

Sustainable Development Plan with Solar & Biomass Adaptation for Parador Villa Sotomayor

By:

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A Master's project submitted in partial fulfillment of the requirements for the degree of Master of Science & Master of Landscape Architecture (School for Environment and Sustainability)

University of Michigan

Ann Arbor

April 2022

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Abstract

Puerto Rico was devastated by Hurricane Maria five years ago, and even now the much of the island's population experiences sporadic power outages. After the privatization of Puerto Rico's energy distribution, the power security of Puerto Rico only exacerbated. Local communities in the town of Adjuntas and a local non-profit organization Casa Pueblo are exploring different technologies in hopes to achieve energy resilience. Excess biomass, a common side product from local agriculture activities, can generate carbon neutral energy through the aide of next-generation gasifiers. This can potentially reduce the cost of maintaining a stable microgrid while increasing community autonomy and sustainability. The main task of this project is to create a development plan for Parador Villa Sotomayor, a resort in Adjuntas, including an energy model and improvement of their tourism experience. This work aims to illuminate pathways toward improved quality of life and sustainability, not only for Parador Villa Sotomayor but also for other similar regions in the Caribbean.

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Acknowledgments

We would like to thank Artuto Massol-Deyá from Casa Pueblo for their mentorship and support throughout this project.

We would like to thank and acknowledge Parador Villas Sotomayor (Marribel Torres and Sr. Jesús Ramos) for providing their energy load data and other valuable information that was pivotal into completing our energy model and for their commitment to a resilient Puerto Rico.

We would like to sincerely thank past colleagues of MBRACE Larry Borum III, Andrew Richardson, and Stephen McShane giving us advice, context, past research and support on our project.

Special thanks to the University of Michigan's School for Environment and Sustainability (SEAS), Sustainability Without Borders, Planet Blue and Rackham Graduate School.

A special thanks to our advisors Dr. José Alfaro, Dr. Ivette Perfecto and Dr. John Vandermeer.

Lastly, we would like to show our gratitude to our friends and family that have supported us during this very unprecedented year.

Introduction

On September 17, 2017, category 5 Hurricane Maria struck the island of Puerto Rico, knocking out the island's power grid, shutting down virtually all cellular communication, and destroying nearly all traffic lights and road signs.¹ Months later, a vast area of the island was still left in darkness, with no signs of regaining electricity. Regardless of income, everyone on the island suffered from the power grid failing. Priority to power restoration was given to urban centers, even though smaller rural villages were closer geographically to power plants.² In total, it took up to 11 months for the island to recover its energy infrastructure to a functional level.

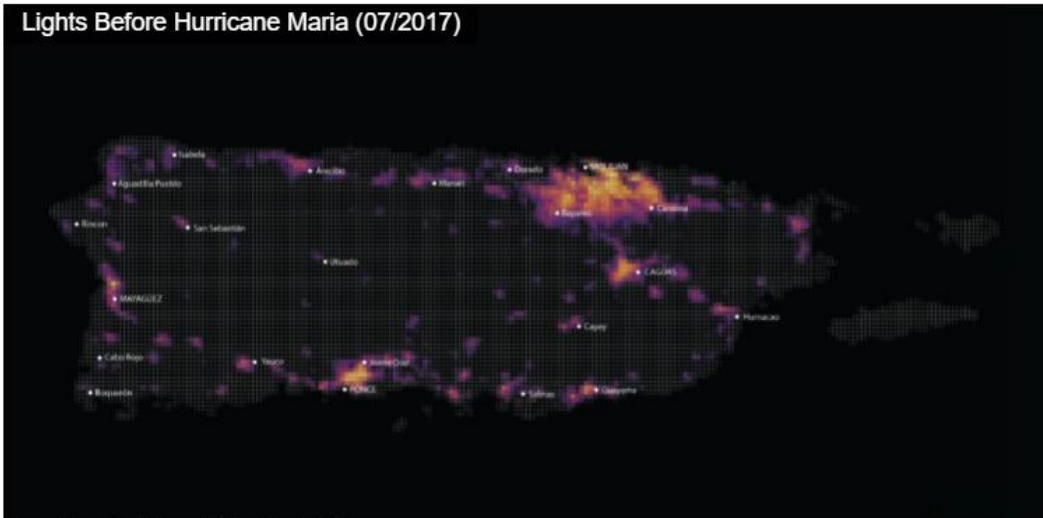


Photo Credits: Before NASA After NASA



Photo Credits: Before NASA After NASA

¹ <https://www.climate.gov/news-features/understanding-climate/hurricane-marias-devastation-puerto-rico>

² <https://journals.plos.org/plosone/article?id=10.1371/journal.pone.0218883>

At the same time, without a resilient power grid, their power system remains fragile and unreliable today – five years after Hurricane Maria. The situation worsened after LUMA Energy, a private company, took over the transmission and distribution of electricity in June 2021³. Their management and maintenance can't meet the surging demand in Aug and Sep, which led to more outages along with those brought by hurricanes. Puerto Rico's power grid desperately needs an upgrade. At the same time, more and more people and communities are seeking alternative energy production sources to become less reliant on the power grid.

Our partner Casa Pueblo is a non-profit organization in Adjuntas, Puerto Rico. Over the past forty years, it has grown into a hub for resilience, education, and environmental advocacy in the mountain town of Adjuntas, Puerto Rico. Entirely run by solar power since 1999, Casa Pueblo became the sole energy provider of the local community after hurricane Maria. People gathered at Casa Pueblo to connect their life-saving equipment even weeks after the storms subsided. Casa



Pueblo is an outspoken advocate for solar and other renewable energies for local communities. For the past five years, the School for Environment and Sustainability has partnered with Casa Pueblo in this transition through the project Mini-grids from Biomass Residues for an Agricultural Circular Economy (MBRACE).⁴ This project focuses on reimagining the energy and agricultural systems in Puerto Rico through the use of agricultural residues, gasification, and biochar. Through this multi-year engagement with Casa Pueblo, past groups have begun demonstrating the feasibility of gasification for a circular economy and the possibility of biomass to help local communities obtain energy resilient. To support the project's goals, Casa Pueblo and SEAS have partnered with Parador Villas Sotomayor, a local resort in Adjuntas, in order to deploy a hybrid biomass and solar photovoltaic (PV) grid.

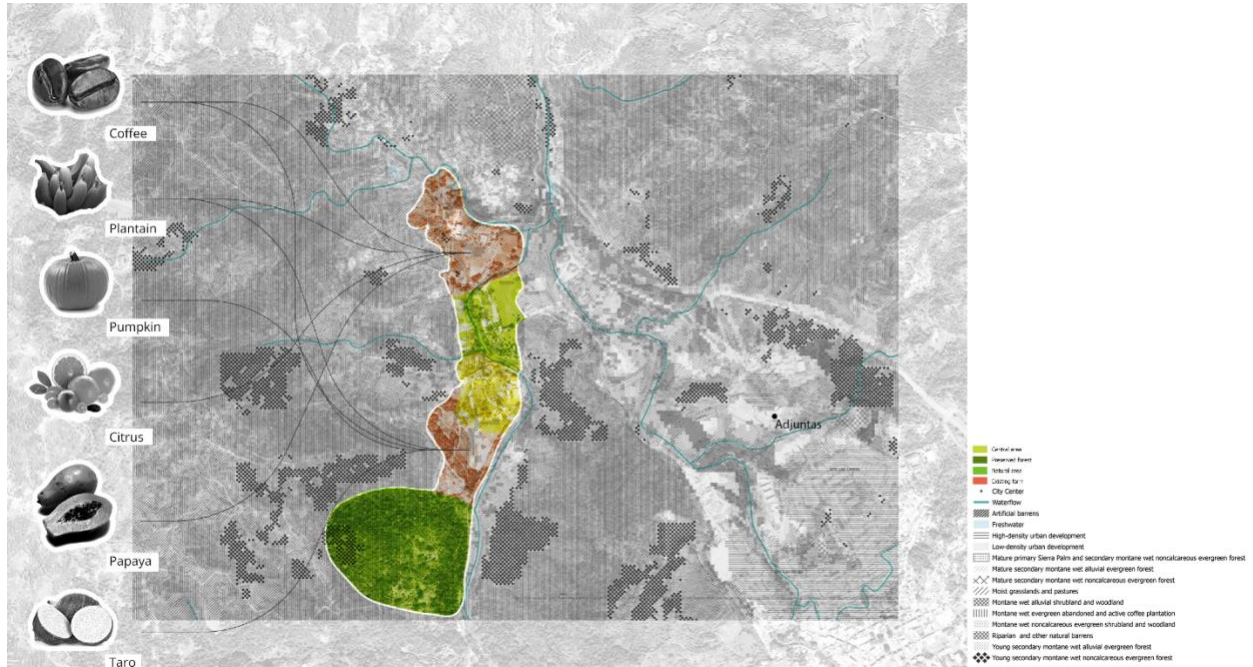
The main objectives of this project are:

