An Integrated Design Approach for Sustainable Community Development

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Abstract

This paper presents our study in designing a 700 acre low-energy community on the Island of Hawaii. This study was an interdisciplinary collaboration among engineering, architecture, landscape architecture and business management. We took an integrated approach, which encompasses reducing energy demand, optimizing on-site renewable energy generation, implementing an efficient energy distribution system as well as effective energy management, and conserving natural resources. Technologies and their system integration were modeled and analyzed including solar photovoltaics, battery and compressed air energy storage, plug-in hybrid electric vehicles, demand response, microgrid, energy aggregator, passive and deep source cooling, microclimate and alternative landscaping. Various business models were developed. We showed that, with careful planning, it is feasible for a low energy or net zero energy community to become environmentally friendly and economically profitable at the same time. This community will benefit its residents, developers, investors, the utility company and the rest of the world.

1. Introduction

Realigning human and natural systems is critical to the world's immediate future. The sense of urgency is nowhere more apparent than on the Island of Hawai‘i, which is 90% dependent on imported fossil fuels and which has the highest electric energy costs in the nation. With a population of only 140,000, the Island of Hawai‘i currently expends $750,000,000 per year on the import of fossil fuels [1]. This tremendous financial burden on the Island's economy is coupled with the burden of knowing that the Hawaiian Islands constitute the most isolated land mass in the world, thus making fuel shipment lines unusually long and vulnerable. This situation stands in sharp contrast to the fact that the Island of Hawai‘i has the capacity to move toward total energy self-reliance – renewable sources of energy such as wind, solar, hydro, wave, and geothermal are all readily available [1].

At the same time, the electric system on the island faces a complex series of reliability, environmental and economic issues [2] such as:

- A rapid load growth on the west side of the island with primary power plants' located on the northeast or Hilo side of the island has created transmission loading problems and voltage problems especially during certain line contingency situations;
- Adding central station renewable energy sources such as solar and wind has the potential to add significant additional stress to the existing electric system;
- The relative low night-time loads present on electric the system has sometimes resulted in the need to curtail available renewable energy.

In this paper, we present an integrated design approach for a low-energy community to address many of these issues. The community, currently under construction, is located on a 700-acre piece of land on the west side of the island. This master-planned community will contain a mid-size business hotel, over 1,000 residential units, a town center with retail businesses, an industrial park, hospital, wastewater treatment plant and a university campus.

In the design process, we considered the needs of various stakeholders who are directly or indirectly impacted by the community development including residents living in the community, residents living on the rest of the island, the developers and the utility company. Our goals are to mitigate any negative impact the community might have on the rest of the island including its electric system, to reflect the stakeholders' needs, and to create a situation that offers favorable financial returns for the investors.

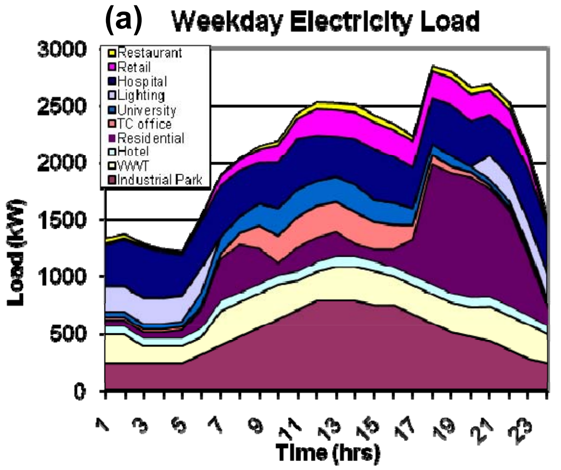
Energy is at the center of our design process. A sustainable energy system within the community is critical to achieving our goals. To create a low-energy community, we have considered:

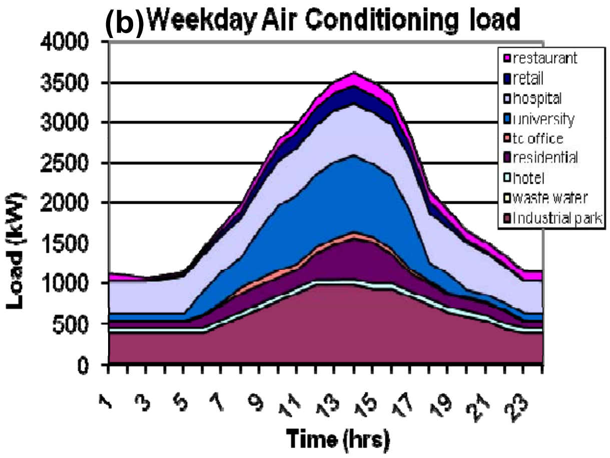
- Reducing peak and total energy demand
- Optimizing the utilization of on-site renewable energy
- Implementing effective energy management
- Conserving natural resources

