2015-2016 ACRP UNIVERSITY DESIGN COMPETITION

Incorporating Renewable Power into Major U.S. Airports

Design Challenge: Airport Management and Planning

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1 Executive Summary

Airports account for 5% of the aviation sector's global carbon emissions per year (Alliance to Save Energy, 2012). Many airports around the world are already implementing innovative operational changes in order to decrease these emissions and increase aviation sustainability. Indiana's Indianapolis International Airport (KIND) is home to the largest airport-based solar panel field in the United States Hangar 25 in Burbank, California is the world's first "green" hangar, creating 110% of its own needed power.

Choosing the best alternative energy source and implementation method for each situation is crucial to the success of these projects. Our research develops a step-by-step procedure for airport project management teams to apply during the planning, implementation, and operation of renewable energy sources.

This is accomplished by using the following tools:

(1) A preset step-by-step procedure for design and implementation

(2) A design matrix to compare renewable technology.

(3) A risk assessment to identify risk associated with implementation of these designs.

(4) Relevant industry interactions to understand the limitation involved with the design.

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3 Problem Statement

Composing 2% of the world's CO_2 emissions, decreasing the amount of aviation energy while growing aviation services is a key focus point in aviation sustainability (The World Bank, 2012). The major attention given to decreasing energy usage is focused on reducing aircraft fuel consumption and emissions. Large reductions in energy consumption have already been made with domestic airlines now flying at 0.54 aircraft miles per gallon; an increase of more than forty percent increase since 2000 (Grose, 2013). These improvements are thanks to fuel developments, aircraft design changes, and policy implementations. Aircraft, however are not the only drain on resources in the aviation industry. Airports themselves account for 5% of the aviation sector's global carbon emissions per year (Alliance to Save Energy, 2012). From terminal building amenities to ground equipment to lighting, airports and their surrounding structures are consuming varying levels of energy 24/7. Terminal building heating and cooling systems account for fifty percent of airport energy usage alone, and are powered by electricity which can be created more cleanly, cheaply, and conscientiously (European Commission, 2014). If the same amount of focus and initiative applied to aircraft fuel emissions were also applied to ground-based energy usage, at airports, the savings would be substantial. In order for the aviation industry to remain sustainable, airport operational changes and innovations will need to be strategically implemented to reduce energy usage while providing a high level of service and safety. The technology needed to reduce airport energy consumption already exists. Wind, water, solar, and geothermal power sources all provide renewable energy, and many have already been implemented at airports around the world. The major implementation consideration is: How to select which technology is best for each airport?

4 Background

Aviation sustainability may be thought of as the initiatives taken by the aviation industry to increase efficiency in resource planning. It studies social coherence, environmental quality, and economic welfare and their impact on the terms of ‘sustainable development’ and ‘applied sustainability’ to increase the current and future endurance of aviation as a whole.

This definition is the basis of our research and design to support the implementation of renewable energy at major U.S. airports. The importance of aviation sustainability has become prominently recognized by multiple agencies around the world, including well-known aviation organizations such as the Federal Aviation Administration (FAA) and International Civil Aviation Organization (ICAO). These organizations have developed and publicized their own definitions as well as created programs like the FAA’s Noise Compatibility Program, Voluntary Airport Low Emissions Program, and Airport Improvement Program. Such programs are built around the pillars of sustainability included in each organization's definition. The FAA's programs follow their four pillars of sustainability: Environment, Economy, Community, and Operations. These initiatives have assisted in integrating the concept of sustainability into future airport plans as well as updates on current airports by providing valuable information on effective methods for implementing sustainable practices (Airport Sustainability, 2015).

5 Literature Review

The following sections review some of the information that has been found regarding airport energy usage, renewable energy sources, and airports already utilizing renewable energy systems effectively.

5.1 Airport Energy Usage

A large portion of energy usage at airports is electrical power used to light the facility as well as control its temperature. Unlike most facilities, major airports do not close except for rare occasion or an emergency. “Airports consume up to 180M kWh per year in electricity with terminals consuming about 60% of this. The remaining 40% is allocated to airfield lighting, hangars, parking decks, workshops and other ancillary buildings.” (Schluneger, 2014).