1. Create a development plan for Parador Villa Sotomayor based on our survey and energy model.
2. Create a virtual tour for the Parador Villa Sotomayor to increase its visibility on the web.

³ <https://www.nytimes.com/2021/10/19/us/puerto-rico-electricity-protest.html>

⁴ "Solar and Biomass Microgrid in Adjuntas, PR", 2020

Site Context



The entire resort of Parador Villa Sotomayor is about 3.2 acres; it has two separate farming areas adjacent to the central guest area, and a large forest reserve on the south. The main agricultural products are coffee, plantain, papaya, citrus, pumpkin, and taro, most of which have a life cycle of about three years. It can produce an abundance of biomass that can be used in the gasification process. Its location in between a mountain area outside downtown Adjuntas makes it a good place to connect with natural environments and local endangered species conservation.

Local Endangered Species



Cyathea Dryopteroides



Cordia Bellonis



Juglans Jamalensis



Polystichum Calderonense



Epicrates inornatus

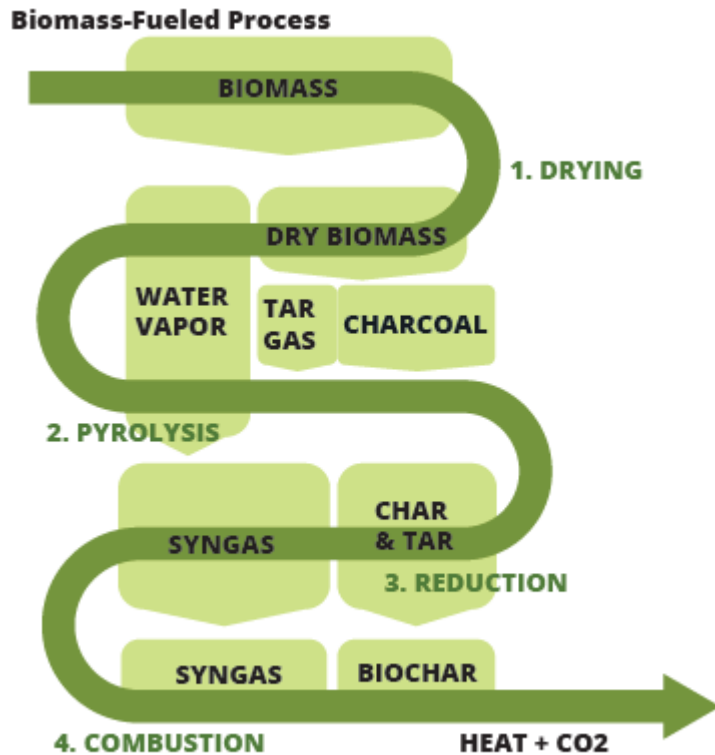


Accipiter striatus venator



Buteo platypterus brunnescens

Bio gasification & Mini grids



The thermochemical process (shown in figure) that uses heat and oxygen to break down biomass into hydrogen rich biogas that can be used as fuel to generate electricity is called biogasification. The byproduct, biochar, can be used as soil amendment improving soil health. ⁵

The gasification process still produces a small amount of carbon; however, it can be offset by the large amount of carbon extracted from the atmosphere in biomass production. For biomass to be carbon neutral, we must ensure that land that produces biomass continues to grow biomass to capture carbon. Another benefit of the gasification process is that it is fueled by biomass, which is likely to be composted or

thrown away as waste, rather than harvesting the potential benefits of the resource.

The operation and maintenance of the gasifier require the cooperation between different disciplines. To promote this mode among rural communities, we may need to embed education and engagement into our planning process. Also, the agricultural byproducts may contain contaminants (dirt, rocks, etc) that can affect equipment. In addition, biogasification relies on the establishment of a good biomass supply chain to maintain the operation of the biogasifier. When establishing supply chains, accurate pricing can be complicated and can vary from community to community and the scale of operations.⁶

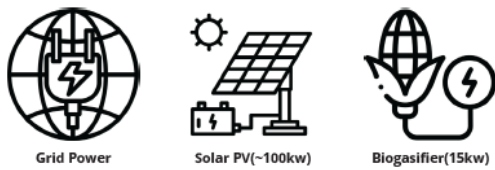
Previous Work and Energy Scenario Plan

Previous teams worked with Parador Villa Sotomayor on designing a hybrid gasifier model and a microgrid energy model using HOMER Pro after surveying their cost and demand for electricity. After our on-ground trip to Puerto Rico, Professor José Alfaro and Andrew Richardson from the

⁵ <https://regenerationinternational.org/2018/05/16/what-is-biochar/>

⁶ "Solar and Biomass Microgrid in Adjuntas, PR", 2020

last team refined the energy model and the design of gasifier, which are embedded in my design proposal.



The current proposed microgrid consists of a grid connected system with solar PV and a 15 kW gasifier. It has a 5-year payback period, 19% IRR, 15% ROI, 0.21/kWh cost of electricity. The roof areas of the main buildings in Parador Villa Sotomayor (~230m²) are used to calculate the solar potential production. The renewable energy penetration is around 30-40%, which can be improved in our design proposal through different strategies.