Since all four aspects are interrelated, an integrated approach is necessary. This paper is organized as follows. First, we analyzed the energy demand and electricity load profiles in the community. Then we examined several options in energy demand reduction. Next, we evaluate the potentials of renewable energy generations (mainly solar energy) and associated energy storage. To enable flexible employment of renewable and distributed energy generations, we proposed a microgrid system for energy distribution for the community. Finally, an energy aggregator is investigated to connect residents, developers and the utility company's interests.

2. Energy Load Analysis

An accurate profile and assessment of the energy demand of the community is necessary for further engineering analysis. For this purpose we created an expected weekly peak demand load curve for each component of the development including the industrial park, wastewater treatment plant, hotel, residential homes, town center offices, university, street lighting, hospital, and restaurants. The curves are shown below in Figures 1a-c.





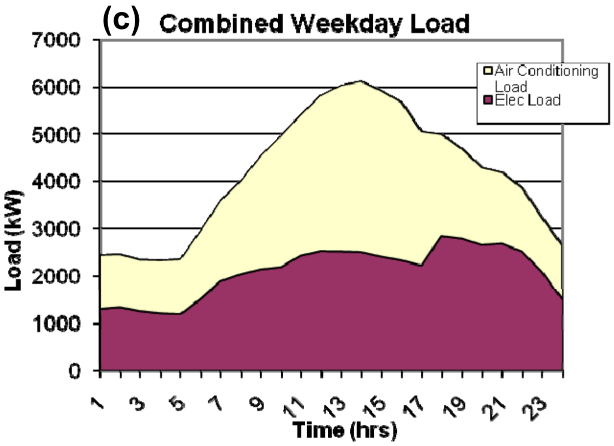


Figure 1. Temporal profiles for (a) electricity (not including air conditioning) demand, (b) air conditioning electricity demand, and (c) combined electricity demand.

The curves in Figure 1 represent a "business as usual" prediction of the daily peak load for a typical week for the project. It is important to note that residential loads dominate the electrical usage and that air conditioning accounts for a majority of the electrical load for the development. Thus residential and air conditioning energy consumption is the main focus in our subsequent analysis.

The electricity load duration curve, shown in Figure 2, illustrates how the infrequent but high power demand periods can quickly increase power capacity requirements for the community. If all peak electricity is purchased from the utility company, the reliability of the island-wide electrical systems will likely be further compromised considering the existing transmission bottlenecks [1].

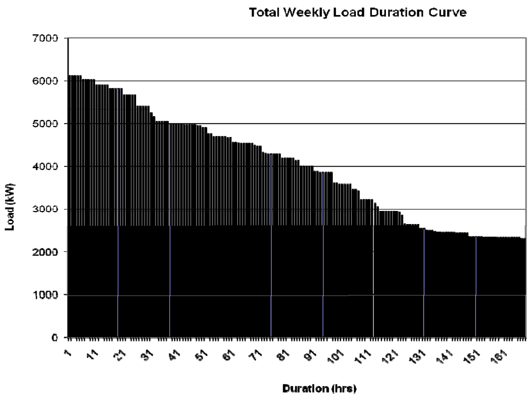


Figure 2. Electricity load duration curve for the community

3. Energy Demand Reduction

3.1. Demand Response (DR)

Demand response could be used to reduce or interrupt non-critical electrical loads such as pool pumps and laundry equipment during periods when the system is at or near capacity or during emergencies to prevent the system from failing due to overload. We estimated the potential load that is curtailable through demand response for each sections of the community as shown in Table 1.

Table 1. Estimated percentage of Electric Load curtailable through Demand Response

Section	% of Load Curtailable
Residential	5%
Hotel	3%
Town Center Office	5%
Retails and Restaurants	10%
Industrial Park	10%
Hospital[1]	85%
Waster Water Treatment Plant	15%

[1] This presumes that the hospital has a backup generator capable of supplying 85% of its power needs during an emergency. This backup generator would be activated during a DR event.

