Assessing Carbon Offsetting Programs for the Puerto Rico Project Center

Photo Credit: Para La Naturaleza

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by

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Abstract

WPI's Global Projects Program (GPP) sends hundreds of students to project centers around the world, which contributes to carbon dioxide emissions. This project partnered with the Puerto Rico Project Center (PRPC) to explore carbon offsetting initiatives within Puerto Rico and develop an offsetting recommendation for the PRPC and the GPP. We developed comparative criteria, mapped potential offsetting organizations within Puerto Rico, and developed four case studies representing different offsetting schemes: solar panels, coral reef restoration, reforestation, and mangrove restoration. Our results suggest that Para La Naturaleza's reforestation program is most viable considering affordability, imminence, permanence, student engagement, and co-benefits.

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Introduction	All	All
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Methodology	All	All
Objective 1: Developing comparative evaluative criteria	Loukedes	Chlebowski, Dubord, Shea
Objective 2: Mapping offsetting organizations in Puerto Rico	Chlebowski, Loukedes	Dubord, Shea
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Reforestation	Loukedes	Chlebowski, Dubord, Shea
Mangrove Restoration	Chlebowski, Loukedes	Dubord, Shea
Discussion	All	All
Conclusion	Chlebowski, Loukedes	Dubord, Shea

The chapters which are labeled as "ALL" were a result of collaborative writing in which sections were divided among members and compiled into one chapter. All sections were edited by all team members.

Table of Contents

List of Figures

List of Tables

Executive Summary

Over one million students travel annually through higher education study abroad programs globally. While study abroad programs can offer powerful learning opportunities for students, travel associated with these programs emit carbon dioxide that contributes to climate change. Study abroad programs have recognized this tension and begun to incorporate initiatives to minimize the environmental costs, such as carbon offsets.

WPI's Puerto Rico Project Center (PRPC) intends to implement a carbon offsetting plan to become carbon neutral with an approach that focuses on local, Puerto Rican organizations. Unlike multinational offsetting schemes, a partnership with a Puerto Rican organization would create benefits for the local community while still serving the ultimate goal of a carbon neutral PRPC. Thus, the goals of this research project were to: (1) develop comparative evaluation criteria for carbon offsetting schemes; (2) map out organizations in Puerto Rico that practice offsetting schemes; and (3) develop four case studies that represent key offsetting initiatives (solar panels, coral reef restoration, reforestation, and mangrove restoration).

Methodology

Objective 1

Our team began by developing comparative evaluation criteria to measure different offsetting schemes. To create a set of criteria tailored to study abroad programs, we first analyzed existing criteria used by prominent environmental organizations to evaluate their offsetting projects. We then built upon these criteria in conversation with our sponsors to develop a tailored set of criteria for this project. The five criteria used for our analysis are affordability, imminence, permanence, student engagement, and co-benefits.

Objective 2

We then identified and created a list of relevant offsetting organizations using keyword searches. We classified the organizations we found as either a "direct" offsetting organization or a "snowball" organization. Direct offsetting organizations organize, set up, and participate in activities that sequester carbon emissions, and snowball organizations fund or collaborate with direct offsetting organizations. Once we identified and documented potential offsetting organizations, we contacted 26 organizations on our list by phone and email and requested a formal interview.

Objective 3

We conducted semi-structured interviews with nine organizations that were directly or indirectly related to the field of carbon offsetting. Post-interview, we categorized each organization based on its scheme. The schemes fell into four main types: solar power, coral reef restoration, reforestation, and mangrove restoration. We developed a case study for each type. Each case study contained a detailed description of a preferred local partner organization coupled with an analysis of each criterion outlined in objective 1.

Carbon Offsetting Case Studies

The following four case studies were structured to include the following discussion points: background information on the type of scheme presented, a potential partner for that scheme located in Puerto Rico, and an analysis of our five evaluative criteria of interest (affordability, imminence, permanence, student engagement opportunities, and co-benefits). Case studies were organized around the assumption that one cohort of 23.5 WPI students taking round trip flips to Puerto Rico from Boston emit 19.5 tons (0.829 tons per student) of carbon (Floria et al., 2021).

Solar Panels

In 2022, 97% of Puerto Rico's electricity was derived from fossil fuels and 3% from renewable energy, three-fifths of which was solar power (U.S Energy Information Administration, 2023). The Pedro G. Goyco School is a potential organization that can be partnered with to build upon Puerto Rico's emerging solar network. The imminence of solar panels is three years with a 6-kWh system for the PRPC to offset one cohort's emissions. For a total cost of $1,250, PRPC could purchase and support the installation of a single solar panel onto La Goyco's existing solar energy system. Although solar panels do not directly offset carbon, they reduce electricity bills, increase home value, and operate as backup generators, providing valuable co-benefits. Solar panels have high permanence since they require very little maintenance and can be taken down or reinstalled in the presence of a hurricane. However, compared to other schemes, they offer lower student engagement opportunities, as students might not receive much hands-on experience.

Coral Reef Restoration

Sociedad Ambiente Marino (SAM) has been working on a 3D-printed coral reef restoration project in Culebra, Puerto Rico. Though their projects do not directly sequester carbon, they help protect seagrass beds, which sequester carbon. Carbon offsetting through this case study would cost a reasonable $390 and would take 3.7 years to offset for one cohort, proving to be affordable and good imminence. Unfortunately, due to ocean acidification and frequent hurricanes, the coral reef structure is not likely to survive for the next 20 years, meaning this project is low in permanence. However, SAM is largely community-driven and offers strong student engagement opportunities and social and ecological co-benefits; with over 3,400 volunteers at 7 locations, student volunteers can contribute hands-on by helping create and plant 3D-printed corals. Coral reefs bring many co-benefits to the environment, including providing habitat for marine life and acting as a buffer against erosion.

Reforestation

Organizations such as Para La Naturaleza (PLN) lead large-scale reforestation efforts on the island. With five nurseries, PLN plants over 150,000 trees per year. Those trees undergo a five-year monitoring program. With an average cost of $40 per tree, the PRPC could offset one cohort’s worth of student emissions over 25 years for a relatively cheap cost of $1,480. In addition to these direct carbon offsetting benefits, PLN's efforts have strong co-benefits and opportunities for student engagement. They increase biodiversity in Puerto Rico, prevent soil erosion, and bear fruit that local communities can benefit from. Cooperation with PLN would also allow WPI students to volunteer in tree planting projects. One concern with this scheme, however, is that it is a hurricane-prone region and therefore faces challenges around permanence. A hurricane might wipe out the planted trees, undoing whatever carbon offset benefits had been accrued. Despite this risk, we believe that the many benefits outweigh potential threats to the project’s permanence.

Mangrove Restoration

Despite their tremendous ecological value, mangroves are rapidly decreasing in Puerto Rico. For WPI to successfully offset a single cohort's carbon emissions, 186 mangroves must be planted for a relatively cheap cost of $1,860. The imminence of offsetting a cohort's emissions with 186 planted mangroves is 25 years. Mangroves provide direct carbon sequestration benefits that can be quite significant, which include resilience to rising waters and protecting fish from invasive species. Despite these strengths, like reforestation initiatives, these efforts can be destroyed due to hurricanes. Questions of permanence remain. A potential partner organization for a mangrove offsetting scheme in Puerto Rico is the Corporación Piñones se Integra (COPI). Students could receive hands-on experience by planting and monitoring mangroves resulting in high student engagement.

Recommendation

Among all schemes, coral reef restoration (SAM) was the cheapest option, provided many co-benefits, includes the most opportunities for student engagement, but is the least permanent. Solar panels were the most permanent, but were expensive, provided little student engagement, and few co-benefits. Both reforestation and mangrove restoration are well rounded options since they had low costs for offsetting, provided many opportunities for student engagement, included co-benefits, but were threatened by hurricanes. Based on our results, we found that reforestation (PLN) is overall the most effective scheme for WPI's PRPC carbon offsetting goals.

Conclusion

While study abroad programs provide powerful learning opportunities, there are unaddressed environmental costs, such as contributions to CO_2 emissions. Our study sought to recommend a carbon offsetting program for the PRPC. Based on our findings, we recommend that WPI invests in a local organization such as PLN given the benefits it provides for the unique goals of the PRPC.

Chapter 1: Introduction

Over one million students travel every year through higher education study abroad programs globally, at a growing rate (Institute of International Education, 2022). In the United States alone, the number of students studying abroad more than doubled from 2001 to 2017 (Institute of International Education, 2022). Ample data shows that study abroad programs enrich students' academic experiences. Students are shown to develop intercultural sensitivity during their study abroad experience (Rexeisen et al., 2008). Intercultural sensitivity is defined as the ability to be aware and accepting of cultural differences (Sieck, 2021). Reports show that students studying abroad develop learning independence (Amuzie et al., 2009). Learning independence is defined as ownership and control of one's learning as well as the ability to assess one's learning (Livingston, 2012).

While study abroad programs can offer powerful learning opportunities for students, travel associated with study abroad programs emit carbon dioxide (CO_2) that contributes to climate change. Concerned about this issue, scholars Hans de Wit and Philip G Altbach published a paper in University World News that boldly suggested studying abroad should be eradicated to "cut international education's carbon footprint" (University World News, 2020). Though currently no source exists to describe all United States study abroad emissions, it can be estimated with data from The Institute of International Education (IIE). In 2018 around 350,000 students in the U.S. participated in study abroad programs. These trips are likely to have produced 40,406,073 tons of CO2 by 1,524,758,500 miles of travel, assuming 53 pounds of CO2 were produced per mile (BlueSkyModel, 2014; Appendix A).

Study abroad programs have recognized the tension between the value of study abroad programs and their environmental costs and have begun incorporating initiatives to minimize them. For example, study abroad programs like the Cultural and Educational Programs Abroad Foundation (CEPA) and The American Institute for Foreign Study (AIFS) exist to preserve critical study abroad values and the benefits gained, such as cultural sensitivity and learning independence, while also operating as carbon neutral (AIFS, 2022; CEPA, 2022). CEPA has pledged to offset their on-site carbon emissions created by all their study abroad programs for students from the United States. They do so by supporting the planting of native trees at the Osa Conservation Area in Costa Rica, managed by Fundación Saimiri. This conservation area focuses on the protection of endangered tree species for future generations and ecosystem health. Similarly, a branch of the American Institute for Foreign Study, AIFS Abroad, developed a green initiative and committed to reaching carbon neutrality by 2025. They plan to offset carbon emissions by purchasing verified carbon credits for all their program participants' round-trip flights (American Institute for Foreign Study, 2022; AIFS Abroad, 2022).

Carbon offsetting programs can be divided into one of two categories: large multinational schemes which operate in different parts of the world, and local offsetting schemes. Most study abroad programs that advertise their offsets do so through global schemes. Second Nature, which is offers knowledge to accelerate climate action, initiated a Carbon Credit and Purchasing Program (C2P2) which supports colleges and universities in developing and marketing innovative carbon offsets to facilitate their sustainability goals (Second Nature, 2023). Currently, 401 campuses in the U.S. are involved in the climate leadership network, and 278 of those are part of the C2P2 (Second Nature, 2023). However, every campus that is part of the C2P2 develops offsets to the Verified Carbon Standard (VCS) called Verra. Verra operates standards in environmental programs including C2P2 as well as their carbon crediting program, the VCS. Unfortunately, Verra has an unreliable history of overstated carbon emissions data (SourceMaterial, 2023).

WPI's Puerto Rico Project Center (PRPC), where our team was located for this research, has been active for 30 years and works on projects related to resilience, sustainable development, and climate change adaptation. Our project explored the landscape of carbon offsetting initiatives within Puerto Rico to develop a recommendation for the PRPC and the broader WPI community. We built on a previous IQP project from 2021 that developed an effective roadmap for sustainability by focusing on potential ways to mitigate carbon emissions generated by WPI's Global Projects (Floria et al., 2021). Their project researched offsetting companies, spoke to stakeholders, and developed tools to estimate emissions. They then created a roadmap of recommended steps toward facilitating carbon neutrality at the PRPC that could be used for other project centers as well, including how to estimate, reduce, and offset carbon emissions. The roadmap also includes tools for greater climate literacy and relevant resources (see Figure 1). We then put this roadmap to use to create a carbon offsetting recommendation for the PRPC.