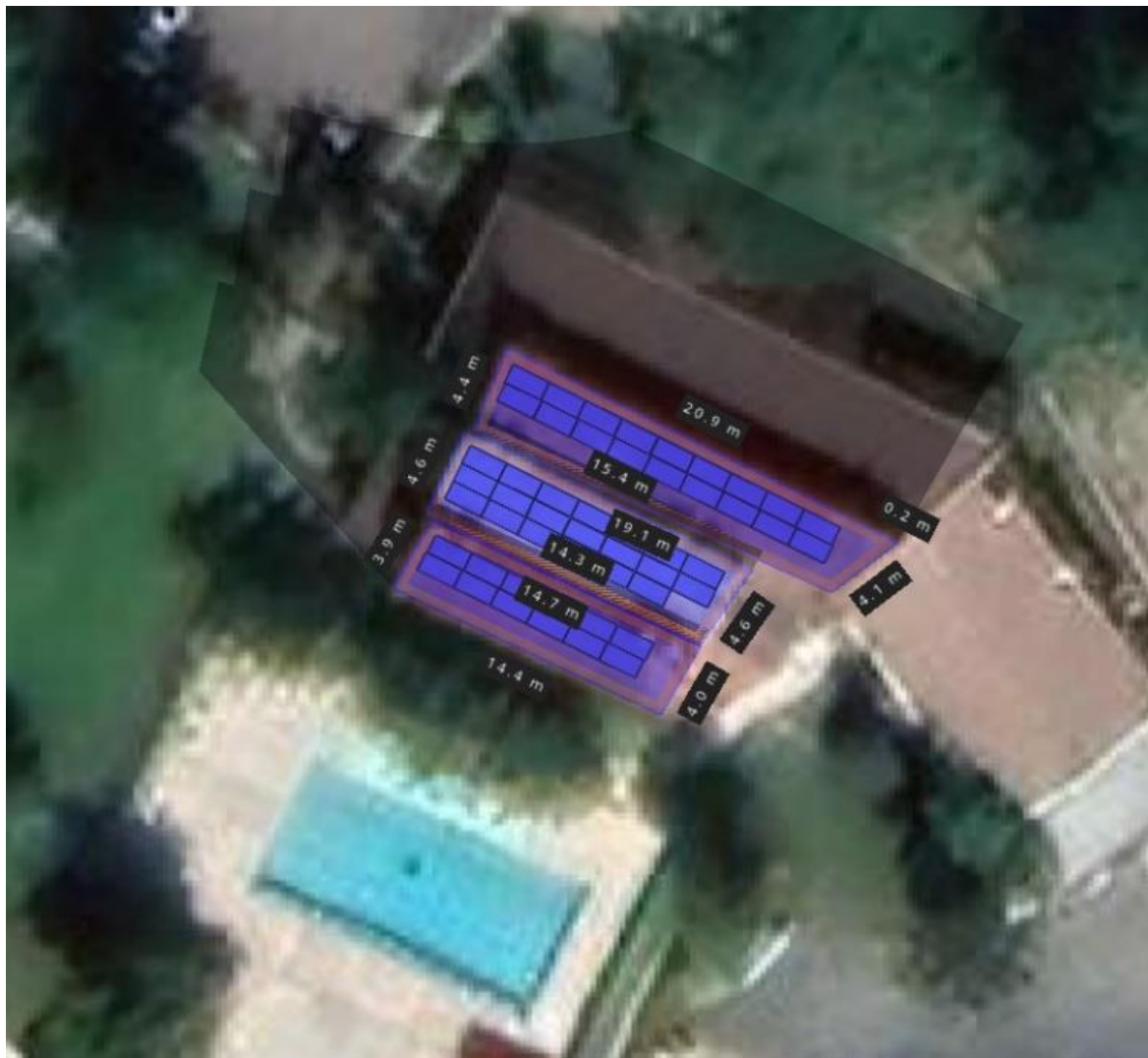


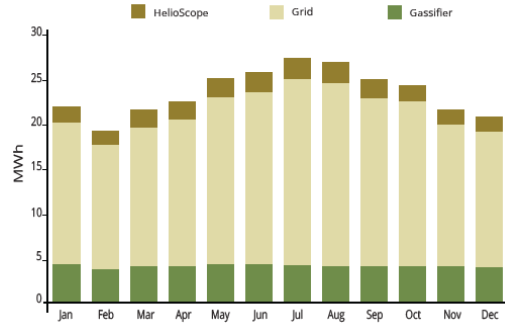
Figure 1 Helioscope model used to calculate monthly PV electricity production

Cost Summary
Winning System Architecture

-  HOMER Cycle Charging
-  Grid
-  Gasifier - 15.0 kW
-  HelloScope - 1.00

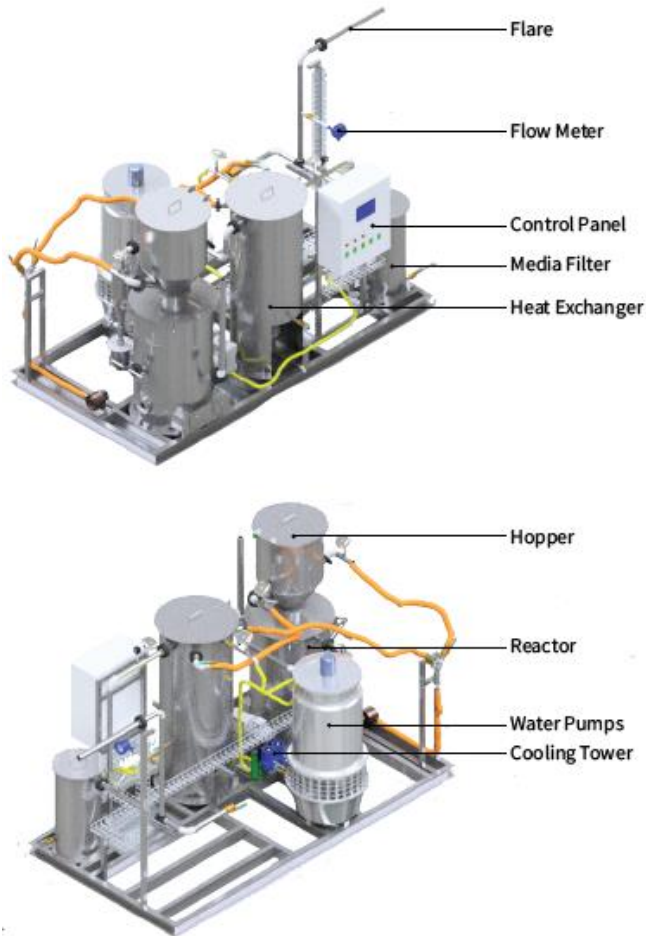
- Base Case Architecture**
-  HOMER Cycle Charging
-  Grid

	Base Case	Lowest Cost System
NPC ⓘ	\$696,020	\$629,145
Initial Capital	\$0.00	\$69,500
O&M ⓘ	\$65,202/yr	\$52,427/yr
LCOE ⓘ	\$0.234/kWh	\$0.210/kWh



The figure below provides an overview of the updated gasification equipment design performed by previous teams.

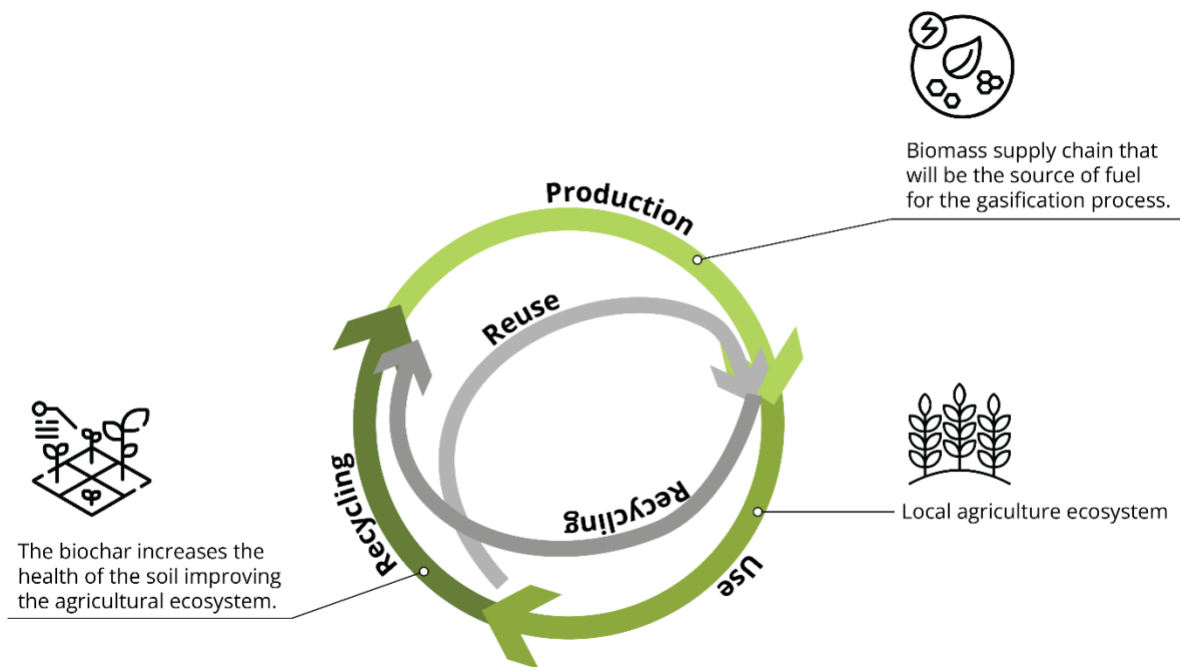
Gassifier Model Design



Mini grids(Microgrids)

In consideration of the energy resilience in the face of potential damage from natural disaster, microgrids can be the better choice for local communities.⁸ Microgrids are typically composed of different energy sources that can provide independent and redundant power to designated critical loads upon loss of the primary source of energy. For Parador Villa Sotomayor, we consider combining solar PV with biogassification. It has a lower cost compared to other energy sources and storage. These helps create a more sustainable and affordable solution to Parador Villa Sotomayor.