3.2. Residential Energy Demand Reduction

The residential homes are the most significant factor in total energy demand of the community. For this reason, it is essential to use energy-efficient design techniques for the residential structures. Through architectural alterations and material/equipment specifications, mechanical-cooling, energy consumption can be substantially reduced. We quantified the energy savings using the Quick Energy Simulation Tool (eQUEST) [3] supported as a part of the California Energy Design Resources program for the different alterations. Figure 3a-c and Table 2 demonstrate the results.

Figure 3a shows the projected baseline energy consumption and its components for the largest home, called Model D, being planned for the community. Figure 3b depicts the energy consumption of Model D home after implementing energy efficiency measures on windows, daylighting, area lighting, shading and air conditioning units. Furthermore, our analysis on passive cooling strategies suggested that we can design the home to meet the satisfactory thermal comfort levels without air conditioning. Figure 3c illustrates the energy consumption for this aggressive design.

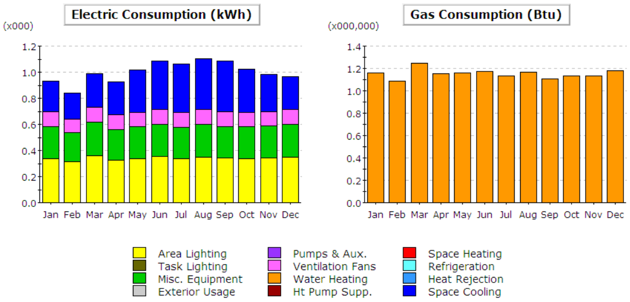


Figure 3a. Baseline energy consumptions for Model D home

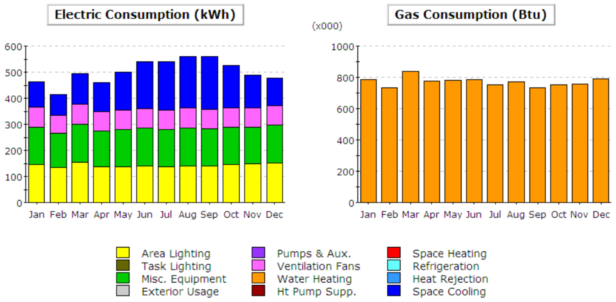


Figure 3b. Energy consumptions for Model D home after implementing energy efficiency measures

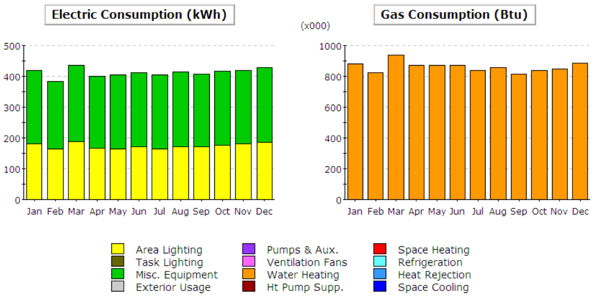


Figure 3c. Energy consumptions for Model D home after implementing energy measures and passive cooling strategies (removal of air conditioning unit)

Table 2 lists the peak electrical loads and annual electricity consumptions for the largest home, Model D and the smallest home, Model A, compared against the energy consumption of an average Hawaiian home (which size is between Models D and A).

Table 2. Peak loads and annual electricity consumptions for different home designs

Home	Scenario	Peak Load (kW)	Annual Consumption (kWh)
Hawaiian Average	Baseline	N/A	8,400
Model D	Baseline	3.49	12,010
	Efficiency	2.19	8,821
	Efficiency and Passive Cooling	1.25	4,951
Model A	Baseline	2.49	8,107
	Efficiency	1.59	6,027
	Efficiency and Passive Cooling	0.88	3,422

Through this process, the largest home in the community could have an average annual electric energy consumption that is approximately 3,500kWh less than the average Hawaiian home.

3.4. Energy Demand Reduction through Natural Systems

In addition to technologies that directly generate, use, or manage electricity, load reduction using natural systems of plants, organisms, and water should also be considered. These strategies utilize site-specific environmental systems to passively reduce electrical load and water usage. The cycles of collection, purification, irrigation and growth continue to effectively function and in fact improve with maturation, bringing additional electricity, water use, and cost reductions over time. Specific microclimate strategies of tree orientation and density surrounding residential buildings are recommended to reduce cooling loads. Various wastewater systems using conventional chemical treatment and alternative biological treatment would be beneficial, and a biological treatment system with composting of solid waste is also proposed. To reduce water load (and hence electrical demand) on the waste treatment system as well as demands on water supply systems, alternative landscape solutions such as rainwater collection, grey water systems, and native plantings could be very beneficial.