Another resource used abundantly by airports is fuel. In 2015, U.S. air carriers consumed 10,741.3 million gallons domestically. Even with fuel at one of its lowest average prices in the past decade, $1.82/gallon, the total cost was of $19,995.3 million (United States Department of Transportation, 2016). Airports also consume fuel while powering their Ground Support Equipment (GSE), which are made up of aircraft tugs, baggage carts, belt loaders, forklifts, ground power units, pick-up trucks, and service trucks, to name a few. An estimated 81 percent of these ground vehicles still operate using fossil fuels; 51 percent gasoline and 33 percent diesel, with the rest using a combination of liquefied petroleum gas (LPG) and electricity (Sierra Research, Inc., 1999).

5.2 Alternate Energy Sources

This section of the literature review discusses wind, water, and solar as possible sources of renewable energy at airports.

5.2.1 Wind Energy

Natural air movement or wind can be used as an energy source by converting the mechanical movement of wind turbines into electrical energy. In the United States wind resources are classified into density classes ranging from 1 (low power generation) to 7 (high power generation). Energy created from wind turbines is a renewable and non-polluting resource. Currently, the initial investment required for implementing wind farms is higher than other renewable energy sources; however this cost is reducing gradually. There are some environmental concerns with this type of system such as noise produced by the rotor blades and aesthetic concerns by people living in the region. Choosing the location of a group of wind turbines or wind farm can be problematic as well. Normally wind farms are placed in remote locations due to the obstruction and obstacle that they can create; because of this, there will be often some power loss in the transfer of the electrical energy from the turbine farm location to the final energy location (Wind Energy Development Programmatic EIS Information Center, n.d.).

Figure 1 The Brazos Wind Farm, Texas

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5.2.2 Energy from Water

Water can be used to create energy in several different ways. The three most prominent are hydroelectric power, wave power, and tidal power. All three involve using the natural movement of water to rotate an underwater turbine blade. The mechanical energy from the turbine blade is then converted into electrical energy. Other, less common forms of renewable water energy include: rain power, hydrogen fuel, seawater derived jet-fuel, and geothermal energy and fracking. Energy from water is not a feasible source of direct energy near an airport which is close to a water source and it would be more economical and effective to set up a power plant to power the airport as well as the neighboring community (Zielinski, 2014).

5.2.3 Solar Energy

Radiant light and heat from the sun can be collected and converted into another form of renewable energy. The potential growth and affordability of solar power makes it a promising alternative to conventional energy sources. In terms of the potential growth of solar energy in the United States, "The SunShot Vision Study provides the most comprehensive assessment to date of the potential for solar technologies to meet a significant share of electricity demand in the United States during the next several decades. The study explores a future in which the cost of solar technologies decreases by about 75% between 2010 and 2020" (U.S. Department of Energy, 2012). Solar energy technology is becoming more affordable than it has been and is used in a large-scale application like the solar field at the Indianapolis International airport.

5.3 Airports with alternate energy sources

Domestic and international airports utilizing renewable energy are explored

5.3.1 Indianapolis International Airport

Indianapolis International Airport (KIND) is an example of an airport that has embraced renewable energies. KIND has partnered with local companies and government to install a large solar field on the airport grounds. The solar fields are used in conjunction with the airport's Leadership in Energy & Environmental Design (LEED) certified buildings to promote renewable energy and reduce power consumption. The electric power produced by the solar field is sold to the local energy companies and residents as a completely renewable energy source. In this case, KIND does not directly benefit from the solar field because the panels are not directly connected to the airport's power grid. The power produced by the solar panels is fed directly into the grid for community use.

5.3.2 Bob Hope Airport, Hangar 25

Hangar 25 located at Bob Hope Airport (KBUR) in Burbank, California is another good example of an airport facility that has utilized alternative energy sources. The entire facility uses only solar power. Their solar panels are used to power lights, computers, office equipment, ceiling fans, and even charges the electric Ground Service Equipment (Berrios, 2014).

5.3.3 Seymour Airport, Ecuador

Seymour Airport (SEGS) was transformed into the Galapagos Ecological Airport in 2012, making it the first airport terminal to be powered exclusively on wind and solar energy. The Galapagos Islands are remote and are known for their vast biodiversity and now have an airport designed to back up their ecological preservation mindset (Velasco, 2015). The Galapagos Ecological Airport terminal is constructed entirely of recycled or environmentally responsible materials. Much of the recycled materials came from the original terminal building, including oil pipelines that are now used as support pillars for the front of the building. The airport's photovoltaic solar panels provide 35% of the power production, while four wind turbines provide the remaining 65%. The terminal building features automated mechanical shutters that open and close in order to control the building's heat. Even the building's water source is provided through the airport's own desalination plant, which converts local sea water to fresh water (Egere-Cooper, 2015).

