array.
- Creates a wide range of outputs and graphs that can be used to better understand the system. There will be many goals , and the available analysis tools are diverse enough to support many of them.
- Helps to not only identify the best system to supply electricity but also helps one understand *why* it is the best system.

Source: http://decarboni.se/publications/electricity-storage-and-renewables-island-power-guide-decision-makers/3c-storage-renewables-reliability-and-cost-how-do-they-fit-together