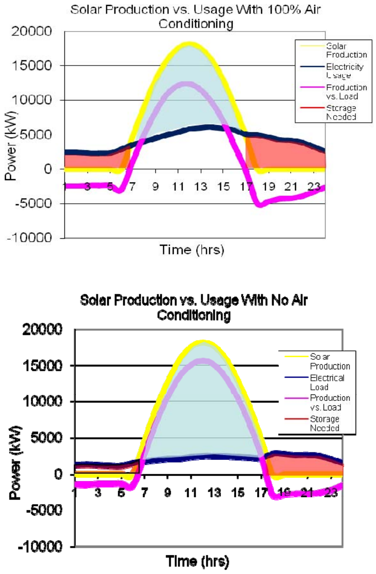
3.5. Deep Source Cooling

District cooling combined with deep source cooling can be used to eliminate the need for air conditioning in structures not conducive to passive cooling techniques. Areas of the community such as the industrial park, town center, hotel, and university campus demand 25% of the entire community's peak energy load for cooling alone. Our analysis suggested that a district cooling system is able to reduce the cooling load by more than half. To further reduce the cooling load, we modeled a pipeline system which is run from the nearby deep seawater system to the community. This system can provide the same amount of cooling as a traditional district cooling system, but with 10% the electric usage.

4. Energy Generations and Storage

4.1. Energy Generation

We examined various on-site energy generation options including solar, wind, geothermal and waste gasification. Solar was identified as the most feasible option given the yearlong fair weather conditions present on the west coast of the island. We developed a model to optimize the siting of photovoltaic (PV) arrays. The optimal tilt angle for annual solar energy generation was found to be 22.5 degrees. Figure 4 shows the comparison of solar PV electricity generation from all available roof space and electricity demand in the community under two scenarios, 100% of the residential units having air conditioning (Figure 3a) and no air conditioning for residential units (Figure 3b).



(a)

(b)

Figure 3. Comparison between solar PV electricity generation and electricity demand in the community. In (a) it is assumed that all residential units have air conditioning. In (b), it is assumed that no residential units have air conditioning.

It is clear that there is excess solar electricity during daytime and that electricity demand exceeds generation from early evening to next morning. Therefore energy storage is necessary to achieve the benefits of solar energy. Moreover, the total number of PV panels, as well as the size of energy storage, depends on the requirements of the developer and residents. These issues will be analyzed further in the aggregator model in a later section.

It is worth noting that a single two-square-meter panel could provide for all the hot-water needs of a family of three throughout a year based on our analysis. Thus solar thermal would not take away significant roof areas for solar PV installation.

4.2. Energy Storage

Energy storage allows the variable load from the PVs to provide a steady electrical supply to users. A storage system for the development must be able to meet the charge/discharge capacities, storage requirements, and site characteristics while being compatible with distributed solar generation, and must be conducive to third party ownership. We conducted cost/benefit analysis on three available technologies, lead acid and sodium sulfur (NaS) battery banks and small-scale compressed-air energy storage (CAES) in fabricated vessels [4]. We also investigated the feasibility of plug-in hybrid electric vehicles (PHEVs), which will be soon commercially available.

4.2.1. Battery Banks and CAES

Table 3 compares the various specifications among lead-acid battery banks, sodium sulfur battery banks and compressed air energy storage. We assumed that 1) the lifetime of the storage system is 30 years and 2) solar PVs provide 1,100 kW of peak load and the rest of the peak load is purchased from the utility company.

Table 3. Comparisons between different energy storage options

	Lead-acid battery Banks	**NaS battery Banks**	**CAES**
Power Capacity (kW)	1,100	1,100	1,100
Storage Capacity (kWh)	8,184	8,184	8,184
Size (ft^2)	5,074	1,637	24,552
Annual Natural Gas Usage (ft^3)	N/A	N/A	23,269,017
Initial Capital Costs	\$1,679,700	\$2,211,000	\$1,642,080
Annualized Costs	\$374,444	\$267,007	\$587,338

This comparison suggests that sodium sulfur batteries are the most attractive option. They are the least expensive with the smallest footprint. The initial capital costs of lead-acid batteries are roughly 3/4 the price of sodium sulfur batteries, amounting to over \$0.5 million. However, lead-acid batteries require replacement every 5 to 6 years, while sodium sulfur batteries have upwards of 15-year lifetimes and require a single replacement over the 30-year period. CAES is much more expensive, mainly because natural gas prices in Hawaii are roughly three times the national average. Initial capital costs for CAES are only \$1.7 million, equal to the initial capital costs of lead-acid, but when combined with annual fuel costs, the annual costs of CAES exceed both sodium sulfur and lead-acid batteries.