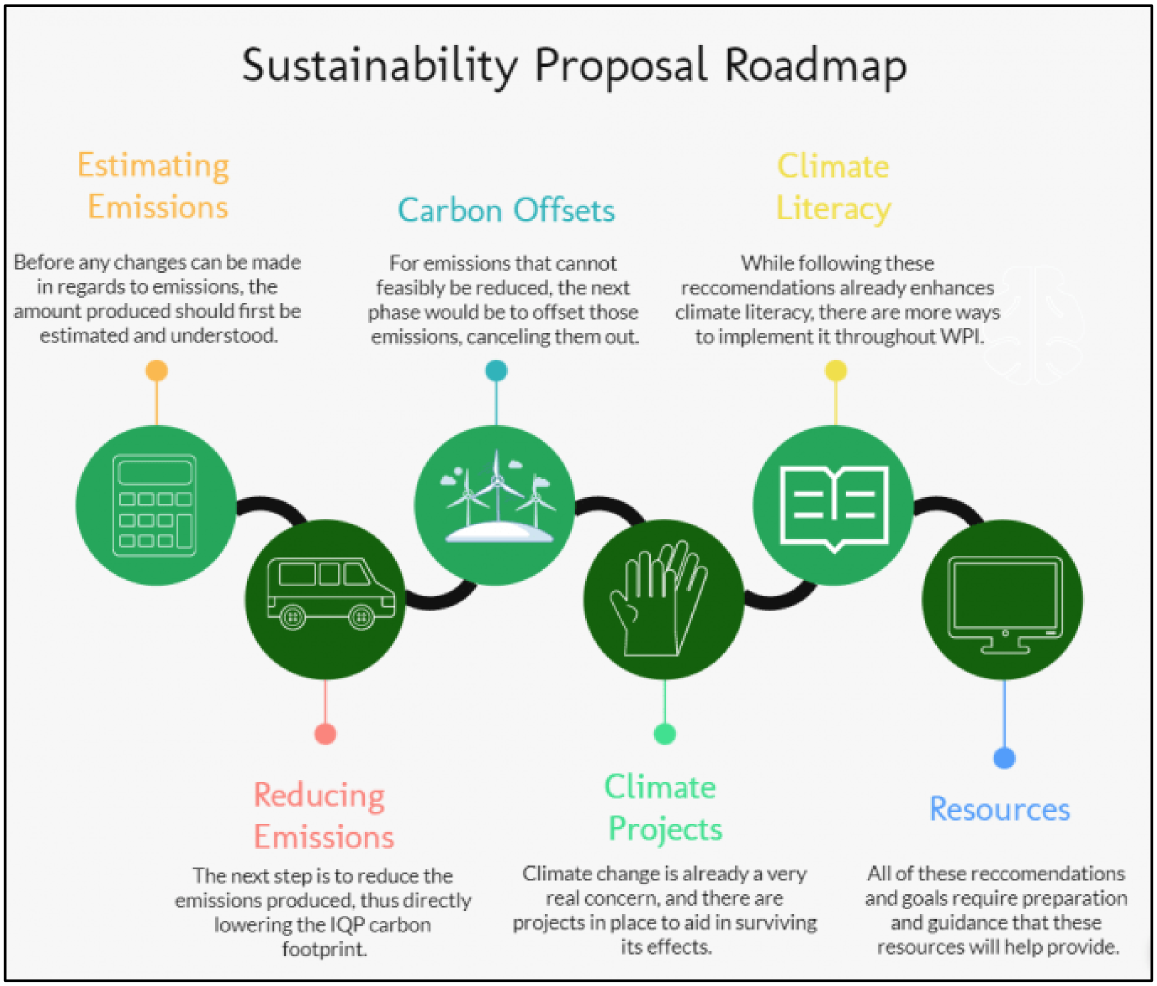

Figure 1: Sustainability proposal roadmap for the Puerto Rico Project Center (Floria et. al., 2021)

Our recommendation included an organization that could be partnered with to support offsetting carbon emissions from student travel to and from Puerto Rico. We did not account for emissions produced while in Puerto Rico since the rate of emissions from flying is significantly higher. The three objectives followed to reach our overarching goal include: (1) develop comparative evaluation criteria for carbon offsetting schemes; (2) map out organizations in Puerto Rico that practice offsetting schemes; (3) develop four case studies that represent key offsetting initiatives (solar panels, coral reef restoration, reforestation, and mangrove restoration). Our methodology section provides an in-depth overview of how we achieved each of these three objectives.

We anticipated that there might not be a plethora of offsetting organizations in Puerto Rico due to frequent natural disasters and economic volatility. The organizations that we found were analyzed based on a set of criteria. This was developed by combining sets of criteria for a successful carbon offsetting initiative from the Green House Gas Management Institute. The Green House Gas Management Institute is a non-profit organization based in the United States whose primary mission is to educate people about the basics of greenhouse gas accounting, train professionals to meet high standards of expertise and ethical conduct, and research greenhouse gas measurement (Greenhouse Gas Management Institute, 2015). Using their existing criteria as a starting point, which primarily focus on the reliability of a given offsetting scheme including factors such as additionality, uncertainty, and supply, we then created our own set of criteria (with guidance from our sponsors) that are best suited to study abroad program needs like ours. After we interviewed potential offsetting organizations in Puerto Rico, we categorized them into one of four schemes based on their work. We developed four case studies representing the primary offsetting schemes in Puerto Rico: solar panels, coral reef restoration, reforestation, and mangrove restoration. These case studies delved into organization-specific schemes and described the scheme's affordability, imminence, permanence, student engagement, and co-benefits. We ranked each project based on each of these criteria by way of a low-to-high ranking system, which enabled us to compare each case study.

Chapter 2: Background

2.1 The Value of Study Abroad Programs

In 2018, before the World Health Organization declared COVID-19 a global pandemic (WHO, 2020), around 350,000 students in the United States participated in study abroad programs, which has been steadily increasing since the early 1990s (Institute of International Education, 2019). Despite the pandemic, the Institute of International Education noted U.S. institutions reported a 523% increase in students going abroad for the summer of 2021, which suggests travel numbers may be on the rise yet again (Institute of International Education, 2022). With the number of student travelers rising, more students will experience the positive values of studying abroad, such as the development of cultural sensitivity, the ability to be aware and accepting of cultural differences, and learning independence (Ruddock et al., 2007; Sieck, 2021; Vanden Berg et al., 2019).

Articles published by University World News and InPlace suggest the need to entirely "cut international education's carbon footprint" and to "only travel when we need to" (University World News, 2020; InPlace, 2021). On this point, Hans de Wit and Philip G Altbach (University World News, 2020) lauded the Japan Student Services Organization (JASSO) for their decision to no longer support short-term programs (eight weeks or less), which make up 60% of all their study abroad programs. While this may reduce carbon emissions, eradicating study abroad programs would diminish the educational and cultural benefits students may receive. In contrast to JASSO, short-term study abroad programs provide a long-term perspective on global citizenship, including students' orientation to co-cultural and intercultural interactions (Vanden Berg et al., 2019). While JASSO has reduced its emissions on short-term programs, it is possible that its students are missing out on these wider benefits. In the following sections, we unpack the value of study abroad programs, including cultural sensitivity, learning independence, and the long-term impact of a short-term study abroad program, and explain why those who study abroad are at an educational advantage.

2.1.1 Cultural Sensitivity

Cultural sensitivity is defined as the ability to be aware and accepting of cultural differences (Sieck, 2021). Part of cultural sensitivity includes understanding any nuances reflected in body language, dialect, and customs. Understanding these differences and effectively communicating with others from different cultural backgrounds has been recognized to assist people in their living and work environments (Landis et al., 1996). For students who travel abroad, their cultural experiences, such as interactions with locals, force them to adjust how they communicate and transform their sensitivity to their surroundings (Ruddock et al., 2007).

Studies have explored whether it can be empirically demonstrated that study abroad programs improve intercultural sensitivity among college students (Rexeisen et al., 2008). The Intercultural Development Inventory (IDI) measured study abroad students' overall development of intercultural sensitivity during their abroad experience (Hammer & Bennett, 2002). After faculty trained and certified by the Intercultural Communication Institute (ICI) interviewed students and measured their intercultural development, they reported that the post-test averages increased for all hypotheses compared to the pre-test averages. The main findings were that students believed the culture they were in was superior to their own. Students also reduced their degree of minimization. Individuals at the stage of minimization are unaware of the projection of their own cultural values (Bronx Partners for Healthy Communities, 2022). Reduction of minimization is an important step in adapting to another culture and learning to value the surrounding culture. By the end of the students' study abroad journey, they demonstrated acceptance of the surrounding culture, which was correctly predicted by faculty from the ICI.

Another study abroad program in 2004 demonstrated similar results. This research dove into whether having an international learning experience as part of a nursing education program promoted cultural sensitivity in nursing students (Ruddock et al., 2007). Similar to Rexeisen, these in-depth interviews presented students' positive adjustment to another culture. One study abroad student received social support from local Australian students, who helped them "adjust to cultural differences," including being invited to their homes to feel involved with the host culture (Ruddock et al., 2007). Over the course of their study abroad program, the inclusion of other students and residents resulted in being more open to its dynamics and acknowledging the social structures. The students developed cultural sensitivity by understanding another culture's structure. These studies show that students who study abroad are at an educational advantage because of the aforementioned cultural sensitivities they develop.

2.1.2 Learning Independence

Independent learning is the process where learners have ownership and control of their learning (Livingston, 2012). Studying abroad can change students' language-learning beliefs and what they believe about learner autonomy. This has led to studies into the relationships among beliefs of learner autonomy and length of study abroad in order to understand why beliefs change while abroad (Amuzie et al., 2009). Two groups from the United States were composed for interviews that would be administered during and after their study abroad experience. Evidently, after the experience, students from both groups had a stronger belief that they were responsible for learning their second language and that their educational success depended on themselves rather than relying on a professor. The changes in learner beliefs imply an overall growth in learner independence.

Increased learner independence from study abroad programs may lead to students earning higher GPAs than their domestic peers. To test this, a study divulges onto the academic performance of study abroad students and non-abroad students (Xu et al., 2012). The report specified that the study abroad students excelled in almost every category compared to the domestic students and even mentioned the four-year, five-year, and six-year graduation rates were higher by 18%, 24%, and 23%, respectively. Moreover, study abroad student's grade point averages were higher by 13.5%. To better explain this difference, research has compiled statistics on prior academic data (high school GPA and SAT scores) (Xu et al., 2012). While the high school study abroad students achieved higher scores than those who did not study abroad, suggestions indicate a more important research question is whether the better performance was due to the demographics: socioeconomic backgrounds and having more resources to succeed (Xu et al., 2012). Regardless of demographic data influencing students, study abroad learners reported a strong belief in finding opportunities to use their second language while abroad (Amuzie et al., 2009). The extent to which the students' attempt was successful depended on their individual efforts. This data was also expressed in student interviews (Amuzie et al., 2009).

2.1.3 The Long-Term Impact of a Short-Term Study Abroad Program

Beyond students' adaptation to cultural sensitivity and learning independence while abroad, research has shown that student alumni have demonstrated the long-term impact of their short-term study abroad programs, one being their development of a global citizenship identity (Vanden Berg et al., 2019). For example, a three-week study abroad course in Jamaica (titled the

Jamaica Development Interim) addresses the country's development and the role of tourism on the island (Vanden Berg et al., 2019). Though only offered ten times between the years 2002 and 2019, the study yielded strong results from alumni. Even years after participating in the Jamaica Development Interim, alumni identified how it had impacted their attitudes toward co-cultural and intercultural interactions (Vanden Berg et al., 2019). Nearly 70% of the alumni agreed that the program influenced their perspective on minority issues abroad (Vanden Berg et al., 2019). Additionally, over 60% agreed that the interim influenced their discussions about international and trans-cultural issues (Vanden Berg et al., 2019).

A 2014 study titled "The Impact of Study Abroad on the Global Engagement of University Graduates," discovered similar results among their 1980-2010 alumni (Murphy et al., 2014). One thousand students participated and reflected a positive philanthropy outcome within the global engagement domain, compared to the alumni who did not study abroad. 26% of the participants reported that they've volunteered for human rights, including women, minority groups, and LGBT groups (Murphy et al., 2014). While the 2019 Vanden Berg study confirmed the perspective of alumni on minority issues, the 2014 Murphy study confirmed the participation of alumni in human rights groups, which has a slight percent increase compared to those who did not study abroad. Both studies drive the point that studying abroad can influence a student's perspective on a topic like human rights, which would be thwarted if study abroad opportunities were eradicated.