Circular Economy



The goal of a circular economy is to eliminate waste by the continual reuse of resources. With the biomass supply chain, our local communities can achieve circular economy and add value to wasted biomass from their farms. This starts with the biomass supply chain that will be the source of fuel for the gasification process. Then the gasification occurs providing energy for the microgrids and biochar for agriculture. The biochar increases the health of the soil improving the agricultural ecosystem. This improvement bolsters the biomass supply chain completing the circular economy.⁹

⁸ Microgrids for Energy Resilience: A Guide to Conceptual Design and Lessons from Defense Projects (nrel.gov)

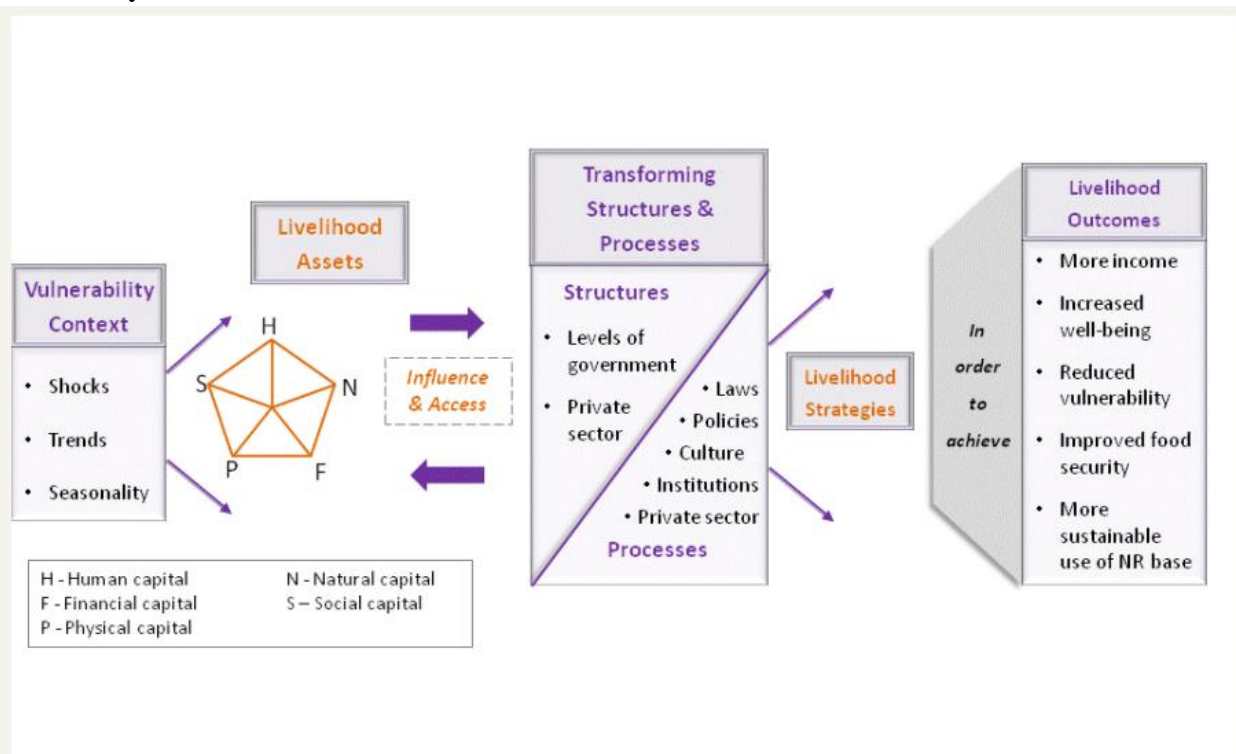
⁹ "Solar and Biomass Microgrid in Adjuntas, PR", 2020

Virtual Tour Creation

During that trip, I also documented a complete virtual tour of Parador Villa Sotomayor. After processing, it's ready to launch for their website. I used an inta360 camera to shoot 360 degree videos on-site and then used Pano2VR software to process and create the virtual tour.

Sustainable Design

Sustainable design was the most critical and client-centered part of this master's work. To ensure approaching our project in an ethically and equitable manner, the multi-year MBRACE project has consistently operated using the Rural Livelihoods Framework which emphasizes holistic, community-led assessment and action.¹⁰



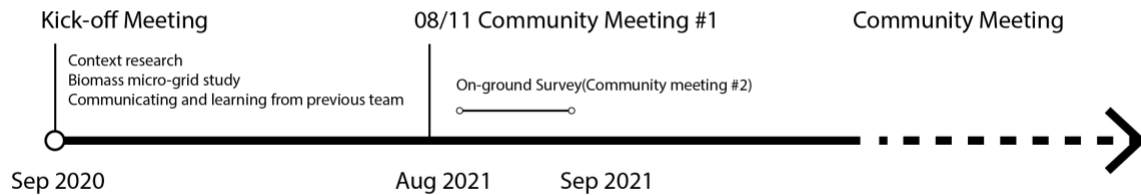
Source: DFID (1999) p. 1.

Our design goal is to focus on improving their livelihood outcomes. The three main stakeholders considered in this project are local farmers, local Parador, and tourists. Based on our analysis, we will create a development recommendation plan for our client using ArcGIS, AutoCAD, SketchUp, Lumion, Adobe Photoshop, Adobe Illustrator.