5.3.4 Cochin International Airport, India

Cochin International Airport (VOCI) in India, under a Public-Private Partnership (PPP), has established itself to become the world’s first airport to be completely powered by solar power. Forty-five acres of land near Cochin's cargo complex have been used to host the solar panels producing 12 MWp (Mega Watt Peak) that is then consumed by the airport for its daily operations (Cochin International Airport Limited, n.d.). The Airports internal grid draws power generated from the solar panels and the surplus will go to the state’s electric grid, acting as a backup power generation system on days when power generation is low. The airport targets a generation of 200 MWh in the next 10 years by expanding this project. Additionally, in the next 6 years, the airport hopes to recover its capital expenditure or approximately $9.4 million by selling surplus power to the state (Koshy, 2015).

Figure 2 Solar Panels near Cargo bay at Cochin International Airport, India

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6 Problem Solving Approach

Our design team developed a step-by-step procedure for airport project management teams to apply during the planning, implementation, and operation of renewable energy sources. The suggested procedure contains legislative concerns, cost/benefit analyses, location selection, among other considerations. Analysis tools such as a Pugh matrix are used to compare renewable energy resources and aid in technology selection, as well as a risk assessment matrix used to help plan for and mitigate hazards before they become imminent. To demonstrate the procedure and its tools, a basic example scenario for a solar installation is included at various steps.

6.1 Matrix

Pugh matrices are widely used as a decision-making tool which compares options on a quantitative scale. The concepts being compared are ranked positively or negatively in each category in comparison to a null reference concept, or datum. The categories themselves can hold a certain weight or multiplier based on their level of importance in the decision. The metrics used to measure each category are determined on a case by case basis and ideally creates an accurate scale for each concept. After a rank for each category has been determined and properly weighted, the ranks are added together to create the final score for each concept. The concept with the highest final score is the best option based on the categories measures (iSixSigma, 2016).

Table 1 contains is the Pugh matrix developed by the team as a tool to assist airports in choosing the renewable energy source which best fits their specific situation. The datum in this case is the current system using fossil fuel power. The concepts being compared, which can be changed depending on the scenario, are wind, water, solar, and geothermal power. Ranks or weights given to each category will be on a scale of 0 to 3, with 0 as normal importance and 3 as very important. Scores given to concepts in each category are on a scale from –3 to +3, with –3 being much worse than the datum and +3 being a great improvement over the datum. The proposed metrics used to quantitatively measure each compared category are based on the suggestions made by the Sustainable Aviation Guidance Alliance (Sustainable Aviation Guideline Alliance (SAGA), n.d.). These metrics take airport size and level of operation into consideration by setting each category indicator next to either annual revenue or yearly passengers. This makes the output of each category proportional to the size and operation of the airport being considered.

		Best Sustainability Technology for (Insert Airport)				
	Total Score	0	0	0	0	0
	Options	Current Fossil Fuel Power	Wind Power	Solar Power	Geothermal Power	Water Power
Qualities of this Decision	Weight (multiplier)	Datum (Always null)	Option #1	Option #2	Option #3	Option #4
Energy Production Cost [Revenue($US)/Energy Cost($US)]	3	0	0	0	0	0
Initial Cost [Revenue ($US)/Initial cost($US)]	2	0	0	0	0	0
Upkeep Cost [Revenue ($US)/Upkeep cost($US)]	1	0	0	0	0	0
Decrease in Emission Output [Yearly number of enplainments/Emission decrease(GlobalWarmingPotentials)]	3	0	0	0	0	0

[Weight: 3 = very important | 2 = pretty important | 1 = important]

[Score: 3 = major improvement | 2 = medium improvement | 1 = small improvement | 0 = same as datum |
| -1 = slightly worse than datum | -2= worse than datum | -3 = much worse than datum]

Table 1 Pugh Matrix Tool

6.1.1 Example Scenario

The example implementation scenario presented is based on the use of solar energy. Research conducted on renewable energy sources used at airports has shown solar power to be a popular choice. A large reason for the popularity of solar energy is the ease of implementation of solar panel units both on open land and onto unused roof space on terminals and hangars. Discussions with Indianapolis Power and Light about KIND's solar field project explained that densely populated urban areas, where airports are normally located, are not well suited for wind and biomass power. Wind power can also be a considerable risk to aircraft and therefore are not as easy to implement safely. Pilots can also feel less comfortable when landing at an airport with wind turbines near the runway. Biomass is considered a risky approach to renewable energy as it is entirely dependent on the quality of the land and its current condition.