Battery banks can be arranged in three different setups: centralized storage, by which one large battery bank serves the entire community; block storage, composed of smaller banks for clusters of homes and/or businesses; and individual storage, by which each home has its personal battery storage system. A centralized storage bank would be most conducive for maintenance, the energy aggregator, and third-party ownership, while individual home storage is the most applicable for linking with residential solar generation, PHEVs, and the microgrid. Overall, block storage emerges as the most appealing system, capturing benefits from both centralized and individual storage systems. The residential section of the community will be divided into four "blocks" for storage, with an additional storage block for the hotel and town center and one for the industrial park. The battery banks should be located relatively close to the block they are charging/discharging with.

4.2.2. PHEVs and V2H

If coupled with vehicle-to-home (V2H) technology, PHEVs could provide additional energy storage capacity as well as emergency backup power for individual homes. In order to investigate this concept we developed a model to simulate the V2H/PHEV concept. The modeling components include a house (taken as the Model D with air conditioning as described in Section 3.2), a PV system (as described in Section 4.1), the grid, and a PHEV. The house acted as a load while the PV system generated electricity during the day. The grid was either a source or a sink of power depending on whether electricity was needed by the house or the PV system was producing excess electricity. The PHEV was assumed to have a 16 kWh battery, which can be plugged into the house during any hour of the day and can be discharged or charged depending on the situation.

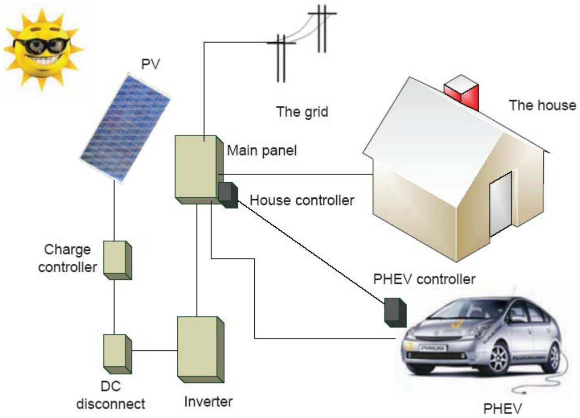


Figure 4. A sketch for the Vehicle-to-Home concept

Twenty-four different scenarios were simulated with the PHEV returning home at various times of the afternoon with its battery in various states of charge (SOC). The battery of the PHEV is then recharged until approximately 6 pm. After 6 pm, the PHEV is available to supply the house with electricity. The PHEV is recharged to a full SOC from 1 am to 5 am using grid electricity.

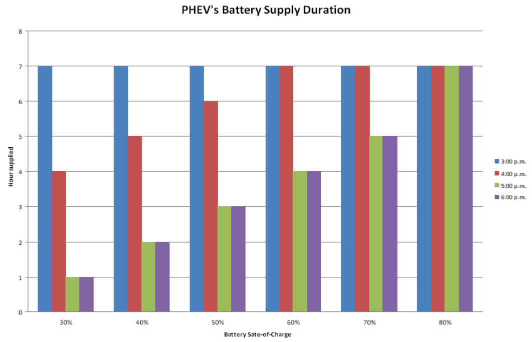


Figure 5. Duration of PHEV battery supply to home

Figure 5 illustrates the simulation results. Note that a PHEV that comes home at 3 p.m. can supply all of the evening load. A PHEV returning at 4 p.m. with a 30% SOC manages to serve the house load for four hours.. It is clear (and obvious) that if a PHEV is to supply electricity for its house, the PHEV must either come home well before 6 pm to allow time for the PV to charge its battery, or it must arrive with a high SOC. Several additional scenarios were investigated including a "bad solar day" scenario where it was assumed that the PV system was producing 50% of its rated output, a weekend scenario where people typically sleep in, go out for some activity, and come home in the afternoon, and a "blackout" scenario where the PHEV is required to provide emergency backup but the residents are not allowed to run major appliances. Under all of these scenarios, the PHEV plays an important role in the community's energy management needs.