¹⁰ https://www.soas.ac.uk/cedep-demos/000_P528_RF_K3736-Demo/unit1/page_22.htm

Community engagement

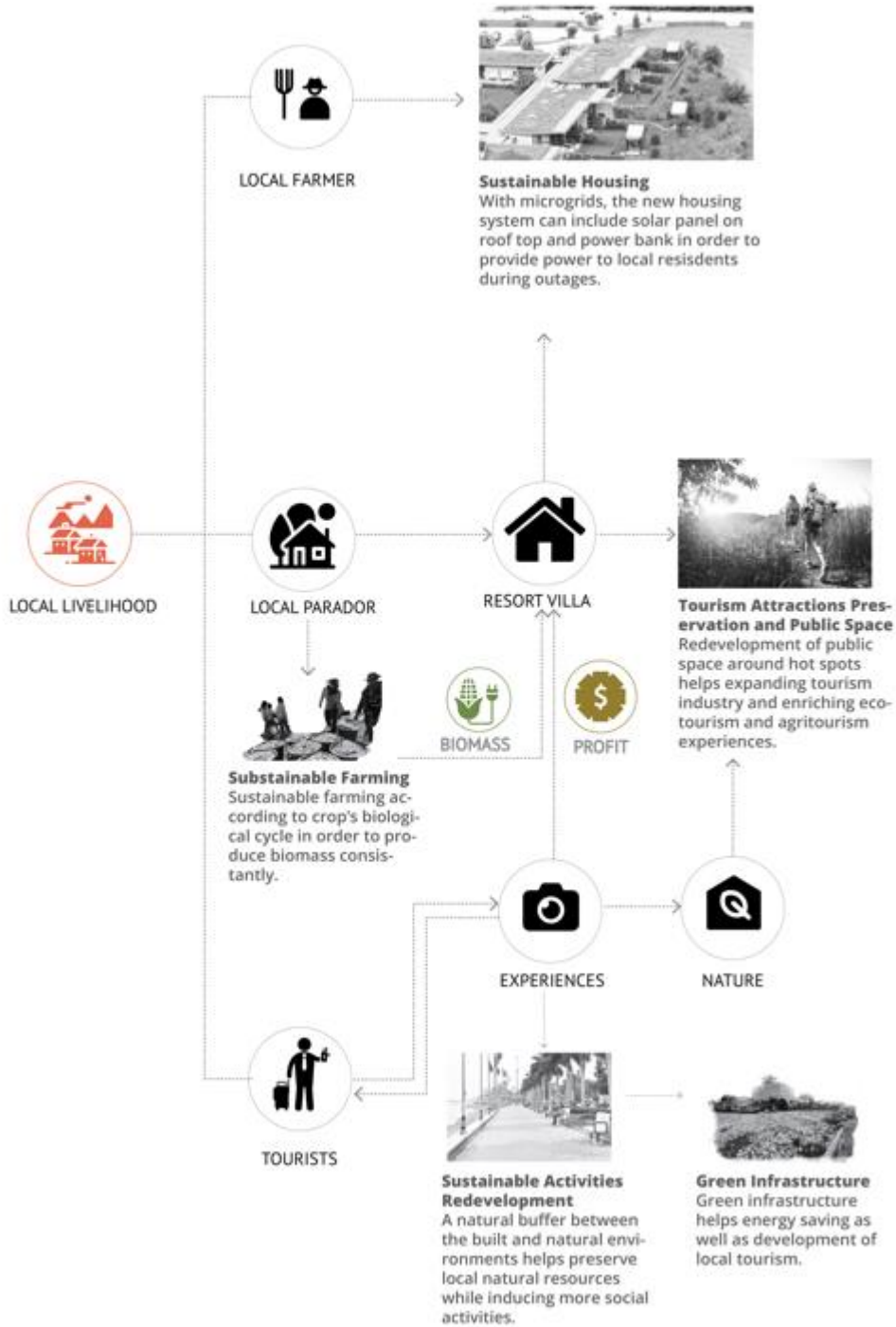
Timeline



Main Feedback & Expectation from community

1. Attract more tourists, and improve their engagement.
2. Improve the sight guidance towards their entrance.
3. Preserve forests, and add more natural trails.
4. Reliable biomass gasifiers & solar system.

Recommendation



Strategies

Our development plan focuses on improving local livelihood through energy modeling and design of the local attractions at the parador. The main stakeholders considered in this project are local farmers, tourists, and Parador Villa Sotomayor. Sotomayor serves as a tourist complex in the mountains of Puerto Rico; it provides job opportunities and housing for local farmers. With the adaptations of microgrids, we developed a scheme of upgraded housings for the Parador and local farmers. And in our planning process, our task is to combine the applications of our renewable energy strategies with design to the greatest extent.

Considering their geographical location (not on the shoreline), their main target customers will be tourists interested in experiencing tropical rainforests and mountain life. Improving tourists' experiences and engagement can provide a stable income for local Parador and farmers. (Experience economy)

Agritourism is a commercial enterprise that links agricultural production and processing with tourism to attract visitors to farms, ranches, or other agricultural businesses, entertain and educate visitors, and generate income for the business owner.¹¹ Only a 2-minute walk from Las Garzas Waterfall and 7 km from La Hamaca suspension bridge on Lake Garzas, Parador Villas Sotomayor is a prime location for ecotourism, and agritourism development.

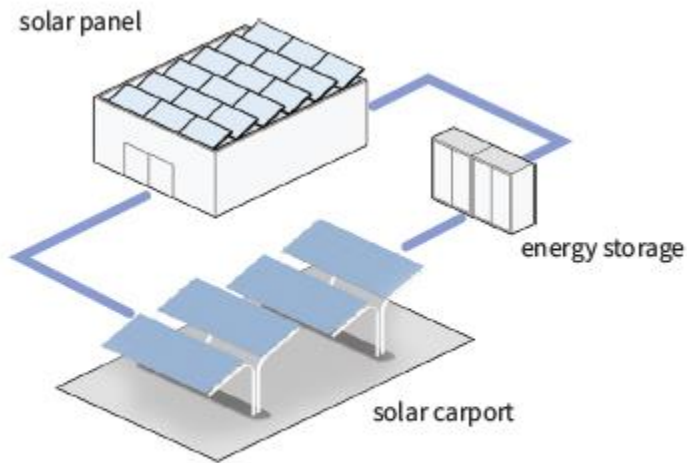
Therefore, we developed our specific strategy from the following three aspects:



¹¹ <https://nationalaglawcenter.org/overview/agritourism/>

Energy related:

1. Solar grid



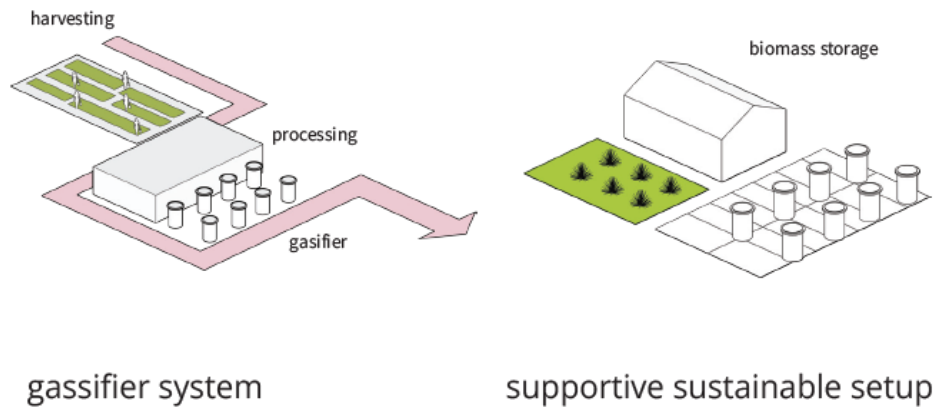
solar grid

Based on Parador Villa Sotomayor's layout and landform, we suggest developing two main clusters of villas to develop two separate off-grid solar grids. Each solar grid would have solar panels and a battery bank for energy storage. In our first energy model, we use the roof area of Parador Villa Sotomayor's restaurant (about 238 m²) to calculate the amount of energy we can get from it (shown in figure 1). If we adopt the design of the solar carport and upgraded housing units, we can achieve two times the area for solar panels giving it higher potential.

Energy Plan For Community Resiliency



2. Gasifier system and Supportive sustainable setup



Biomass Facilities Buildings

Our biogasification strategy need a series of setup to support it, from processing to storages spaces.

Tourism experience related (agritourism):

1. Natural activities



nature activities

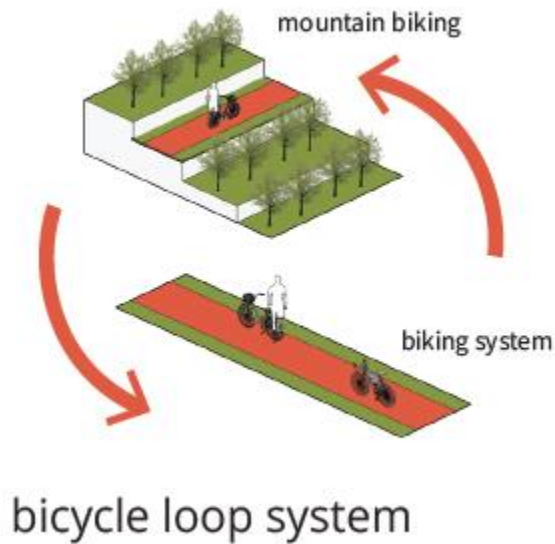
Parador Villa Sotomayor has many natural open spaces and social gathering spaces, which has potential for more natural activities embedding local culture, for example, camping, star watching, and clay making.