2.2 Environmentally Responsible Study abroad

Though there are benefits to study abroad programs, there are also numerous environmental costs due to the emissions associated with student travel. A small sample of study abroad programs shows that individual students can emit between 0.883 to 4.33 metric tons of carbon during a program, depending on its length (Floria et al., 2021; University of Virginia, n.d.; University of Wisconsin-Madison, 2022). Though the trans-continental flights for these programs are the main contributor to these large emissions, numerous universities are finding ways to make study abroad travel emit less net carbon, such as implementing sustainable practices and activities that have lower carbon footprints and attempting to offset carbon emissions.

2.2.1 Current Initiatives for Environmentally Responsible Study Abroad Programs

In the past two decades, efforts have been set up to create a partnership between international education and sustainable study abroad practices (Dvorak et al., 2011). As of 2023, there had been an increase in the number of study abroad programs that included sustainability efforts to reduce the carbon footprint of their students' travel and on-ground activities. The efforts each program made varied widely depending on the institution and location of travel, but overall, there were two forms these efforts took: carbon reduction and carbon offsetting.

The first group of efforts consisted of institutions attempting to reduce the carbon footprint of their students by suggesting and facilitating sustainable practices. The University of Denver (UoD) acknowledged the significant contribution its extensive study abroad program had on its emissions as an institution – 10% of the institution's CO_2 emissions came from study abroad, and the students' flights emitted 600% more emissions than if they had driven (University of Denver, n.d.). The University also estimated that $30 is enough to offset most students' study abroad emissions. Additionally, UoD provided a list of tips that students can incorporate to travel more sustainably. Some of the tips included learning the local food system, making the least carbon-emitting food choice, utilizing alternative forms of transportation, accepting a more minimalist lifestyle, and taking the Green Passport Pledge – a program that aims to make study abroad more sustainable by educating students and host communities (Green Passport, 2010). While the tips are useful, UoD did not mention if it actively offset the emissions its students produced, nor did they share if they had tracked whether these initiatives had reduced carbon emissions.

The second group of efforts was composed of institutions and organizations that actively attempted to offset the emissions of their students. The institutions usually partnered with an organization that offered an analysis of which carbon offsetting method was most beneficial for their company. One of the most common projects institutions chose to fund was forest conservation projects. One such example is the Green Program, an educational program that aims to offer sustainable education through study abroad programs. The Green Program, with the help of Carbonfund (an organization that linked carbon offset programs with buyers), decided to fund a Tropical Forest Conservation project in Acre, Brazil (The GREEN Program, 2016). This approach allowed institutions to seemingly perform a one-and-done transaction and no longer worry about the carbon they emitted. A drawback of this approach is that it is virtually impossible for the institution to know whether the money spent was used for its intended purpose. An example of such an approach is the University of Virginia's study abroad program, which aimed to be carbon neutral by buying carbon credits from the International Organization for Standardization (ISO) (University of Virginia, n.d.).

In addition to these efforts, there were also several study abroad programs that focused on teaching sustainability while practicing their learnings. One such study took place in New Zealand and the Cook Islands in 2009 (Dvorak et al., 2011). Students met local members of the community, such as Parliament, the Maori community, local farmers, marine biologists, and representatives of the foreign ministry, to discuss the biological, political, and environmental impacts of sustainability efforts in the country. Along with visiting other countries such as Australia, China, and parts of Eastern Europe, this experience gave students insight into the many steps required to commit to habitat and biodiversity protection. Furthermore, students also experienced challenges associated with the fossil-fuel economy. These considerations are important to realize that implementing study abroad programs in green-driven communities can help students take note of less resource-intensive economic practices that countries such as the United States can implement. After each student calculated their individual carbon footprint from the trip, they found that they had produced less carbon per person while in New Zealand than they would have back in the United States since they carpooled with eight people in a van and stayed in simple dormitory housing. Carpooling has a large impact on released carbon. For example, installing High Occupancy Vehicle (HOV) lanes on highways has helped reduce overall annual emissions by 0.02% to 1.64% in each state (Javid et al., 2016). Limiting car usage by carpooling or staying at a location with close-proximity buildings is an ideal way for study abroad programs to reduce their carbon footprint.

Another program, which ran in both 2008 and 2010, brought students from Minneapolis, Minnesota, to Vancouver, British Columbia, then to Portland, Oregon, and back to Minneapolis (Dvorak et al., 2011). The main takeaway from this program was that taking the Amtrak to destinations in the U.S. and Canada uses fewer carbon emissions than air travel, so the students traveled back to Minneapolis by train, utilizing the longer travel time to their personal advantage. The specific amount of carbon emissions a flight gives out depends on numerous factors, such as the length of the flight and the model of the plane, but a 10,000 km flight (6,214 miles) can emit between 800 and 1,000 kilograms of carbon dioxide per passenger (Baumeister, 2017). In comparison, traveling by train instead of plane would reduce individual emissions by around 84%, and taking a train instead of a car for medium-sized trips would cut emissions by 80% (Ritchie, 2020). Even choosing a study abroad location in Western Europe can greatly decrease travel carbon footprint; a study abroad program at the University of Louisiana has taken this into account and encourages students studying in this area to travel by train via their Extensive Rail Network by providing information on how to do so (University of Louisiana at Lafayette, 2014).

Another route involves studying abroad in a city with a sustainability plan. Such is the case with North Dakota State University of Agriculture and Applied Science, which is in the process of developing plans to visit two sustainability-focused Finland cities: Helsinki and Porvoo (Cary-Waselk, 2022). These two cities are undergoing experimental projects focused on challenges in the urban environment (Laakso, 2017; Commission on Sustainable Development, 2016; City of Porvoo, 2019). An advantage of heading towards a sustainable-focused economy is that these cities are also committed to creating better well-being for their citizens. The students can pick up the practices from these green economies and implement them into their daily life or recommend them to policy leaders in the United States. Some of these methods may include equal opportunities for health and public affairs, improvement of productivity and quality of work, creation of sustainable and safe communities, and implementation of a carbon-neutral society (Cary-Waselk, 2022). Implementing sustainability education or practices in travel abroad programs can be beneficial since sustainability is a global issue. Gaining awareness by viewing firsthand how other countries' negative environmental impacts affect other parts of the world, as well as ways communities in other countries are attempting to cancel out these harmful practices, can ignite motivation and ideas for implementing an environmentally responsible study abroad program.

2.3 Carbon Offsetting Frameworks That Verify Schemes

While many universities are working on approaches to offset carbon emissions, achieving carbon neutrality using those approaches alone is difficult and often confusing. To help alleviate confusion and streamline the process of identifying legitimate offsetting schemes, various organizations have set up criteria that projects must comply with. While there is no universally accepted set of criteria, most organizations use similar requirements/functionality: additionality, independent verifiability, and permanence.

Professor John Sterman from MIT Sloan developed a framework to determine a carbon offsetting scheme's effectiveness. The developed framework is called AVID+, which is based on its requirements that include Additionality, Verifiability, Imminence, and Durability. An offset is considered additional if it reduces emissions that would not otherwise be reduced if no offsetting action had taken place. Verifiability means that the offset must be able to show that emissions are cut. An offsetting scheme is immediate if it can be implemented right away, unlike planting a sapling that will not offset emissions for a few decades. Lastly, durability is when the offset can store carbon over time and will not reenter the atmosphere (Vereckey, 2022).

All requirements should be met for the scheme to be considered effective. When all four requirements are met, then offsets meet the "plus (+)" of AVID+. The "plus", in addition to the climate benefits, is when an offset scheme reaches other societal goals such as job creation, poverty reduction, health care, and social justice, to name a few. Sterman claims that if an offset fails on any one of the requirements, then it will not reduce many emissions. Any offsets bought that fail the AVID+ requirements cannot claim that the investment offsets emissions. Rather, it wastes resources and can further the negative impacts of climate change (Vereckey, 2022).

While MIT Sloan developed the AVID+ network, the Carbon Offset Guide given by the Greenhouse Gas Management Institute focused more on helping people and organizations use offset credits rather than reducing one's own carbon footprint (Greenhouse Gas Management Institute, 2020). Their criteria describe their schemes to be effective if they are additional, not overestimated, permanent, not claimed by another entity, and not associated with significant social or environmental harm (Greenhouse Gas Management Institute, 2020).

The additionality and permanence aspects of these criteria overlap with MIT. They are both crucial in actively reducing carbon emissions. Unlike the MIT criteria, however, the Greenhouse Gas Management Institute’s other three criteria (that schemes must not be overestimated, not claimed by another entity, and not associated with significant social or environmental harms) cover more risk-factor aspects of carbon credits.

No overestimation is a subset of additionality because any carbon-offsetting organization may claim to offset more than the organization does. Overestimation leads to net positive carbon emissions, which are more harmful to the atmosphere than if the offset had not been issued. In the event that an organization may use land with already preserved forests, no carbon is being offset since there are no additional trees being planted to offset more carbon. Overestimation can be abused by organizations so that the public eye sees false offsetting data. Furthermore, if two entities claim the same carbon offset credit, they will both claim to offset as much carbon that was emitted. In the case that this much carbon was offset in full, the two entities' claims will lead to an overestimation of double the real amount. Finally, it is crucial that the offsetting method has no negative impacts on society or the environment.

Another framework that may be potentially impactful for offsetting projects is published by ClimateSeed. ClimateSeed is an environmental consulting company that supports over 200 organizations in their decarbonization journey (Climateseed, 2023). ClimateSeed connects businesses that are interested in offsetting their emissions with people and organizations that own carbon credits. ClimateSeed has developed its own set of criteria that offsetting projects must satisfy before it connects them with their customers. ClimateSeed's criteria are project certification, being real, measurable, additional, independently verified, unique, permanent, transparent, and must include co-benefits (Climateseed, 2023). Most criteria of ClimateSeed are similar to that of MIT Sloan and Greenhouse Gas Management Institute. However, Climateseed may be viewed as stricter than other frameworks given that it includes a greater number of criteria overall.

The first of the additional criteria is that projects must be certified by an international or national standard. While theoretically this is a good idea, international organizations that certify carbon offsets are not always transparent or trustworthy. Many international organizations have come under fire for certifying projects that were not legitimate. In fact, the largest carbon registry in the world – Verra – that certifies 75% of the world's carbon credit, has been accused of having the lowest standards for its projects. It has even certified projects that not only did not offset emissions but ended up emitting more carbon (SourceMaterial, 2023).

Another characteristic ClimateSeed looks for in the projects it promotes is transparency and the measurability of the offset. ClimateSeed only supports projects that have a precise estimate for offsets that account for adjustments due to uncertainty and that have a clear path for where the funds are going. ClimateSeed does not participate in the secondary carbon market and suggests retiring carbon credits.

Drawing from the criteria and frameworks of these different offsetting verification programs and organizations, we developed our own criteria to best suit the needs of a study abroad-specific offsetting scheme analysis. In the following section, we outline how we achieved this. Permanence, imminence, and co-benefits were prominent amongst these frameworks, indicating their importance within realistic offsetting. We believed it was in the best interest of the PRPC to recommend an organization that follows these criteria in order to offset emissions properly.

Chapter 3: Methodology

Our goal of exploring the landscape of carbon offsetting initiatives within Puerto Rico and developing an offsetting recommendation for WPI and the PRPC was achieved by following three objectives:

Objective 1: Develop comparative evaluation criteria for carbon offsetting schemes;

Objective 2: Map out organizations in Puerto Rico that practice offsetting schemes;

Objective 3: Develop four case studies that vary in offsetting initiatives.

A grant provided by The Collaborative for Technology and Transformative Justice (JustT Collab, at WPI) will be utilized to invest in an organization that we believe is the best fit for carbon offsetting based on our research and analysis.

3.1 Objective 1: Develop Comparative Evaluation Criteria for Carbon Offsetting Schemes

To create our own set of evaluation criteria, which is tailored to study abroad programs for the PRPC, we first analyzed existing sets of criteria from leading offsetting evaluation and certification organizations. We examined the criteria from the Greenhouse Gas Management Institute, the AVID+, MIT Sloan and ClimateSeed frameworks, and evaluated which criteria were most applicable for an offsetting scheme tailored to a study abroad program (permanence, imminence, and co-benefits) and eliminated the criteria that were not as relevant. Additionally, we discussed with the PRPC directors to include criteria specific to the PRPC's projects. The final set of criteria we decided to use to evaluate the projects were: 1) affordability, 2) imminence, 3) permanence, 4) student engagement, and 5) co-benefits. Table 1 displays the criteria for effective and reliable offset programs.