It is worth noting that community residents will also see significant transportation cost savings by using PHEVs given current electricity and gasoline prices. At the same time, charging PHEVs at night may provide additional revenue sources for the utility company. Next, we developed a financial model to elucidate the benefits of PHEVs to the residents and the utility company. Table 4 summarizes the data used, the model assumptions, and the results.

Table 4. Baseline data, assumptions and results from a financial model simulating the benefits of PHEVs

Data used for base case		
Hawaii average vehicle mileage per year	7405	
CAFÉ mileage standard (MPG)	27.5	
Medium SUV gas mileage (MPG)	18	
Model Assumptions		
	Prius PHEV	Escape PHEV
Discount Rate	9%	
Car loan period (months)	84	
Car loan interest rate	7.50%	
Subsidy per vehicle	$5,000	
Down payment	$5,000	
Cost	$30,500	$35,500
Battery capacity (kWh)	5	11
Gas mileage (MPG)	65	50
Electricity rates ($/kWh)	$0.31	
Gasoline price ($/gallon)	$3.90	
Results		
PHEV annual savings	$261	$223
PHEV gasoline avoided (gallons)	155	263
Revenue to the utility company	$348	$813

Our financial model indicates that PHEVs can be deployed today at reasonable cost, and do not need major subsidies to be economically viable. However, our analysis also suggests that the initial push to deploy PHEVs at the community level will likely have to come from some type of public/private partnership. Ultimately, once PHEVs are deployed, the private sector should be able to manage the majority of the product life cycle.

5. Energy Distribution: Microgrid

An ideal electrical system for a sustainable community should be able to

- Provide residents and businesses reliable and low cost electricity
- Enable flexible employment of distributed energy generation and demand response resources
- Facilitate energy management within the community and reduce stress on the power systems beyond the community

Conventional electrical systems do not meet these requirements due to their centralized nature, while a microgrid, properly designed, can potentially achieve most of the requirements. Developers often expect their developments to be flexible in adopting new technologies over a five to ten year horizon. Thus, a microgrid system can be regarded as an enabler of distributed energy resources and efficient energy management for a long time to come.

A microgrid is an integrated energy system consisting of interconnected loads and distributed energy resources. Our analysis of the microgrid is based on the Consortium for Electric Reliability Technology Solutions (CERTS) microgrid concept [5], which has many desirable features such as:

- Seamless islanding and reconnection through a separation device (static switch) at a single point of connection
- Peer-to-peer operation
- Plug-and-play capability
- No dependence on a central controller

A one-line diagram of the microgrid we developed for the community is depicted in Figure 6. The microgrid comprises two ring subdistribution systems and one radial sub-distribution system with the utility company's 12.4-kV line running across the development from both ends.

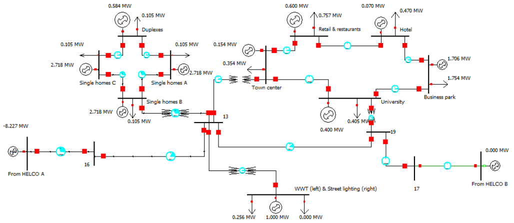


Figure 6. One-line diagram of the microgrid system designed for the community

The residential section (left side of Figure 6) was divided into four clusters. Three of these clusters represent the single homes, while the fourth cluster represents duplexes. The second ring system (right side of Figure 6) comprises the industrial park, the town center, retail and restaurants, the hotel, and the university site. In the analysis, it was assumed that the underground cables were Alcoa aluminum steel-reinforced cables. An ambient temperature of 122 degrees Fahrenheit (representing a worst-case scenario) and a conductor size of 795,000 Circular mils were also assumed. This gave a line impedance value of 0.1288 + j0.393 ohms per mile. The various line lengths were estimated from the scaled diagrams provided.

To build a microgrid system in the community, a mesh distribution network should be installed instead of a radial network, However, there are some practical challenges to implementing a microgrid system. Microgrid's are still in an experimental stage, and have never been applied at community scale. As depicted in Figure 7, we recommend the community start with a traditional radial network that can be modified easily and install conduit in preparation for implementation of ring.