Ecotourism & Agritourism activites



2. Bicycle loop system

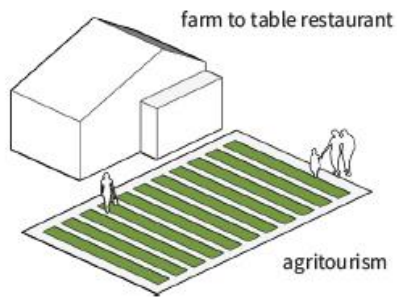


We are increasingly aware of the importance of bicycles in urban design. A recent study from Deloitte in 2020 also highlights the importance of bikes in the coming years in improving public health.¹² Considering their area and natural environment, bicycle loop will be an excellent addition to improve connectivity and protect wild forest. And based on their landform, we can design a mountain bike trail in their preserved forest area along with the bike trail loop on their property.



¹² Technology, Media, and Telecommunications Predictions 2020

3. Interactive farmscape



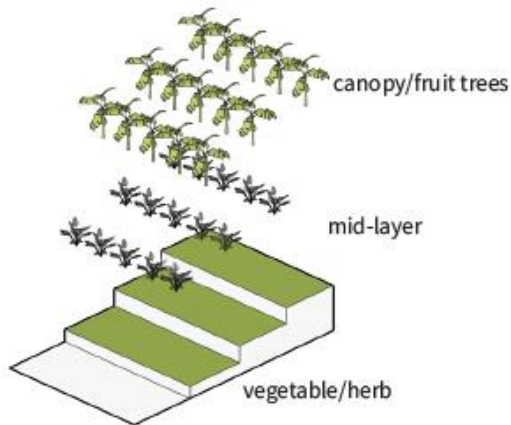
interactive farmscape

Parador Villa Sotomayor has abundant farm resources; for example, they have farms and hydroponic greenhouses. For now, their restaurant focuses on customers who stay in their hotel. To bring more local customers to their farm and improve their engagement, we can build a new farm-to-table restaurant and set up some land or planting beds for families. Farm to Table, also known as farm to fork, is always defined as a social movement in which restaurants buy locally farmed ingredients directly from farmers, which is a site advantage of Parador Villa Sotomayor.



Sustainability related:

1. Layer farming



productive farm terrain



West Indian Walnut

Source: Encyclopedia Britannica



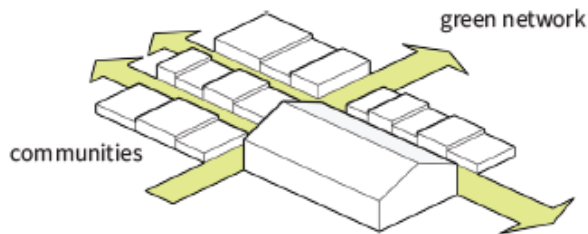
Cassava

Source: Gardening Know How

Both of farming areas at the Parador are mountainous landforms. Layer farming has already been adopted in Latin America and some Asia areas. It plants multiple crops at different levels, using the full height of a forest.¹³ Parador currently has a layer of two crops: banana and coffee. We suggest adding one to two more layers to their farms, a bottom plant, and a taller, long-term canopy tree. For example, cassava(yuca) is a tropical plant that can grow in shade, base area, and condition soil, and west indian walnut(15-20m) it's an endangered species growing locally in Puerto Rico. The advantage of the system is that it has continuous yields.

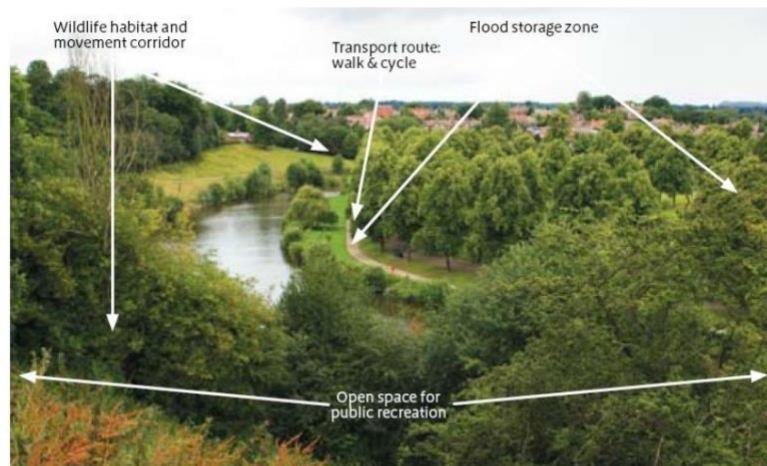
¹³ <https://earthbound.report/2013/02/13/saving-the-forests-with-layer-farming/>

2. Green infrastructure



green infrastructure

Green infrastructure covering everything from parks to street trees and green roofs to bioswales can help delay and absorb stormwater.¹⁴ It can help protect the natural water cycle. Parador Villa Sotomayor locates in a mountainous area, and it has a high forest rate and a high permeable surface. So, setting up rain gardens around their built space can provide social and educational benefits to the local neighborhood. A well-maintained community of rain gardens can encourage residents to spend time outdoors and create opportunities to improve social networking.¹⁵ Also, selecting native species and other perennials can help attract pollinators and protect native sustainability.



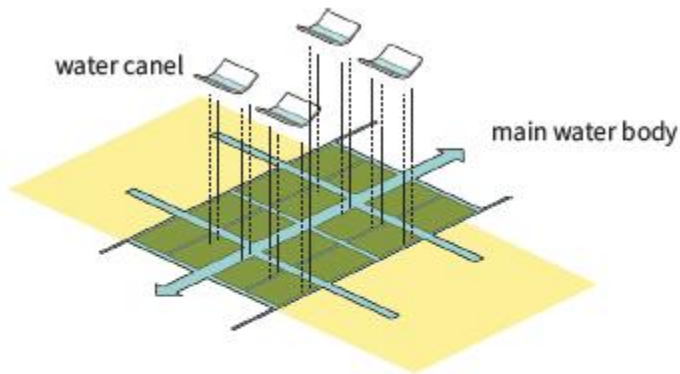
The multifunctional role of green infrastructure, an example from Shrewsbury
Photo by Nigel Jones, Natural England



¹⁴ <https://www.asla.org/contentdetail.aspx?id=43535>

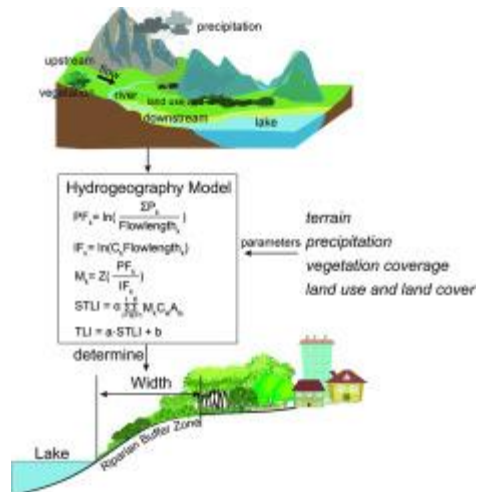
¹⁵ Nassauer, J. I., and Y. Feng. 2018. Different Contexts, Different Designs for Green Infrastructure. NEW-GI Technical Rpt. No. 1. 49 pp.