Criterion	Description
Affordability	Each method will have different costs to offset; a lower cost would be ideal, but this should not be the main deciding factor.
Imminence	The time it would take an offsetting scheme to fully offset a certain amount of carbon.
Permanence	Offset reductions must be as permanent as the emissions that they cancel out. GHG reductions should not be reversed, which occurs when GHGs are subsequently emitted, resulting in no net reduction.
Opportunities for Students Engagement	Many offsetting projects depend on community volunteers; if there are ways that students or other members of the community could help with these efforts, they could gain practical, hands-on experience and a better understanding of how these schemes work.
Co-benefits	Any benefits other than carbon sequestration that would help the local community or environment, such as promotion of biodiversity, increased resiliency etc.

Table 1: Criteria for effective and reliable offset programs tailored for the PRPC

3.2 Objective 2: Map Offsetting Organizations in Puerto Rico that Practice Offsetting Schemes

3.2.1 Keyword Search

The first step toward achieving this objective was to create a list of potentially relevant offsetting organizations. Because of the PRPC's desire to support local environmental organizations, we began by investigating offsetting schemes exclusively within Puerto Rico. To do this, we performed keyword searches on Google to pull together a preliminary list of organizations. We used an expansive list of keywords in English and Spanish to make our research more thorough (Appendix C).

The organizations we found with keyword searches were either a "direct" offsetting organization, or a "snowball" organization. The difference between a direct offsetting organization and a snowball organization is its ability to directly offset carbon through its practices or to indirectly support it. For example, a direct organization offsets carbon via an offsetting scheme, such as tree planting, mangrove planting, and seagrass conservation. A snowball organization may consist of a larger organization (e.g., multi-national) that indirectly supports carbon offsets by donating to a direct offsetting organization. Every relevant organization that was encountered was added to our list of contacts (Appendix B).

One limitation we faced while performing our initial keyword searches was that some organizations did not have an online presence. Additionally, some organizations did not advertise themselves as offsetting organizations, even though they may practice offsetting schemes. We sought to mitigate these limitations by using a snowball sampling method. A snowball sampling method is where research participants help recruit future subjects for a study (Simkus, 2022). The "snowball" organizations, as well as some "direct" organizations, assisted us in identifying offsetting organizations in Puerto Rico that did not have an online presence but were nonetheless potential organizations to consider. By asking local offsetting organizations to share who they cooperated with, we were able to better capture the full landscape of carbon offsetting organizations in Puerto Rico.

3.3 Objective 3: Develop Four Case Studies that Vary in Offsetting Initiatives

3.3.1. Categorization of Organizations

Once we identified and documented potential offsetting organizations, we then contacted the direct organizations on our list by phone and email. Snowball organizations were not used beyond this point. Each email that was sent contained information about our group, our interests in the organization, and a request for information about their organization's offsetting practices. During this pre-interview process, we continued to document all the information the organization provided online and in their email replies, including how they specifically offset carbon and if their initiatives may be of interest to the PRPC. We then requested a formal interview with suitable organizations.

We conducted 9 semi-structured interviews for our formal research interviews to preserve a holistic and conversational environment with the interviewee. The interview questions (Appendix D) touched upon the interviewee's experience in their organization and their knowledge of carbon offsetting practices. The interviews were organized so that each team member contributed: two team members facilitated the interview conversation, while the other two team members took notes concurrently during the interview process. Permission for an audio recording was asked upon the start of the interview, and the interviewees were notified that the interview was completely voluntary and that they could leave at any time.

After the interview process, we categorized each organization based on its scheme. The schemes fell into four main types: those that focused on solar power, coral reef restoration, reforestation, and mangrove restoration. For categories that included multiple potential partner organizations, the most promising organization was selected to represent the category (the "Potential Partner").

3.3.2 – Case Studies

After categorizing each organization based on their scheme, we developed four case studies that vary in offsetting approach. Each case study contained a detailed description of the organization, and an analysis of which criteria were met. The criteria we used to assess each organization were all from Table 1 in objective 1. We obtained most of the information for each criterion needed to assess each organization through interviews.

Each team member conducted one of the four case study organizations. Each case study included a background and potential partner as well as comparative variables of interest: affordability, imminence, permanence, student engagement, and co-benefits. These enabled us to rank the schemes in the following section (Discussion).

The schemes in the discussion were presented from a "low" to "high" scale (low representing "not viable," medium representing "partially viable," high representing "viable"). Table 2 shows the low to high scale criteria for each variable of interest. Permanence, for example, describes a "low" rating as "scheme doesn't last long enough to offset", while a "high" rating is "scheme lasts longer than the intended offset." Our final recommendation was compiled by the ratings given to each scheme.

Variable of Interest	Low	Medium	High
Affordability	Scheme is over $2,500 to offset 19.5 tons in given imminence	Scheme is between $1,000 and $2,500 to offset 19.5 tons in given imminence	Scheme is less than $1,000 to offset 19.5 tons given imminence
Imminence	Scheme takes over 15 years to complete offsetting	Scheme takes between 5 to 15 years to complete offsetting	Scheme takes less than 5 years to complete offsetting
Permanence	Scheme doesn't last long enough to offset	Scheme lasts just long enough to offset	Scheme lasts longer than the intended offset
Student Engagement	Students are not involved (detached from project)	Students have some involvement. They contribute to the project in some way, but not "hands-on"	Students have multiple opportunities for involvement (working hands-on closely with the local community)
Co-Benefits	Carbon offsetting is the only benefit	Has up to a few other benefits biodiversity, resilience, and economic benefits, but carbon offsetting is still the most significant	Has numerous other benefits that are equal or are more significant than carbon offsetting such as those in the "medium" section plus more benefits

Table 2: Rating scale for variable of interest of each carbon offsetting scheme

Chapter 4: Findings and Discussion

4.1 Introduction

Each of the four case studies offers some background on the general focus and intent of the scheme, as well as a potential local partner organization in Puerto Rico. We then look at the four comparative variables of interest for our analysis (affordability, imminence, permanence, student engagement, and co-benefits). These are all indicated as subheadings in each case study, in the following order: background, potential local partner, affordability, imminence, permanence, student engagement, co-benefits.

The affordability subheading for the case studies, which is a critical variable for the PRPC, includes a breakdown of how much should be invested (depending on the scheme) to offset 19.5 tons of CO_2 for 23.5 students (numbers averaged from previous cohorts utilizing the IQP Cohort Air Travel Carbon Emissions Calculator in Appendix E). The imminence subheading describes how quickly a scheme can offset a cohort's emissions. The permanence subheading assesses the longevity of the offsetting scheme and discusses outside factors like natural disasters, monitoring, and maintenance. Student engagement analyzes the possibility for students to be involved in the organization's projects. Co-benefits discusses the additional advantages beyond carbon offsetting that may have an impact on the community or environment.

Prior to introducing the four case studies, we first discuss a globally focused offsetting scheme that anyone can invest in. These multi-national organizations are typically among the cheapest and most popular offsetting options. While they may offer some benefits, such as low offsetting cost and immediate carbon credits, this is an easy "off-the-shelf" option to receive carbon credits and not engage in the process of carbon offsetting.

4.2 Global Carbon Offsetting Enterprise

A handful of multi-national carbon offsetting organizations promise to provide great quality offsets for low prices. Purchasing offsets online through multi-national schemes is easier than going out of one's way to invest in a local scheme that may end up being more expensive. TerraPass, for example, allows one to offset 0.5 tons of carbon dioxide for just $7.99 (TerraPass, 2023). Supporters of TerraPass, like NativeEnergy and Sustainable Travel International, also allow the purchase of offsets for $18.00 per ton and $16.00 per ton, respectively (TerraPass, 2022; NativeEnergy, 2021; Sustainable Travel International; 2019). Unfortunately, many of the large offsetting organizations, including the aforementioned, are unreliably verified by Verra. SourceMaterial reported two of Verra's forestry projects that they analyzed, which accounted for 95 million carbon credits, only produced 5.5 million carbon credits, vastly overstating how much they offset (SourceMaterial, 2023). Furthermore, funding an offsetting scheme through such an organization would not provide any project opportunities for student engagement. Accounting for affordability, permanence, student engagement, and co-benefits, we developed four offsetting case studies that satisfy local engagement.

4.3 Solar Panels

4.3.1 Background

Puerto Rico is home to one of the largest solar power-generating facilities in the Caribbean. The Oriana facility, which is the largest solar farm consisting of 45 megawatts, accounted for approximately three-tenths of solar generating capacity. In 2022, 97% of Puerto Rico's electricity was derived from fossil fuels (43% natural gas, 37% petroleum, and 17% coal-fired power plant). About 3% of the island's electricity was derived from renewable energy, of which three-fifths is solar power (U.S Energy Information Administration, 2023).

When sunlight hits a solar panel, the sun's energy is converted to electrical energy. These panels are arranged in systems that can be stand-alone, grid-connected, or hybrid modes (Dias et al., 2022). This process of using the sun's energy for electricity reduces reliance on the power grid, where electricity comes from a power plant. In turn, this reduces the number of fossil fuels burned to provide electricity, which cuts carbon emissions.

Recognizing that renewable energies are generally underexploited in PR but that solar is the dominant renewable energy source when and where renewables are implemented, we examined solar expansion opportunities. Casa Pueblo and the Pedro G. Goyco School emerged as two organizations that could be partnered with to build upon Puerto Rico's emerging solar network. We determined that the most promising of the two organizations was the Pedro G. Goyco School in the Calle Loiza neighborhood of San Juan.

4.3.2 Potential Partner

Many community centers around the island utilize a solar energy system to power equipment like refrigerators and stoves to provide basic provisions to those in need. The Pedro G. Goyco School, now the Taller Comunidad La Goyco Inc., was an elementary school in San Juan that closed in 2015 due to a combination of complex issues justified by debt crisis and island-wide austerity measures. In 2018, the community successfully fought to convert the abandoned structure into a community center. The goal of the community center is to provide vital art and cultural services and host activities to empower the local community. The center offers education, health, and culture programs each week and serves as a resilience hub as well (Am et al., 2022).

La Goyco is a critical place for the PRPC as an established relationship between them already exists. The community center itself represents the community, solidary, autonomy, and self-sufficiency of Puerto Rican culture. This comes as a result of La Goyco's three fundamental aspects of culture, health, and environment (Am et al.,2022). Each of these characteristics deemed Taller Communidad La Goyco to be the best option for a potential partner based on what they represent and offer to the community.

Figure 2: La Goyco community enter solar panel system

4.3.3 Affordability

There is no impact on the environment when solar panels are in use. They do not release any carbon dioxide or greenhouse gases into the atmosphere. The panels also do not cause water pollution or create hazardous waste (Hantula, 2020). Although the panels do not release any greenhouse gases when in use, emissions are released during the manufacturing process. It is estimated that 0.11 tons of carbon emissions are produced per solar panel. Solar panels typically last 25 to 30 years, and the batteries typically last 5 to 15 years (Revolsun, 2022). In the lifespan of the solar panel, it will completely offset all its carbon emissions and continue to offset carbon emissions.

In Puerto Rico, it is typical that a 6-kWh roof solar system is installed. A 6-kWh solar system as a baseline cost would be around $11,765 (after a 30% federal solar tax credit). This cost does not include the installation cost. There are other associated costs with solar panels, such as the inverter, battery system, permitting, and inspection. These additional costs differ between installation companies (SolarReviews, 2023). To simplify cost calculations, the average cost of a solar panel and installation was used to minimize the variability. The cost of a single solar panel is between $200-300 ($250 average). The cost of a roof-mounted system is $1,000 per panel. The PRPC would pay $1,250 to purchase a single solar panel and mount it to add to La Goyco's existing solar panel system. This amounts to $53.20 per student (Appendix F).

4.3.4 Imminence

Annually, Puerto Rico has 5.32 hours of sunlight a day, so a 6-kWh system will produce 24 kWh of electricity per day and 8,760 kWh per year. In one year, a 6-kWh solar panel system will offset, on average, 7.70 tons of carbon (Appendix F). In 2.5 years, the system would offset the 19.5 tons of carbon from 23.5 students (on average) traveling to Puerto Rico and manufacturing emissions. In the three-year period, the solar system would have offset 23.1 tons of carbon. In the lifespan of the 6-kWh system, it would offset 192.5-231 tons of carbon.