7 Safety Risk Assessment

0 – 5 = Low Risk 6 – 10 = Moderate Risk 11 – 15 = High Risk 16 – 25 = extremely high unacceptable risk		Severity of the potential injury/damage				
		Insignificant damage to Property, Equipment or Minor Injury 1	Non-Reportable Injury, minor loss of Process or slight damage to Property 2	Reportable Injury moderate loss of Process or limited damage to Property 3	Major Injury, Single Fatality critical loss of Process/damage to Property 4	Multiple Fatalities Catastrophic Loss of Business 5
Likelihood of the hazard happening	Almost Certain 5	5	10	15	20	25
	Will probably occur 4	4	8	12	16	20
	Possible occur 3	3	6	9	12	15
	Remote possibility 2	2	4	6	8	10
	Extremely Unlikely 1	1	2	3	4	5

Figure 3 Risk Assessment Sample Table (Wolf, 2015)

As recommended by the FAA in Advisory Circular 150/5200-37 (Federal Aviation Administration, 2007), a predictive risk assessment on the installation and use of the selected energy source at an airport would be completed using risk matrix depicted in Figure 3 (Federal Aviation Administration, 2010). This matrix is used under the assumption that, $Risk = Severity * Likelihood$. Each aspect of risk will be assigned a risk value based on the severity of the consequences that could occur because of the risk, as well as the likelihood that this situation will take place. Proper risk management is determined based on the assigned risk value: the higher the risk value, the more corrective and preventative action that will be required. (Ridal, Garvin, Chambers, & Travers, 2010) Table 3, in section 8.3, contains relevant risks, their determined risk value, and the respective actions needed for risk management for the solar energy installation example. A full list of risk considerations can be found in the FAA's Technical Guidance for Evaluating Selected Solar Technologies on Airports (Federal Aviation Administration, 2010).

8 Design Steps

Figure 4 is a suggested procedural flow chart depicting the developed step-by-step process to be followed by airport project managers all the way from the beginning of renewable energy project planning, through to the final post-implementation analysis.

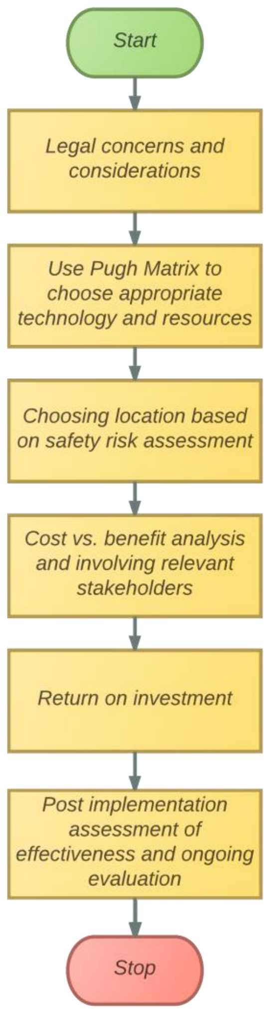

Figure 4 Design Steps for Renewable Energy implementation at U.S. Airports

The procedure includes: legal concerns and considerations, Pugh matrix for technology selection, location selection based on safety risk assessment, cost vs. benefit analysis and involving relevant stakeholders, return on investment, and post-implementation assessment.

8.1 Legal Concerns and Considerations

According to the Public Utility Regulatory Policies Act of 1978 an electric utility is defined as, “any person. State agency, or Federal agency, which sells electric energy” (Public Utility Regulatory Policies Act of 1978, 1978).

With respect to legislative changes to increase future renewable energy implementation projects, the following has been proposed by the team:

The Federal law make an amendment to the "Public Utility Regulatory Policies Act of 1978" to allow an airport to implement a renewable energy source if:

(1) A viable source of energy exists

(2) A renewable energy technology be could feasibly installed

(3) The airport is financially able to see the project through

(4) The chosen renewable energy source has a reasonable return on investment

(5) The long-term gain goes towards airport development and public welfare.

As long as the plans for construction of renewable energy do not conflict with the Public Utility Regulatory Policies Act of 1978, the Airport does not sell electric energy, and only provides the required energy to power its own facilities, the Airport can move forward.