3. Riparian buffer zone



waterfront bufferzone

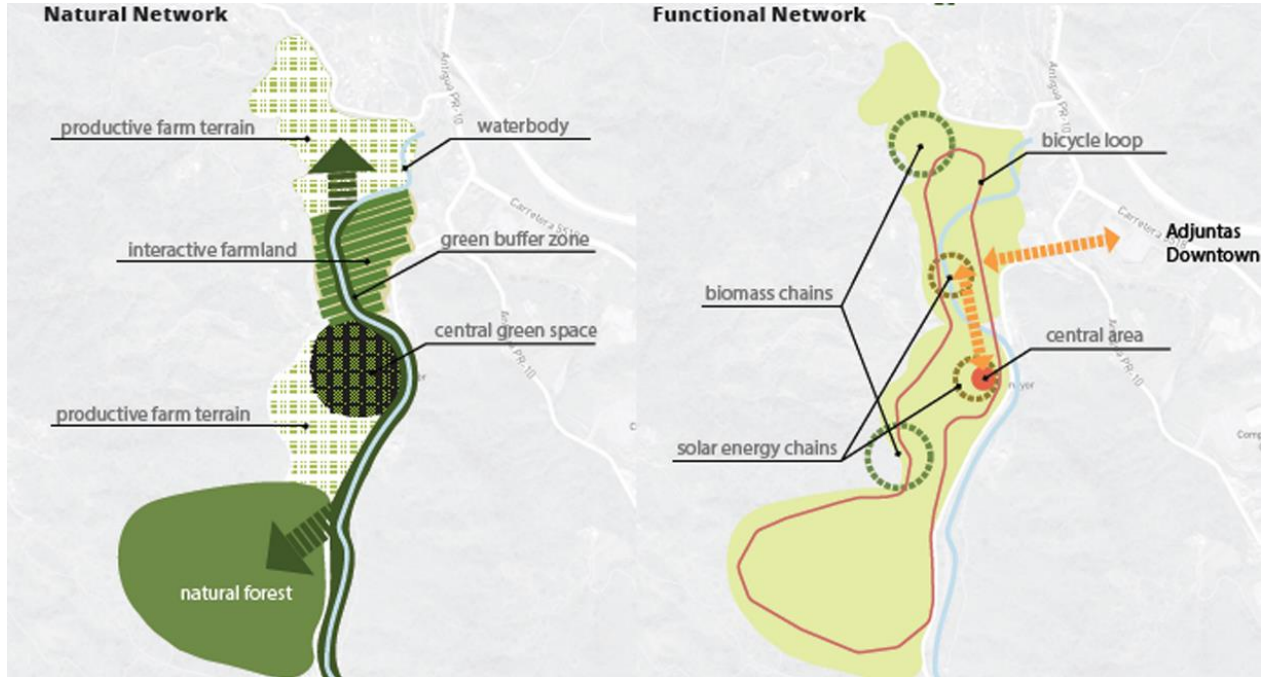
Parador Villa Sotomayor has a river running through their property which presents flooding issues during rainy season. Riparian buffer zone refers to an ecotone between human-disturbed area and river or other natural water body, which can benefit the ecosystem.¹⁶ The width and vegetation composition are the key element of this system, and we can define the width of riparian zone based on latest research (figure 2). We can see a difference in water quality in the stream, which has a buffer zone, compared to sites without buffers.¹⁷ And we can also add seasonal water canal to the section next to their plain productive farm.



¹⁶ https://link.springer.com/referenceworkentry/10.1007/978-94-007-6172-8_53-7

¹⁷ <https://www.pca.state.mn.us/water/buffers-improve-water-quality>

Our recommendation plans



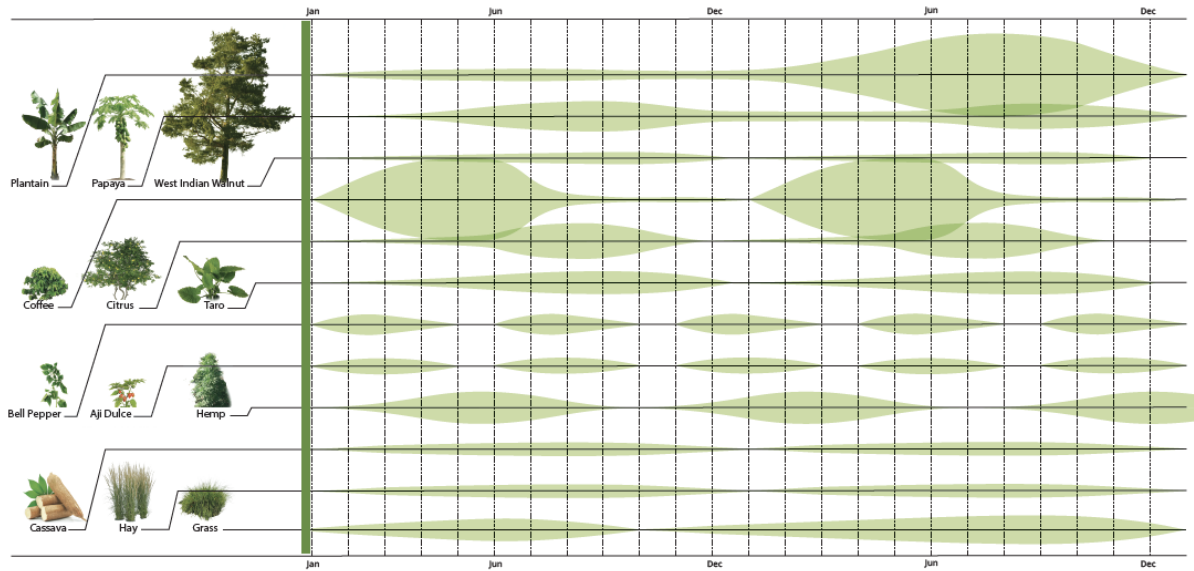
After I finished developing the strategy kits, I began the network-building process. For the natural land-use distribution, I suggest setting up a buffer zone (~10') along the river that runs through their property first and developing activities space based on this main structure. From their elevation, we can see the flattest area is located in the center of their property which is also their restaurant and central area are located right now. Based on that, I suggest they make use of the northern area of the flat land as their sub-developed area, and they can put agritourism activities in that area too as it's a connection area between downtown Adjuntas and the central of Parador Villa Sotomayor. Their two farms are located on the terrain area which I will suggest keeping as is and developing a better layer farming layout. Out of the consideration of preserving the natural forest, I only suggest adding bicycle land and trails to it but not adding more construction space to this area.

For the functional network, the two main new functional setups we add to their property are the solar grid and biomass chain. Besides that, we also propose a bicycle loop to loop all agritourism and ecotourism activities up to get a better connection and experiences for their customers. I propose two microgrids system for the two main residential areas, which both has its own solar energy chain and biomass chain. By separating them into two microgrids, it can increase the resiliency and the stability of the wire system.



From this master plan, we can see more clearly about the design proposal. Area a carries the most agritourism program, it contains a hydroponic greenhouse and a large space for seasonal crops, which can introduce tourist/customers to the entire cycle from planting to harvesting. Areas c and b show the two main residential areas, the open space in these two areas can be utilized as camp sites during peak seasons (over 30 tents space in total), and easily converted to host local events during off seasons. The blue rectangles are the solar grids for these two areas. In area b, I put a farm-to-table restaurant and a larger solar parking lot which can provide parking space for both tourists and restaurant customers. In addition to tourists, we hope it can attract more local customers who will come to the restaurant regularly with their families. This area is