4.3.5 Permanence

There are positive and negatives to the permeance of the solar panels. Solar panels require very little maintenance. Andrew Sendy from Solar Reviews recommends that the solar panels be cleaned two to four times per year or when a noticeable dip in productivity is seen. The productivity of the panels can be tracked through an app or monitoring system. The most extensive monitoring is when a panel breaks or requires repairs (Sendy, 2019). Strong winds can blow the solar panels out of its racking. The panels would need to be removed before any large storm and returned after the storm passes. In July 2020, Tropical Storm Isaias passed Puerto Rico blowing Casa Pueblo community center solar panels out of their racking. The panels did not get damaged and were able to be reinstalled (Krantz, 2020).

4.3.6 Student Engagement

This project has a low potential for student engagement as students would not receive any hands-on experience with the solar panels. Solar companies and engineering companies would do the designing and installation of the solar panels. Given that the PRPC currently has an established relationship with La Goyco, students could benefit from educational experiences such as learning about solar panels. If the PRPC invests in a solar panel that would be added to La Goyco's existing system, the students could organize a celebratory unveiling event. Students would also be given the opportunity for cultural engagement by participating in the events held at the community centers.

4.3.7 Co-Benefits

Solar panels provided additional benefits from the creation of solar energy and had no impact on the environment. Solar panels reduce electricity bills through less reliance on the grid and net metering. An arrangement called net metering allows for a person to sell their excess solar electricity (power produced but not used) back to the electric company. Solar panels with a battery system can also operate as backup generators during a power outage (Hantula, 2020).

4.4 Coral Reef Restoration

4.4.1 Background

Coral reef restoration is the process of replanting the coral reefs that were damaged by extreme weather. Most often, the damaged coral reefs are brought back to the nursery, where they are reattached piece by piece with cement, zip ties, and nails (Coral reefs, 2021). Some important aspects of coral reef restoration include planting nursery-grown corals back onto reefs, making sure the habitat is suitable for natural coral growth, and building coral resilience to threats such as climate change (Fisheries, 2019). Insufficient coral reef restoration, as well as climate change itself, may lead to coral bleaching. Microalgae that live in the coral reefs' tissues are their main source of food and the source of their color (Coral reefs, 2021). These microalgae leave the coral reef when the water temperature increases enough, leading to coral bleaching, which leaves the corals more susceptible to disease. Rising carbon dioxide levels also lead to oceanic water having a lower pH and becoming more acidic (Natural History Museum, 2019). This, in turn, slows coral reef growth and produces weaker skeletons that can easily erode (Oceana, n.d.)

4.4.2 Potential Partner

Sociedad Ambiente Marino (SAM) is currently working on numerous projects involving coral reefs, including studying stony coral tissue loss disease, using coral reefs to prevent habitat loss of an endangered cactus, and using 3D-printed models of coral reefs to restore reefs impacted by Hurricane Maria. SAM is a non-profit, community-based organization that focuses on fostering the conservation and restoration of marine resources (Sociedad Ambiente Marino, n.d.). They were established in 2001 and became officially recognized as a non-profit organization in 2004. Their main goals are to aid in the conservation and management of their marine resources, rehabilitate ecological function and services of degraded marine habitats, contribute towards the understanding of the dynamics of restored marine habitats, stimulate the local economies by establishing partnerships with key stakeholders, and increase public awareness about the importance of marine resources.

This organization's 3D-printed coral reef restoration project, which works with carbon sinks closest in comparison to their other projects, doesn't directly sequester carbon; the coral reefs benefit adjacent coastal ecosystems, such as seagrass, that undergo carbon sequestration. However, their indirect carbon sequestration efforts have shown a focus on co-benefits and opportunities for student engagement. SAM's offset supply is huge, as they had over 75,000 corals currently in nurseries and over 150,000 cultivated and transplanted corals in total before Hurricane Maria. They have saved over 23,000 corals destroyed by Hurricane Maria, which is the basis for the cost calculations. They are part of a Latin American coral restoration practitioner and have over 280 nurseries spanning Puerto Rico, the Dominican Republic, the Virgin Islands, Cuba, Jamaica, and Florida. On top of this large land abundance, SAM has found a way to speed up the process of coral reef restoration by planting 3D-printed coral reefs without the need for microalgae, which would allow the coral reef to recover (Mercado, n.d.). As a result, the real coral will grow faster over the 3D printed coral, 6 hours as opposed to one year, making the growth 1460 times faster. This will indirectly allow for quicker sequestration of carbon from nearby seagrass. A 3D-printed prototype of the coral can be seen in the figure below.

Figure 3: 3D-printed coral prototype used in SAM's project

4.4.3 Affordability

While coral reef restoration sequesters no carbon directly, restoration is still crucial as this method indirectly sequesters carbon. Young seagrass sequesters large amounts of carbon directly through plant stems, then over time through sediments that accumulate where they grow (US EPA, 2022). Seagrass beds in areas of the Caribbean, such as Tayrona National Natural Park in Colombia, grow in reef lagoons between the beaches and coral reefs (Serrano et al., 2021). Seagrass also grows on the shallow soil of weathered coral in some Caribbean locations, such as San Andres, Colombia (Coralina-Invemar et al., 2012). Seagrass beds depend on coral to grow, and a lack of these reefs can hinder seagrass growth as well as damage existing seagrass, which would release stored carbon (Coral Reefs, 2021; Coralina-Invemar et al., 2012).

A habitat mapping project that took samples from 21 distinct benthic habitat types in Puerto Rico found 756 square kilometers of shallow coral reef systems and 721 square kilometers of submerged vegetation (Kendall, 2002). This demonstrates a near-perfect 1:1 ratio of seagrass (or other oceanic carbon sinks) in conjunction with shallow coral reefs in Puerto Rico in terms of area.

To estimate the total cost to offset a cohort's emissions, the tons of carbon a cohort emits during one program, or 19.5 tons, was multiplied by the cost to offset one ton via seagrass, or $20. This would cost the cohort a total of $390 to offset.

4.4.4 Imminence

SAM's 3D-printed coral reef model allows for quicker coral reef restoration. Because of this, any one saved coral can be fully restored within 6 hours, allowing for immediate sequestration of already-existing seagrass. To estimate the amount of carbon SAM's saved coral reefs have helped sequester, we estimated the total area of seagrass that was affected by these reefs. Some of the coral species SAM has saved from Hurricane Maria include *Acropora palmata*, *Acropora cervicornis*, and *Orbicella annularis*. We found the total area of these corals by multiplying the total number of saved corals, or 23,000, by the estimated area of each individual coral, or 2.6 square meters. We then estimated the amount of carbon stored in these seagrass beds by multiplying the total seagrass area, or 0.058 square kilometers, by the tons of carbon sequestered by seagrass per square kilometer, or 91.43 tons (Reynolds, 2018). These estimations show us that this seagrass method sequesters up to 5.27 tons of carbon per year. 19.5 tons would need to be offset, which would allow a cohort's carbon to be fully offset in 3.7 years (Appendix G).

4.4.5 Permanence

Puerto Rico is a hurricane-intensive area, and many of these hurricanes impact coral reefs. When coral reefs get hit by a hurricane, they disappear, and only flat land is left. Since coral reefs protect seagrass, this would lead to damaged seagrass and released carbon. Also, as climate change worsens, coral bleaching will become more prominent, creating a negative feedback loop where the warmer oceans will lead to damaged corals and, thus, damaged seagrass which emit carbon to further heat the ocean. Current climate change trends will lead to every coral on earth undergoing bleaching by 2100 (Ahmadia et al., 2020). This is a negative example of permanence, as this method can only work along with other methods to reduce greenhouse gas emissions.

4.4.6 Student Engagement

SAM is largely community based; with over 3,400 volunteers actively participating over 7 Caribbean nursery locations. They have over 300 volunteers working at any place and any time. Since SAM is based in the Caribbean, students in the PRPC could help directly with restoring coral reefs. SAM's 3D-printed coral reef project could be of interest to the students. Instead of being carbon based, their printing material is made of corn starch, polylactic acid, and other environmentally friendly materials approved by the EPA. Students could learn about the 3D-printed coral reef project through SAM teaching the process of creating the print material and determining the structure of the artificial coral, as well as having the students 3D-print some coral reefs for restoration themselves.

4.4.7 Co-benefits

Coral reefs bring many benefits to the environment, including providing habitat for marine life, acting as a buffer against erosion, and producing economic benefits. 25% of marine life depends on coral reefs to survive, including sponges, oysters, clams, crabs, sea stars, sea urchins, and 4,000 different species of fish (ICRI, n.d.; US EPA, 2017). These dependencies focus mostly on habitat, feeding, spawning, and nursery grounds. Coral's structure acts as a natural buffer against waves, storms, and floods approaching the shoreline, and this buffer helps protect the seagrass in shallower waters (Smiley et al., 2017). Coral reefs around the world are estimated to contribute a $29.8 billion yearly economic net benefit (Cesar et al., 2002). This breaks down into $9.6 billion towards tourism and recreation, $9.0 billion towards coastal protection, $5.7 billion towards fisheries, and $5.5 billion towards biodiversity.

Overall, this case study is not ideal for carbon offsetting as a prime focus; a partnership with this organization would be more beneficial for aspects such as biodiversity and resilience, since these are their top initiatives. However, this case study is an option because the local community and marine habitat benefit from SAM's project, making this a strong marine-based option that also happens to sequester carbon.

4.5 Reforestation

4.5.1 Background

Puerto Rico – along with some of its neighboring islands – composes one of the world's 35 biodiversity hotspots, the Caribbean Islands Hotspot (Conservation International, 2023). The hotspot is biologically diverse and is considered one of the greatest centers for flora and fauna in the world. Unfortunately, the industrialization and modernization of Puerto Rico's economy have rendered this diversity vulnerable and under stress, while also threatening millions of trees that sequester carbon through photosynthesis. (Fideicomiso de Conservación de Puerto Rico, n.d.).

4.5.2 Potential Organization

Recognizing that increasing industrialization and modern agriculture posed a threat to the natural environment, the United States Department of the Interior and the Government of Puerto Rico signed a Memorandum of Understanding that established the Conservation Trust of Puerto Rico (CTPR) in 1968. The mission statement of the CTPR is to "ensure the functionality and health of the ecosystems in the islands of Puerto Rico." Para la Naturaleza (For the Nature), a non-profit NGO and subsection of the CTPR, aims to achieve this goal by promoting a culture of environmental conservation, inspiring environmental leaders, and ensuring 33% of the island is protected by 2033 (Fideicomiso de Conservación de Puerto Rico, n.d.). With these goals in mind, Para la Naturaleza (PLN) has launched numerous initiatives such as its agroecology project, resiliency centers project, reforestation and conservation projects.

The main project PLN is investing its resources into is the reforestation of Puerto Rico. In the 1970s, PLN aimed to restore the forested areas in Puerto Rico, which had decreased by 94% due to urban development and overexploitation of land for agriculture (Para la Naturaleza, n.d.). PLN, along with other organizations on the island, achieved this goal, as by the late 1980s, the forest had recovered to 55% of its pre-industrialization size. Despite their success, in 2017, the U.S. Forest Service estimated that as many as 114 million trees were lost due to Hurricanes Irma and Maria. Since then, PLN has continued to invest in reforestation, expanding its operations with a goal of planting 100,000 trees per year.

Today, PLN employs over 200 people and has conservation and reforestation projects across Puerto Rico, planting 150,000 trees per year on average. To fuel this large-scale reforestation project, PLN has developed five tree nurseries across the island, nurturing 250,000 trees. In its projects, PLN emphasizes restoring the natural forest by practicing polyculture reforestation, including over 120 different species of flora, 21 of which are endemic to Puerto Rico.

Figure 4: Trees in a PLN nursery (Para la Naturaleza, 2023)

4.5.3 Affordability

On average, each tree PLN plants costs 5 dollars to grow from seed to maturity, where it can be planted outdoors. Monitoring the plant for five years – after which it will have grown enough to survive on its own – costs, on average, 7 dollars per year. In fact, it is this 5-year monitoring plan that gives PLN plants an 85% survival rate, compared to 40% globally. Lastly, considering that we were in Puerto Rico, a territory with a moderately high cost of labor compared to other tropical regions – it is to be expected that PLN's projects will not be the cheapest option compared to offsetting projects in other countries. Taking all these factors into account, we estimated that it is possible to offset the round-trip emissions at a cost of $1,480.