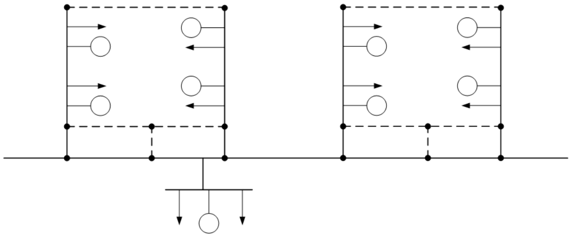


Figure 7. Adaptation to the microgrid system from traditional radial network

6. Energy Management: Aggregator

So far we have discussed strategies such as reducing energy demand, installing distributed energy sources and energy storage, connected by a microgrid within the community. PV panels, battery banks, and PHEVs are all potentially useful technologies for reducing the overall demand for electricity or changing the time to purchase electricity from the utility company. However, if the decision of whether or not to use these devices is left to individual users within the community, a suboptimal situation might arise. Too much or too little generation might be installed to complement too much or too little storage, which would result in increased costs and decreased effectiveness of the system. Based on these considerations, we proposed an "energy aggregator" to purchase and manage the distributed-generation and storage systems.

We developed an energy aggregator model to determine the optimal amount of PV and battery storage for the community, and the potential revenue for an aggregation company. The goal of the model is to size the generation and storage systems so that costs are minimized. The costs being considered are electricity costs from the utility company and the installation and day-to-day costs associated with using and maintaining the generation and storage systems.

We considered three scenarios. In the first scenarios ("standard"), the aggregator can buy and sell power from the utility company according to the current net-metering regulations for Hawaii, the expression for the costs is:

$$Cost = \sum_{n=1}^{Lifetime} 365 * (1+d)^{-n} * \sum_{i=1}^{N} \left(b_i * (1+r)^{n-1} * B_i\right) + g*G + c*C + e*E \qquad (1)$$

where d is the discount factor used for adjusting future dollars to present value; b_i is the cost of purchasing electricity from the utility company at period i, given in \$/kWh; B_i is the power being purchased from the utility company at period i, given in kW; r is the yearly rate of increase for the utility company's electricity prices; g is the cost per kW of peak PV-generation capacity, given in \$/kW; G is the peak PV-generation capacity, given in kW; c is the cost per kW of peak storage power, given in \$/kW; C is the peak storage power, given in kW; e is the cost per kWh of energy storage capacity, given in \$/kWh; E is the total energy storage capacity, given in kWh.

In the second scenario ("buy-only"), the aggregator can purchase electricity from the utility company but cannot sell it back. The same formula for the costs, Equation (1), is used. However, $B_i \geq 0$ since the power purchased from the utility company at period i must be nonnegative.

In the third scenario ("time-of-day"), the aggregator buys electricity from the utility at prices that vary depending on the time of day, but sells to the resident-users at a constant rate. The formula for the costs is:

$$Cost = \sum_{n=1}^{Lifetime} 365 * (1+d)^{-n} * \sum_{i=1}^{N} \left(\cos t_i * (1+r)^{n-1}\right) + g*G + c*C + e*E \qquad (2)$$

$cost_i$ is the cost of electricity purchased from the utility company at period i, given in \$. Additional constrains are that $cost_i \geq bi*Bi$ and $cost_i \geq -sell_i*B_i$, where $sell_i$ is the wholesale value for selling electricity to the utility company at period i, given in \$/kWh. These two constraints ensure that the true cost of electricity from the utility company is reflected in the model. When the aggregator purchases electricity from the utility company it is at the retail price, and when the aggregator sells electricity it does so at the wholesale price.

As we discussed in Section 3.2, significant energy demand reduction can be achieved by implementing passive cooling design and hence eliminating the needs for air conditioning in the residential section of the community. Thus under each scenario, we used three load curves as inputs: no residential air conditioning, all residential units with air conditioning and some fraction of the residential units with air conditioning. Therefore, we simulated total nine cases that are summarized in Table 5.

Table 5. Descriptions of simulated cases

Case #	Load Curve	Utility Pricing
1	No residential A/C	Standard
2	No residential A/C	Time-of-day
3	No residential A/C	Buy only
4	All residential A/C	Standard
5	All residential A/C	Time-of-day
6	All residential A/C	Buy only
7	Some residential A/C	Standard
8	Some residential A/C	Time-of-day
9	Some residential A/C	Buy only

Table 6 shows the selected results for each case including the size of the generation and storage units, the aggregator revenue and cost of power purchased from the utility company. These costs and revenues are over the 25-year lifetime of the generation and storage technology and were adjusted to present value dollars in the same manner the cost inputs were adjusted. in all cases except case 1 and case 7, the aggregator is capable of making a profit at the given electricity rates that are assumed to be increasing annual at 3% for the community residents.