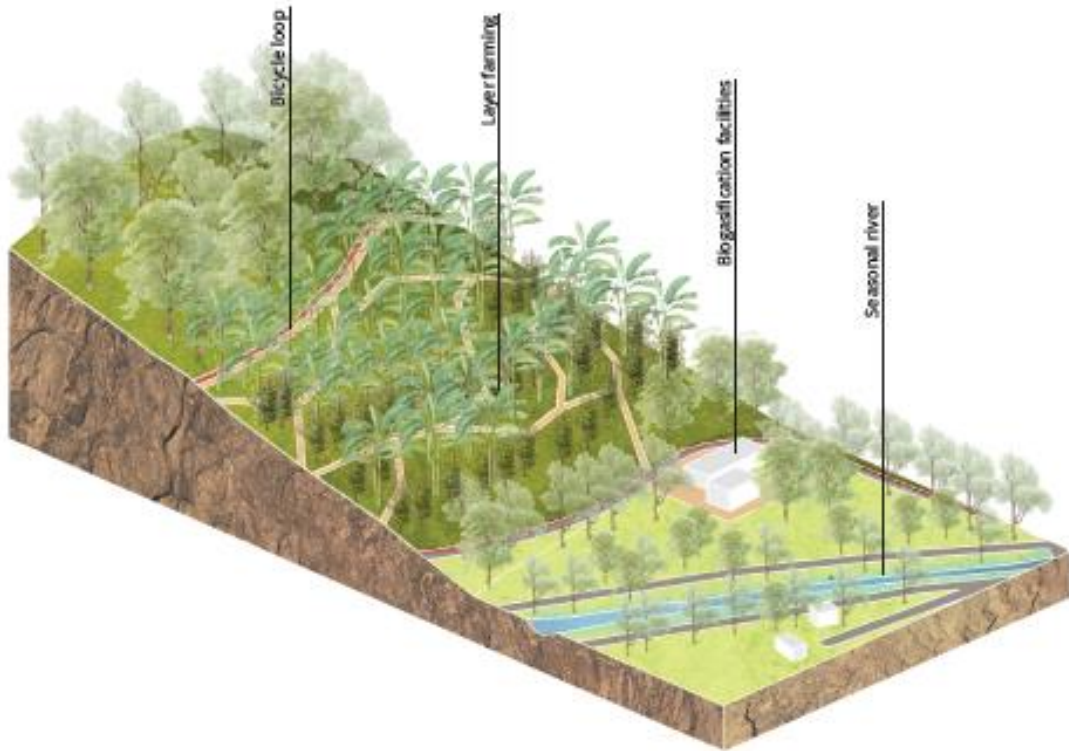
closer to the main road that leads to downtown Adjuntas, so putting a solar carport there along with a billboard can become a local landmark for Parador Villa Sotomayor to increase sight attractions. Besides from the solar grid, we also put two biomass supply chains near two main productive terrains (1&10). 2 and 9 are the biomass-producing areas that contain spaces for processing, gasifying, and storage, ideally all three stages should be performed in close proximity to maximize efficiency. Zooming out, the red lane shown in 12 is the bicycle loop which connects all main attractions in Parador Villa Sotomayor. There is a section of bicycle lane intended for mountain biking enthusiasts inside the forest preserves, outlined in 11.



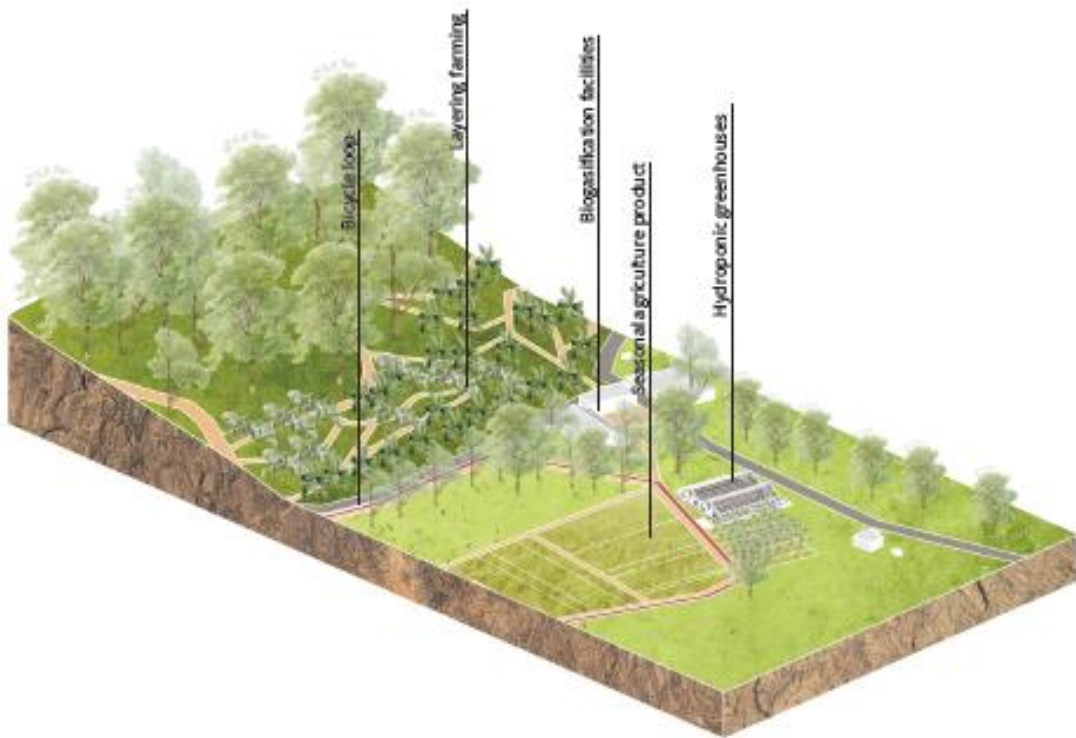
As we discuss in layer farming strategy, we suggest adding one to two more layers to their current farms, a bottom plant, and a taller, long-term canopy tree, such as the cassava and western indian walnut. This graphic roughly shows the yield of biomass in a two-year period based on our suggestions. The pattern shows that it will have a lower production in winter. So in the seasonal agriculture field (4), they can choose some species that have a higher production during the winter to get sufficient biomass during the whole year.

The graphics in the next two pages are mainly showing the spatial relationship of the two biomass chain areas in our design proposal. Our goal is to combine the biomass-producing terrain with trails for tourists to increase ecotourism engagement. This would not only act as an unique tourist attraction on the resort, but also raise awareness of sustainable agricultural practices to more people. In addition to tourist, the resort can also organize tours for local students to educate the next generation in sustainability and environmental responsibilities.

Biomass Chain1



Biomass Chain2



Perspectives



Main Entrance. Solar Carport



Interactive farmscape, farm-to-table restaurant



Hydroponic greenhouses, bicycle loop



Residential area b, bicycle loop

Conclusion

Our design plan is based on the Parador Villa Sotomayor's need and the goal to preserve and support community sustainability and resilience. We took a holistic approach to incorporate the community goals and resources, as well as its current production capabilities to formulate this easily achievable system. Though our initial objective was to ensure energy security for Parador Villa Sotomayor, we provided many more design recommendations to ensure both the long-term environmental and economic sustainability of these changes. Recognizing that sustainability is a long-term community-based objective, we tailored many aspects of our design to also be vectors of raising awareness and educating the public regarding sustainable technologies and practices. Our plan aims at improving the local livelihood with strategic considerations in three main categories: energy, local tourism, and sustainability. This project can be optimized and improved in the future and serve as a prototype for local communities with similar site contexts or backgrounds.

This project demonstrates that the microgrid and design can be combined together to create a resilient plan in Puerto Rico. It also indicates that sustainable engineering and design can work together at an early stage to achieve a more scientific planning solution. While the design plan for Parador Villa Sotomayor has set boundaries, future development planning can adopt a broader view regarding the whole region and surrounding area as a whole and hybrid system to obtain the core of sustainability as well as the innovation of user experience.

Bibliography

Photo Link:

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2.

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Farm:

https://www.google.com/url?sa=i&url=https%3A%2F%2Fwww.finedininglovers.com%2Farticle%2Fgrowing-farm-table-movement-southeast-asia&psig=AOvVaw1aWlsmENIXLgUH-nxkdnCy&ust=1647533265765000&source=images&cd=vfe&ved=0CAsQjRxqFwoTCKjmh-uBy_YCFQAAAAAdAAAAABAD

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Green infrastructure:

<https://www.ceeweb.org/wp-content/uploads/2014/06/12-Jacqui-Stearn.pdf>

<http://cepd.cap.utah.edu/red-butte-creek-research-symposium-2018/green-infrastructure-research-facility/>

Water buffer zone:

<https://www.pca.state.mn.us/water/buffers-improve-water-quality>

<https://www.sciencedirect.com/science/article/abs/pii/S0925857420302895#f0060>

Natural activities:

https://www.google.com/url?sa=i&url=https%3A%2F%2Fraisingchildren.net.au%2Fnewborns%2Fplay-learning%2Fplay-ideas%2Fhomemade-toys&psig=AOvVaw3m3L6VWAzYfOTQysp3dCex&ust=1647563388798000&source=images&cd=vfe&ved=0CAgQjRxqFwoTCKjuzIjyy_YCFQAAAAAdAAAAABAD