4.5.4 Imminence

On average, the trees PLN plants have a lifespan of over 180 years (University of Leeds, 2020). As a team, we decided 25 years to be an appropriate timeline, given the long-term nature of reforestation.

4.5.5 Permanence

Most of the trees PLN plants have long lifespans (180+ years), which means under ideal conditions, there is longevity to the scheme. However, given the location and recent history of the island, the probability of hurricanes wiping out the trees must be taken into account. Since the year 2000, Puerto Rico has been hit by four Category 4 and four Category 5 hurricanes. Category 4 hurricanes can reach speeds up to 251 km/h, while Category 5 hurricanes can be even more violent and don't have an upper-speed limit. In 2017 hurricanes Irma and Maria, both Category 5 hurricanes, wiped out 114 million trees. Given the vulnerability of Puerto Rico to hurricanes, we deem that the trees that would be planted are at serious risk of being wiped out.

4.5.6 Student Engagement

Through its volunteer program, PLN has gained experience in training volunteers and preparing them to plant and monitor trees. A potential partnership between PLN and the PRPC would allow students to volunteer at PLN, where they could plant trees and learn about reforestation efforts in Puerto Rico. This would offer students hands-on environmental education, and it would also allow them to forge a deeper connection to the island of Puerto Rico and its people.

4.5.7 Co-benefits

PLN's reforestation projects benefit more than just the flora of the island – they help uplift the entire ecosystem of the area. PLN's reforestation projects help maintain and promote biodiversity on the island. Scientists combined reforestation data, along with species richness data, and measured that "reforestation and threatened vertebrate biodiversity overlap primarily in the tropics" (Kemppinen et al., 2020). The study excluded reptiles because they "had not been comprehensively assessed," however, it is possible that reforestation also positively impacts them as well. It is, therefore, reasonable to assume that PLN - through its reforestation projects, has indirectly supported biodiversity in Puerto Rico. Furthermore, many trees PLN plants bear fruit, which is collected and sold to the locals. Finally, reforestation protects local communities from natural disasters such as soil erosion and landslides, as tree roots provide mechanical reinforcement to the soil, and tree trunks inhibit surface erosion by forming gullies (Broadhead et al., 2013).

4.6 Mangrove Restoration

4.6.1 Background

Mangroves are coastal trees that thrive in marshlands. The four kinds of mangroves are red (filters salt water, hits the water first), white (lots of roots to drain water, forms dams, nutrients filter to black mangrove), black (roots go deeper, take all minerals), and buttonwood (behind the black mangroves). Together, they all provide coastal resiliency and participate in carbon sequestration. They sequester carbon dioxide from the air and store it in their roots and branches (McVeigh, 2021). Mangrove forests can sequester up to 50 times more carbon in their soil by area than tropical forests (Dani, 2017). Up until six decades ago, the coasts of Puerto Rico used to be covered with thick mangrove forests. Unfortunately, the once-lush forests are now rapidly dwindling due to agriculture, urban development, and hurricanes.

4.6.2 Potential Partner

In order to revert the dwindling of forests, scientists and local activists have set up marathon efforts to restore the mangrove forests. Corporación Piñones se Integra (COPI) is a local organization based in Loiza with an interesting approach to being part of the mangrove solution. COPI was founded in 1999 and is a community-based non-profit organization that aims to improve the quality of life of its community through educational, cultural, developmental, and environmental projects. Located right next to the Piñones State Forest, which is a 1,560-acre park that is home to Puerto Rico's most extensive mangrove ecosystem (Estado Libre Asociado de Puerto Rico et al. 2008), COPI is actively involved in reforestation efforts. The organization has two full-time employees who are tasked with planting mangroves and monitoring a couple hundred more in their nursery.

The COPI nursery has a main goal of restoring and monitoring mangroves. COPI waters the mangroves with salt water to prepare them for the environment they will have to survive in. The lifecycle of mangroves begins with the planting of a seed within their nursery. After a little over a year, where the mangroves are raised to maturity, they are planted along the coasts where they develop with monitorization. Monitorization takes place every 15 days. This includes maintaining the mangroves within the nursery and taking out ones from the forest that are dead. Over more decades, COPI hopes that the mangroves can develop enough where they can protect the community from rising waters and hurricanes (by their shield-like walls).

Figure 5: Mangrove trees in the river behind COPI (left); Mangrove nursery (middle and right)

4.6.3 Affordability

The average growth life of a mangrove is 25 years, and it sequesters 0.3 tons of CO2 from the atmosphere in its growth life, which is 0.012 tons per year (MoreTrees, 2023). For the PRPC to successfully offset a singular cohort's carbon emissions, 65 mangroves, plus an additional 121 mangroves (due to a survival rate of 35%), need to be planted. PETCO and Algae Barn, among other competitors, are organizations that offer mangrove seeds for purchase at around $10 (Petco, 2023; Algae Barn, 2023). With the assumption that mangrove seeds are around $10 per seed due to their high demand in restoration efforts, offsetting 19.5 tons of CO2 would cost $1,860 ($80 per student). That means the cost per ton to offset is $95.38. We did not account for monitoring costs because the data was not available. If WPI wishes to achieve carbon neutrality at the PRPC, however, $1,860 needs to be spent per year for mangrove restoration. Calculations are in Appendix I.

4.6.4 Imminence

It takes at least 25 years to offset a singular cohorts' emissions. This is assuming a mangrove offsets 0.3 tons of CO_2 over its growth life.

4.6.5 Permanence

Mangroves have a lifespan of 100 years under ideal conditions meaning that the trees would continue to sequester long after having offset the carbon that was emitted by students traveling to Puerto Rico. Similarly, to reforestation, the permanence of mangroves are negatively impacted by hurricanes (refer to section 4.5.5).

4.6.6 Student Engagement

An offsetting scheme that is based on planting mangroves provides opportunities for student involvement. Through such a scheme, students can contribute by planting, monitoring, and measuring the mangroves. Through such activities, students are exposed to hands-on environmental experiences that will strengthen their environmental conscience. Additionally, these positions will also allow students to cooperate with the local employees, further strengthening their cultural understanding of Puerto Rico and its people.

4.6.7 Co-benefits

Mangroves in Puerto Rico are the primary lines of defense for coastal communities, which protect land life and infrastructure (Grauvogl, 2021). They provide natural protection against tropical storms and are abundant in biodiversity (Dani, 2017). A COPI employee mentioned that mangroves take 50-60 years to become a full mangrove "shield," which protects against the rising waters of storms. It also serves as a "living dam," protecting fish from predators. The mangroves that COPI plants and monitors also protect COPI and preserve the Afro-Caribbean culture within the community.

Unfortunately, COPI isn't receiving enough volunteers to plant mangroves. WPI students, however, could serve as volunteers to facilitate the planting and monitoring of mangroves.

4.7 Discussion

In this discussion, we compare the case studies based on the criteria presented (affordability, imminence, permanence, student engagement, and co-benefits). The schemes for each criterion are presented from a "low" (not viable) to a "high" (viable) scale. In the end, we provide a final recommendation for the PRPC of the most viable scheme to invest in. We will also provide a roadmap that other project centers could follow to join WPI's efforts in becoming carbon neutral.

4.7.1 Affordability

The most expensive offsetting scheme is solar panels. It costs $11,765 to successfully offset a cohorts' emissions (not including installation costs). As a result, solar panels were given a "low" rating in the affordability field. The second and third most expensive offsetting schemes, reforestation ($1,480) and mangrove restoration ($1,860), which costs approximately $10,000 less than solar panels, were given a "medium" rating in the affordability field. The cheapest offsetting scheme is coral reef restoration at a cost of $390 to completely offset 19.5 tons of CO_2 giving it a "high" rating. A global offsetting program on the other hand would cost roughly $155 to supposedly offset a cohort's emissions.

4.7.2 Imminence

The schemes that take the longest time to offset a cohort's CO_2 emissions are reforestation and mangrove restoration (25 years) which were given a "low" rating. Solar panels and coral reef restoration on the other hand both take less than five years to successfully offset (2.5 and 3.7 years, respectively). As a result, these are given a rating of "high."

4.7.3 Permanence

Each carbon offsetting scheme is affected by Puerto Rico's unpredictable and changing climate to various extents. Coral reef restoration is impacted by an increase in ocean acidification, which weakens the skeleton of the coral via coral bleaching. The weakened coral makes it vulnerable to hurricane damage. If the reefs are vulnerable to this type of damage, they will not live long enough to protect the seagrass, which sequesters the carbon. On the other hand, reforestation and mangrove restoration can last for many years under ideal conditions unless a hurricane wipes them out. Different from coral reef restoration, hurricanes pose the only threat (disregarding survival rate) to trees and mangroves. Solar panels, unlike coral reef restoration, reforestation, and mangrove restoration, can be repaired after hurricanes and require little maintenance during their lifespan. Not only can they be taken down before a hurricane, but they also can be reinstalled after such a disaster. For these reasons we categorized the permanence of solar panels as “high,” coral reef restoration as “low,” and reforestation and mangrove restoration as “medium.”

4.7.4 Student Engagement

Student involvement provides students with the opportunity to obtain a hands-on environmental education while also developing ties with the local community. For solar panels, there is no opportunity for hands-on student engagement, giving it a rank of “low.” There could be opportunities for educational experience of learning about solar panels and also a cultural experience of engaging with the local community members. Mangrove restoration, however, at COPI is a way for students to experience mangrove planting and monitoring. Reforestation is also a way for students to plant trees. PLN is particularly promising because of its history of working with many volunteers. In this way, students receive hands-on experience while also receiving environmental education. SAM provides the most opportunities for future student engagement due to the variety of options available for hands-on opportunities. Students can help 3D-print models of the coral reefs used for restoration or plant them to repair damaged corals. In addition to the hands-on experience, students can also receive environmental education. Students can learn about 3D-printed coral reefs, among other projects. The educational and hands-on experiences given by COPI, PLN, and SAM respectively, give their student engagement a “high” ranking.

4.7.5 Co-Benefits

All the schemes have considerable co-benefits ranging from economic benefits to resiliency. Solar panels, for instance, have economic benefits and are resilient. The installation of solar panels, for example, reduces the cost of electricity. Backup generation from solar panels with a battery is also useful in case of a power outage, which is common in Puerto Rico. Solar panels overall have no impact on the environment as they do not release any carbon dioxide or other harmful toxins. Solar panels’ co-benefits variable was ranked a “medium” since it provides resilience and economic benefits.

Reforestation and mangrove restoration also provide resiliency as their co-benefits, except their primary foci include carbon offsetting. Reforestation uplifts the entire ecosystem of the area and promotes biodiversity. Furthermore, a lot of trees PLN plants bear fruit, which is collected and sold to locals. PLN’s restoration projects also protect local communities from soil erosion and landslides. Mangrove restoration protects land life and infrastructure. Similar to

PLN, COPI's mangrove restoration project protects the local community and prevents the rising waters of storms. As a result, reforestation and mangrove restoration were given a "high" ranking since they provide numerous co-benefits.

While coral reef restoration provides the most co-benefits, their focus as an organization is on coastal resilience, public education, and advocacy. Like all other schemes, besides solar panels, coral reef restoration was ranked "high" in the co-benefits variable because of their numerous co-benefits.

4.7.6 Recommendation

Based on our discussion, we believe that reforestation (PLN) is the most effective scheme that has been assessed for carbon offsetting (Table 3). The cost is relatively cheap compared to the other schemes, provides hands-on experiences for student volunteers, and provides many co-benefits that include the promotion of biodiversity and community resilience. One drawback that reforestation faces, like coral reef and mangrove restoration, is permanence. Hurricanes can cause huge setbacks in reforestation projects by destruction of forests.

Carbon Offsetting Ranking

OFFSETTING SCHEME	AFFORDABILITY	IMMINENCE	PERMANENCE	STUDENT ENGAGEMENT	CO-BENEFITS
Solar Panels	Low	High	High	Low	Medium
Coral Reef Restoration	Medium	High	Low	High	High
Reforestation	Medium	Low	Medium	High	High
Mangrove Restoration	High	Low	Medium	High	High

Table 3. Ranking of each carbon offsetting scheme by variable of interest

4.7.7 Offsetting Roadmap

Our team developed a roadmap (Figure 6) to make our findings replicable to other project centers. This project addresses carbon emissions for one cohort of IQP students, however, each year there are roughly 85 cohorts, each with around 20 students, traveling to 60 project centers.