Table 6. Selected outputs from the energy aggregator model

Case #	Peak Generation (kW)	Peak Storage Power (kW)	Cost of Power Purchased from utility (Million)	Aggregator Profit (Million)
1	12,557	0	\$74.7	(\$0.72)
2	8,720	4,850	\$26.9	\$48.7
3	12,557	7,057	\$0	\$42.9
4	13,146	0	\$76.8	\$0.38
5	9,195	4,990	\$27.7	\$51.2
6	13,146	7,328	\$0	\$45.3
7	12,561	0	\$74.5	(\$0.51)
8	8,731	4,823	\$26.8	\$48.8
9	12,561	7,044	\$0	\$43.0

Table 7 shows the cost of electricity over the 25-year lifetime of the aggregator. In all nine cases the introduction of an energy aggregator to the development saves residents money.

Table 7. Cost of with and without the energy aggregator

Case #	Standard Electricity Cost (Million)	Cost with Aggregator (Million)	Savings (Million)
1	$164.3	$148.5	$15.8
2	$164.3	$135.4	$28.9
3	$164.3	$135.4	$28.9
4	$172.0	$155.2	$16.7
5	$172.0	$141.7	$30.3
6	$172.0	$141.7	$30.3
7	$164.3	$148.5	$15.8
8	$164.3	$135.4	$28.9
9	$164.3	$135.4	$28.9

Tables 6 and 7 above show that an aggregator can be profitable even while saving the residents money. Even though cases 1 and 7 show a net loss for the aggregator, the community residents are saving more than $15 million in both instances, while the aggregator is losing less than $1 million. This means that although an annual increase in a price of three percent may not be financially attractive for the aggregator, it is possible to raise this rate to make the company profitable while keeping it low enough that the residents are still saving money. For example, increasing the annual rate from 3 percent to 4 percent allows the aggregator to make $6.6 million in profit even while saving residents $8.4 million.

Furthermore, there are other benefits that this system could create, and it could possibly generate other sources of revenue. Namely, there is the potential to decrease peak demand and increase the base load of the community, both of which could create value for the utility company. The utility company could save money by not having to run peaking units that are much more expensive to run than base-load plants.

Similar to the value that comes from peak shaving, there is also value in either preventing blackouts or providing backup power when a blackout does occur. Studies have been done to determine the cost of a blackout for different geographical areas and industries. Costs vary depending on who is affected by the blackout and the time of year the blackout occurs, with some blackouts not causing much expense and others being very expensive. If the energy aggregator installed a system that could reduce the number of blackouts per year within the development or could provide backup power for a nearby industry that is reliant on constant power, another revenue source would be created.

Lastly, there are stability and power-quality benefits that batteries provide and the utility company may be willing to pay for. If the utility company were willing to help pay for the on-site storage in return for the benefits it provides to the overall grid, the scale of the battery banks may change significantly.

7. Conclusions

We have learned a number of valuable lessons from our design process which can be applied to future sustainable community development.

First, an interdisciplinary team is needed to design a truly sustainable community. We focused on energy in our design centering on engineering and technologies. However, expertise in architecture, landscape architecture, waste water treatment and business management proved to be invaluable in achieving energy, environmental, and economic sustainability. Designing efficient buildings requires a close collaboration between engineers and architects. Decisions on landscaping and waste treatment often have direct and/or indirect implications on energy consumption. Without a sound business plan, no sustainable community can become financially viable.

Second, an integrated approach is necessary. An integrated approach will maximize design benefits and reconcile design conflicts. For example, the benefits of distributed generation, energy storage, and the energy aggregator cannot be fully materialized without a microgrid system as an enabler. The selection of roof angles and orientations requires consideration of solar energy generation, architectural design (to achieve passive cooling) and landscape manipulation (for roof shading and microclimate).

Third, we showed that it is feasible for a low energy or net zero energy community to become environmentally friendly and economically profitable at the same time. Technologies with careful planning will create new business opportunities which benefit the community residents, developers, investors, the utility company and the rest of the world. It is worth noting that even though the utility company may lose revenue in selling less electricity to the community residents directly, the utility company may generate profits from charging PHEVs, participating in the energy aggregator, and may reduce costs in peak load shaving and baseload increment.

8. References

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