We began by setting up the criteria that needed to be satisfied by an offsetting scheme. For other project centers, new criteria should be set that are tailored to the needs of the specific project center. For our project, we found that affordability, imminence, permanence, student involvement, and co-benefits were the most applicable criteria given Puerto Rico's unique circumstances. Other project centers can conduct similar projects to do this research. After setting up criteria, other projects may send out emails and make phone calls to their local offsetting organizations in an effort to establish communication and set up an interview. We suggest that for future projects, this stage is performed before going to the project location so as to avoid waiting for responses while on the project. Afterward, categorize the organizations based on the type offsetting method they utilize. After categorization, proceed with interviews with the organizations. When it comes to the deep dive, we suggest developing case studies of the most promising organizations. In the case studies, as much relevant information as possible should be included: background information about the organization, information about the affordability and imminence of the offset, potential student involvement but also the risks of the scheme should be provided. Finally, the case studies should be compared and ranked based on the criteria. The organization that satisfies the most criteria should be contacted to begin talks about a partnership. We found that there are no organizations in Puerto Rico with a sole focus on carbon offsetting, but future projects may benefit from partnering with PLN, SAM, or COPI to develop a carbon offsetting scheme as a means to raise additional funding to support their work. That way, the PRPC is not just providing financial contributions to their project but providing additional value while creating exciting IQP projects.

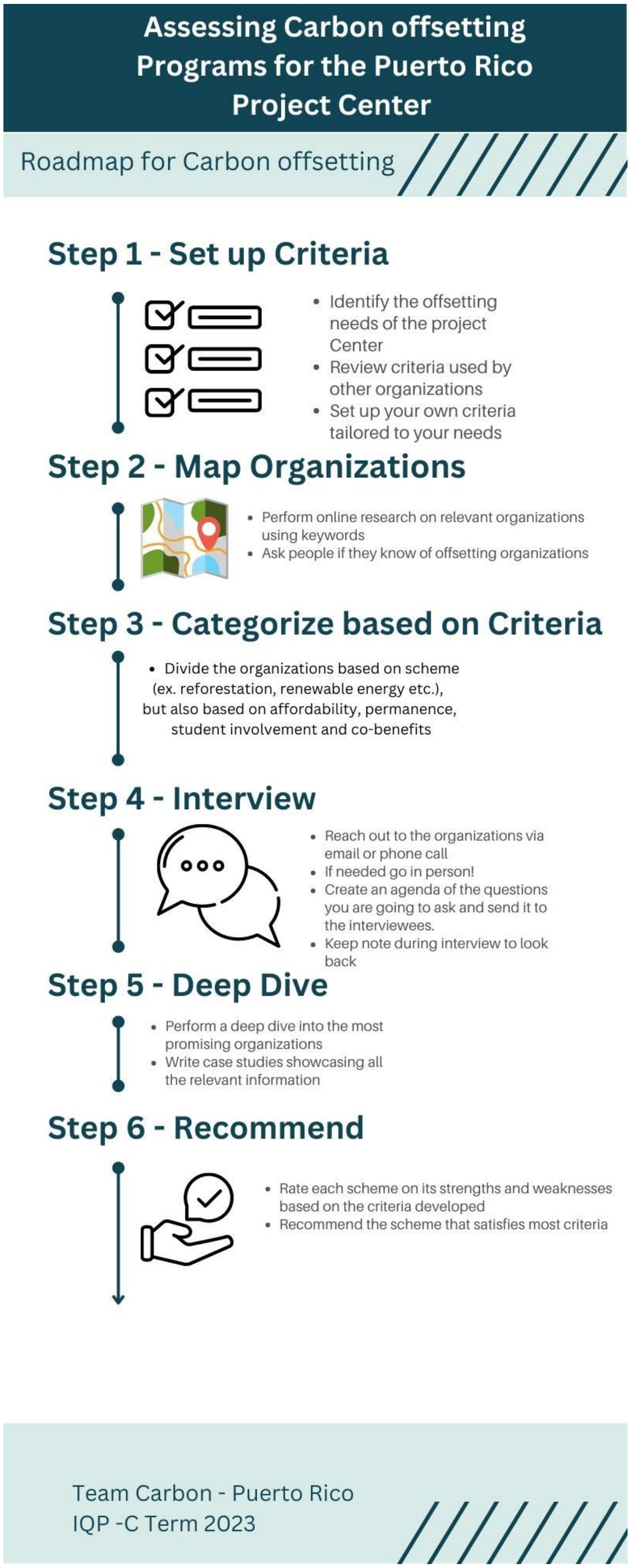

Figure 6: Roadmap for Carbon Offsetting

Chapter 5: Conclusion

Over one million students travel every year through higher education study abroad programs globally, at a growing rate (Institute of International Education, 2022). While study abroad programs provide powerful learning opportunities, there are unaddressed environmental costs, such as study abroad programs' contributions to CO_2 emissions. The PRPC, however, intends to have a carbon offsetting plan to become carbon neutral with an approach that focuses on local organizations. A partnership with Puerto Rican organizations would create benefits for the local community. Our study approached this challenge by (1) developing comparative evaluative criteria, (2) mapping out organizations in Puerto Rico that practiced offsetting schemes, (3) developing four case studies that varied in offsetting initiatives (solar panels, coral reef restoration, reforestation, mangrove restoration).

Based on our findings, we recommend that the PRPC invests in a local organization such as PLN because of their "high" rankings in student engagement and co-benefits. They also only had one "low" ranking (imminence) because of how long it takes for trees to offset emissions in a mature state.

Our process to identify a locally based carbon offsetting solution can be extended to other project centers at WPI and other university study abroad programs. Similar to our project, these future projects can also consider that local organizations provide co-benefits such as community development and resilience. They may also encounter unique challenges that alter their affordability, imminence, permanence, student engagement, and co-benefits rankings (e.g., extreme weather phenomena). Regardless, other study abroad programs can utilize our offsetting roadmap to create their own case studies and take the rankings on a case-by-case basis.

In addition to finding the most suitable Puerto Rican organization for the PRPC to pursue a partnership with and developing a process for other projects to replicate, we were able to highlight the differences between grassroots and large multinational offsetting schemes. Our research found that large international schemes are significantly cheaper than any local scheme. The lower cost of multinational schemes could be explained by their experiences in the offsetting domain (funding projects in more ideal locations); however, it could also flag a "too good to be true" situation. This is because of the evidence that supports that multinational schemes often fail to sequester all the promised carbon.

Despite the uncertainty that comes with multinational offsetting schemes, local schemes face their own challenges as well. Our research highlights that local schemes often come with high costs while also struggling to ensure the permanence of the project. However, we believe that local schemes prove to be better than multinational schemes because they are more transparent, easier to monitor, provide benefits to the local community, and provide opportunities for student engagement.

For these reasons, we believe that carbon-offsetting schemes can only supplement efforts of a carbon free future and should not replace the efforts of reducing emissions.

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Appendix A: IIE Open Doors 2018 Carbon Emissions Calculations

Starting Location	Destination	# of Students	Miles per Student	Total Mileage
Florida	United Kingdom	192,500	4207	809,847,500
Florida	Costa Rica	52,500	1246	65,415.000
Florida	Asia	35,000	8165	285,775,000
Florida	Oceana (Central Pacific)	35,000	3818	133,630,000
Florida	Africa & Middle East (Egypt)	35,000	6574	230,090,000
Total				1,524,757,5000

1,524,757,500 miles * 53 pounds of Co2 per mile = **80,812,147,500 pounds of Co2**

80,812,147,500 lbs * 0.0005 tons =~ **40,406,073 tons of Co2**

Appendix B: Contact List of Organizations

	A	B	C	D	E	F
1	Organization	Link/URL	Emailed?/Called	Response?	Interview (Zoom/In-person)	Date of Interview
2	Conservation Trust of Puerto Rico (CTPR)	http://www.fideicomiso.org/fcpr/home.html	Both	Yes	*	*
3	WestRock	Telling Our Sustainability Story | WestRock	Email	No	*	*
4	CASA BACARDÍ PUERTO RICO	https://www.bacardi.com/casa-bacardi/	Email	Yes	Zoom	31-Jan
5	AES Puerto Rico	https://www.aespuertorico.com/en/sustainability	Email	No	*	*
6	Condado Vanderbilt Hotel	https://www.condadovanderbilt.com/contact-us	Email	No	*	*
7	San Juan Marriott Resort	https://www.marriott.com/en-us/hotels/sjupr-san-ju	Email	No	*	*
8	The Nature Conservancy - Puerto Rico	https://www.nature.org/en-us/about-us/where-we-	Email	No	*	*
9	Carnival Corporation & PLC Sustainability	https://carnivalsustainability.com/	Email	No	*	*
10	Royal Caribbean Group	https://www.royalcaribbeangroup.com/sustainabilit	Email	No	*	*
11	Corporación Piñones Se Integra (COPI)	https://www.facebook.com/CorporacionPinoneseInt	Call	No	in-person (walked there with	1/23 & 1/24
12	Coral reef restoration (ISLA MAR)	https://www.islamarexp.com/projects	Email	No	*	*
13	DXC Technology	https://dxc.com/us/en	Email	No	*	*
14	General Electric	https://www.ge.com/contact/general	Email	No	*	*
15	Unilever plc	Unilever North Latin America Homepage | Unilever (	Both	No	*	*
16	The Ocean Foundation	https://oceanfdn.org/initiatives/blue-resilience/	Email	Yes	Zoom	16-Feb
17	Para la Naturaleza	https://www.paralanaturaleza.org/	Both	Yes	Zoom	6-Feb
18	DRNA	https://pr.gov/Directorios/Pages/InfoAgencia.aspx?F	Email	Yes	Directed us to Reforesta	*
19	First Environment, Inc.	Home - First Environment	Email	No	*	*
20	Terraformation	https://www.terraformation.com/	Email	Yes	*	*
21	Reforesta	https://www.reforesta.com/	Both	Yes	In-person	31-Jan
22	Landlife Company	https://landlifecompany.com/	Email	No	*	*
23	Caras de las Americas	Faces of the Americas, an initiative to promote educ	Email	No	*	
24	Amizade	Global & virtual-service learning for a more just worl	Email	No	*	*
25	Carribean Coral Reef Institute (CCRI)	Caribbean Coral Reef Institute (CCRI) – University of	Email	Yes	Zoom	2-Feb
26	CORALations	CORALations - About CORALations	Email	No	*	
27	Samuel Suleimán (SAM Founder)	https://www.sampr.org/	Call	Yes	Zoom	24-Jan
28	Sociedad Ambiente Marino (SAM)	https://www.sampr.org/	Call	Yes	Zoom	24-Jan
29	Johnson and Johnson (Janssen Ortho)	N/A	Email	Yes	In-person	9-Feb
30	Casa Pueblo	https://casapueblo.org/que-significa-50consol/	Call	*	*	*

Appendix C: List of Keywords

English	**Español**
Reforestation	Reforestación
Mangrove	Mangle
Aquatic Vegetation	Vegetación acuática
Carbon offsets	Compensaciones de carbono
Tree planting	Plantar árboles
Coastal carbon	Carbono costero
Seagrass	Hierba marina
Renewable energy	Energía renovable
Wind turbines	Turbinas de viento
Solar panels	Paneles solares
Carbon capture	Captura de carbon
Direct air capture	Captura directa de aire
Hotel offsetting programs	Programas de compensación hotelera
Cruise line offsetting schemes	Esquemas de compensación de líneas de cruceros
Offsetting	Compensación
Tropical Forest reforestation	Reforestación de bosques tropicales
Forest Conservation	Conservación de los bosques
Puerto Rico	Puerto Rico

Appendix D: Puerto Rico Organizations Interview Questions

Preamble:

We are a group of students from Worcester Polytechnic Institute in Massachusetts, and we are working with the Puerto Rico Project Center and the WPI Office of Sustainability to explore the landscape of carbon offsetting initiatives within Puerto Rico to develop a recommendation for WPI and the Global Projects Program. Currently, we are conducting an interview of carbon offsetting organizations to develop a recommendation for WPI and the Global Projects Program.

Your participation in this interview is completely voluntary and you may withdraw at any time. Please remember that your answers will remain confidential. No names or identifying information will appear on the questionnaires or in any of the project reports or publications. The WPI Global Projects Program will use this information for sustainability efforts at the Puerto Rico Project Center. If interested, a copy of our results can be provided through an internet link at the conclusion of the study. Your participation is greatly appreciated.

Interview Questions for PLN

1. What can you tell us about the natural protected lands?
2. How much land does PLN conserve in PR?
3. Do you know how many trees and what species are present in the conservation area?
4. Do you have a report of all the locations, trees, etc.? Like a sustainability report?
5. Are you involved in carbon offsetting schemes and if not, would you be interested?
6. Do you accept donations and if yes what do you do with them?
7. Are there any other organizations you cooperate with in PR?

Interview Questions for SAM

1. What can you tell us about the Seagrass-coral reef restoration projects (heavily hurricane-impacted coastal areas)?

2. I know most of the projects are for restoration and preservation, but is emission sequestration taken into account for any of these projects?
3. What can you tell us about the 3D coral reef for resilience?
4. Have any of your projects experienced major setbacks, perhaps due to any natural disasters (hurricanes)?
5. What happens to a project when it's completed? Is it monitored?
6. What part of the process are you at with developing numbers for carbon offsetting?
7. Why do you think your project is important?

Interview Questions for COPI

1. What is your process for mangrove planting?
2. Do the different kinds of mangroves sequester more/less carbon?
3. Does COPI focus on community resilience?
4. How much of a threat are hurricanes to mangroves?
5. How much carbon do mangroves at COPI sequester? Do you have any specific offsetting data?
6. How much work does it take to monitor mangroves both in the nursery and Piñones state forest?

Appendix E: Calculating the PRPC Cohort Emissions

Utilizing the IQP Cohort Air Travel Carbon Emissions Calculator developed by Floria et al. (2021), it is estimated that for years 2016, 2019, 2022, and 2023 (years not impacted by COVID19 and Hurricane Maria), the average number of students per year traveling to Puerto Rico is 23.5, which is about 19.5 tons of Co2 emissions per year (assuming round-trip travel from Boston to San Juan).

1. Primary Flight Route Table (One Way)				2. Cohort Information Table
Departure Code	**Arrival Code**	**Carbon Estimate [kg CO_2]**		**Size of Cohort (Students + Advisors)**
BOS	SJU	188		23.5

		---		**3. Air Travel Emissions Estimation**
		---		**Individual Estimate [kg CO2]**
		---		376

		---		**Cohort Estimate [kg CO_2]**
		---		8839

8839 kg CO2 * 2 (round trip) = 17,678 kg CO2
17,678 kg CO2 * 0.001102 ton/kg ~= **19.5 tons of CO2**

Appendix F: Solar Panel Calculations

Fossil Fuel Breakdown Percentage:
43% Natural gas
37% Petroleum
17% Coal

Total Fossil Fuel Electricity Generated in Puerto Rico in a Year = 18×10^9 kWh

Fossil Fuel kWh per Pound of Carbon Emitted Breakdown:
Natural gas = 0.91 lb/kWh
Petroleum = 2.13 lb/kWh
Coal = 2.23 lb/kWh

Amount Fossil Fuel Generated per kWh Breakdown:
Natural gas: $(18 \times 10^9)\ kWh \cdot 0.43 = 7.74\ \times 10^9$ kWh
Petroleum: $(18 \times 10^9)\ kWh \cdot 0.37 = 6.66\ \times 10^9$ kWh
Coal: $(18 \times 10^9)\ kWh \cdot 0.17 = 3.06\ \times 10^9$ kWh

Carbon Emitted per Fossil Fuel in a Year:
Natural gas: $(7.74\ \times 10^9) kWh \cdot 0.91 \frac{lb}{kWh} = 7.0434\ \times 10^9$ lbs
Petroleum: $(6.66\ \times 10^9) kWh \cdot 0.2.13 \frac{lb}{kWh} = 14.1858\ \times 10^9$ lbs
Coal: $(3.06\ \times 10^9) kWh \cdot 2.23 \frac{lb}{kWh} = 6.8238\ \times 10^9$ lbs

Natural gas = 3,521,700 tons
Petroleum = 7,092,900 tons
Coal = 3,411,900 tons

Monthly Solar Radiation in Puerto Rico per Day

Month	Solar Radiation (kWh/m^2/day)
January	5.06
February	5.56
March	5.45
April	5.57
May	5.2
June	5.41
July	5.61
August	5.47
September	5.42
October	5.19

November	5.03
December	4.88

Average Solar Radiation:
$\frac{5.06+5.56+5.45+5.57+5.2+5.41+5.61+5.47+5.42+5.19+5.03+4.88}{12}$ =5.32 $\frac{kWh}{m^2}$ per day

Average Hours of Sunlight per Day:
1 peak sun hour = 1 $\frac{kWh}{m^2}$ sunlight per hour
5.32 peak sun hours = 5. 32 $\frac{kWh}{m^2}$ sunlight per hour

6 kWh system produces 24 kWh per day and 8,760 kWh per year (assuming 5 hour sun per day)

Difference in Fossil Fuel and Carbon Free Electricity Generated:
Natural Gas: $(7.74 \times 10^9)kWh$ - 8,760 kWh = 7,739,991,240 kWh
Petroleum: $(6.66 \times 10^9)kWh$ - 8,760 kWh = 6,659,991,240 kWh
Coal: $(3.06 \times 10^9)kWh$ - 8,760 kWh = 3,059,991,240 kWh

Carbon Emitted per Electricity Generated:
Natural Gas: 7,739,991,240 kWh · 0.91 $\frac{lb}{kWh}$ = 7,043,392,028.4 lbs
Petroleum: 6,659,991,240 kWh· 0.2.13 $\frac{lb}{kWh}$ = 14,185,781,341.2 lbs
Coal: 3,059,991,240 kWh· 2.23 $\frac{lb}{kWh}$ = 6,823,780,465.2 lbs

Natural Gas: 3,521,696.01 tons
Petroleum: 7,092,890.67 tons
Coal: 3,411,890.23 tons

Amount of Carbon Offset:
Natural Gas: 3,521,700 tons - 3,521,696.01 tons = 3.99 tons
Petroleum: 7,092,900 tons - 7,092,890.67 tons = 9.33 tons
Coal: 3,411,900 tons - 3,411,890.23 tons = 9.77 tons

Average Amount of Carbon Offset:
$\frac{3.99+9.33+9.77}{3}$ = 7.70 tons

Timeline to Offset Cohort Carbon Emissions:

Year	1	2	3	4	25	30
CO_2 Sequestered (tons)	7.70	15.4	23.1	30.8	192.5	231

Financial Assessment:

Single solar panel cost: $200-300 (avg. $250)
Roof mount system cost: $1,000 per panel
1 panel and mounting cost: $1,250
Price per student: $\frac{\$1,250}{23.5}$ = $53.20

Appendix G: Coral Reef Cost

- Given:
  - 150,000 cultivated and transplanted corals
  - 75,000 corals currently in nurseries
  - 23,000 corals saved

<u># of shallow coral reef systems in Puerto Rico</u>: 756 square kilometers (Kendall 2002)

<u># of submerged vegetation in Puerto Rico</u>: 721 square kilometers (Kendall 2002)

<u>Ratio of submerged vegetation to coral reefs in Puerto Rico:</u> $^{721}/_{756}$

<u>Carbon sequestration per seagrass bed in Puerto Rico</u>

One acre can sequester 740 lbs per year (Reynolds, 2018)

One acre = 0.00404686 square kilometers

$\frac{(740\ pounds)}{1\ acre} \cdot \frac{(0.0005\ tons)}{1\ pound} \cdot \frac{(1\ acre)}{0.00404686\ km^2} = 91.42891\ \frac{tons}{km^2}$ per year

<u>Time to grow 3D printed vs regular (according to SAM)</u>

$\frac{1\ year}{6\ hours} \cdot \frac{(24\ hours)}{1\ day} \cdot \frac{(365\ days)}{1\ year} = 1460$ times faster

Assuming they're intending to restore their 20 years of progress:

$$\frac{(20\ years)}{1460} \cdot \frac{(365\ days)}{1\ year} = 5\ days$$

It would take 5 days to re-do 20 years of growth for one coral

<u>Average side of SAM coral reef</u>

Types of coral reefs include: *Acropora palmata, A. cervicornis,* and *Orbicella Annularis*

Area ($A = \pi r^2$)

Acropora palmata area:

Radius: 0.75 m (Noyd et al., 2014)

$$\pi(0.75\ m)^2 = 1.76715\ m^2$$

Total: $23000 \cdot 1.76715\ m^2 = 40644.45\ m^2$

$$\frac{(40644.45\, m^2)}{1} \cdot \frac{(1\, km^2)}{1000000\, m^2} = 0.040644\, km^2$$

A. cervicornis area:

Radius: 6 ft (NOAA Fisheries, 2014)

$$\frac{(3\, feet)}{1} \cdot \frac{(1\, meter)}{3.28084\, feet} = 0.9144\, m$$

$$\pi(0.9144\, m)^2 = 2.62677\, m^2$$

Total: $23000 \cdot 2.62677\, m^2 = 60415.71\, m^2$

$$\frac{(60415.71\, m^2)}{1} \cdot \frac{(1\, km^2)}{1000000\, m^2} = 0.060416\, km^2$$

Orbicella Annularis area:

Radius: 1.5 mm (*Corals of the World*, n.d.)

$$\frac{(1.5\, mm)}{1} \cdot \frac{(1\, m)}{1000\, mm} = 0.0015\, m$$

$$\pi(0.0015\, m)^2 = 7.07 \cdot 10^{-6}\, m^2$$

Total: $23000 \cdot 7.07 \cdot 10^{-6}\, m^2 = 0.16261\, m^2$

$$\frac{(0.16261\, m^2)}{1} \cdot \frac{(1\, km^2)}{1000000\, m^2} = 1.6261 \cdot 10^{-7}\, km^2$$

Area of seagrass affected by SAM coral reefs

$$\frac{721}{756} \cdot 0.060416\, km^2 = 0.057619\, km^2$$

Carbon sequestration of SAM seagrass beds

$$91.42891\, \frac{tons}{km^2} \cdot 0.057619\, km^2 = 5.26804\, \frac{tons}{year}$$

Cost to offset through seagrass: $20/ton

$19.5\, tons \cdot 20\, \frac{dollars}{ton} = 390$ dollars total

19.5 tons would need to be sequestered for a 23.5-person cohort (Floria et al., 2021). The cost of offsetting carbon through seagrass is approximately $20 per ton, which would cost the cohort a total of $390 to offset.

Appendix H: PLN Reforestation Cost

Known:

$40 cost to grow tree from seed to maturity & monitoring for 5-years.

Each mature tree sequesters 25 kg of carbon per year.

Trees have 85% survival rate.

19.5 tons of CO_2 emitted for 19.5 students per round-trip to Puerto Rico

Carbon needs to be offset by 25 years.

Calculations:

$\frac{19.5\ tons}{25\ years}$ = 0.780 tons/year = 780 $\frac{kg}{year}$

So, to offset emissions in 25 years, each year 780kg need to be sequestered.

We know each tree sequesters up to 25kg of CO_2 per year.

Therefore $\frac{780}{25} = 31.2$ trees need to survive to offset 780kg per year.

Given an 85% survival rate, $\frac{31.2}{0.85} = 36.7 \cong 37$ trees need to be planted so ensure that 31.2 trees will survive.

To find cost, we multiply all the trees that need to be planted with the individual cost of each tree.

Cost = 40 * 37 = $1,480

Appendix I: Mangrove Cost

<u>Known:</u>

Cohort average: **23.5 students**

CO_2 average (per cohort): **19.5 tons**

Mangrove growth life: **25 years**

Mangrove sequestration (over growth life): **0.3 tons**

Mangrove seed cost (avg): **$10**

<u>Number of mangroves to offset 19.5 tons of CO_2</u>

Sequestration: **0.3 tons / 25 years = 0.012 tons per year**
to offset emissions: **19.5 tons / 0.3 tons = 65 mangroves**
With 35% survival rate: **(65/0.35) =~ 186 mangroves**

<u>Cost</u>

Cost to offset 19.5 tons: **186 mangroves*$10 = $1,860**
Per student: **$1,860/23.5 students =~ $80 per student**
Cost per ton: **$1,860 / 19.5 tons = $95.38**