Further considerations are the specific obligations when using solar energy systems on federally obligated airports. According to Kandt and Romero, “On Oct. 23, 2013, a notice was posted by the FAA on the Federal Register, titled Interim Policy, FAA Review of Solar Energy System Projects on Federally Obligated Airports. The notice states that in 2012, the FAA partnered with the U.S. Department of Energy (DOE) ‘to establish a standard for measuring glint and glare, and clear thresholds for when glint and glare would impact aviation safety. The standards that this working group developed are set forth in this notice.’ The notice also reads: The FAA is adopting an interim policy because it is in the public interest to enhance safety by clarifying and adding standards for measuring ocular impact of proposed solar energy systems. FAA will consider comments and make appropriate modifications before issuing a final policy in a future Federal Register Notice. The policy applies to any proposed solar energy system that has not received unconditional airport layout plan (ALP) approval or a “no objection” from the FAA on a filed 7460-1, Notice of Proposed Construction or Alteration. The FAA expects to continue to update these policies and procedures as part of an iterative process as new information and technologies become available” (Kandt & Romero, 2014, p. 6).

8.2 Using the Pugh Matrix to choose appropriate technology and resources

The next step in our designed implementation process involves the use of the Pugh matrix as mentioned in the problem solving approach. The categories in the Pugh matrix will be calculated based on surveys and research into local renewable resources. The National Renewable Energy Laboratory (NREL) provides access to tools such as Photovoltaic Resource maps and output calculators specifically for solar implementation (Alliance for Sustainable Energy, LLC, 2015). NREL's ‘PVWatts calculator’ can be used by anyone from homeowners to commercial solar power companies to easily create solar system production predictions by estimating the energy production and cost of energy of photovoltaic (PV) energy systems. PVWatts takes into consideration the anticipated system location, type, size, tilt, and even area weather patterns, to give a comprehensive month-by-month energy production estimation (Alliance for Sustainable Energy, LLC, n.d.).

		Best Sustainability Technology for (Insert Airport)				
	Total Score	0	0	5	-6	0
	Options	Current Fossil Fuel Power	Wind Power	Solar Power	Geothermal Power	Water Power
Qualities of this Decision	Weight (multiplier)	Datum (Always null)	Option #1	Option #2	Option #3	Option #4
Energy Production Cost [Revenue($US)/Energy Cost($US)]	3	0	-1	-1	-2	-2
Initial Cost [Revenue ($US)/Initial cost($US)]	2	0	-2	-1	-3	-2
Upkeep Cost [Revenue ($US)/Upkeep cost($US)]	1	0	-2	1	-3	1
Decrease in Emission Output [Yearly number of enplainments/Emission decrease(GlobalWarmingPotentials)]	3	0	3	3	3	3

[Weight: 3 = very important | 2 = pretty important | 1 = important]

[Score: 3 = major improvement | 2 = medium improvement | 1 = small improvement | 0 = same as datum |
| -1 = slightly worse than datum | -2 = worse than datum | -3 = much worse than datum]

Table 2 Example complete Pugh matrix for solar panels

8.3 Choosing location at Airport based on safety risk assessment

By incorporating the safety risk assessment shown in table 3 this section to explore the possible dangers involved with a renewable energy, the location of a specific resource can be better chosen in order to reduce the chance of major accidents before they happen. Important factors to consider with all forms of electricity (renewable or not) are high voltage power lines and the possibility of electrical fires. Maintenance accidents are a possibility as well. In terms of solar energy, a major concern is glare or glint produced by the reflection of the sun off the solar panels. Studies, specifically by the FAA, have already been conducted on this issue and it can be remedied by positioning the panels in a way that would not affect pilots while on landing or takeoff.

Risk	Severity	Likelihood	Risk Value	Risk Management Actions
Damage to Existing Environment	1	2	2	Proper initial research into airport surrounding environment
Cause a Fire on Rooftop	4	1	4	Fire suppression system installed
Cause a Fire in Field	2	3	6	Proper airport fire department training
Glare Causing Aircraft to Crash	5	1	5	Ensure installation of solar panels in the right place
Structural Damage to Terminal Roof	2	1	2	Structural Survey of the building
Injuries During Installation on Rooftop	4	2	8	Following Safety rules set by the contractor
Injuries During Installation in Field	2	1	2	Following Safety rules set by the contractor
Injuries During Maintenance on Rooftop	4	1	4	Following Safety rules set by the maintenance provider
Injuries During Maintenance in Field	2	1	1	Following Safety rules set by the maintenance provider
Communication System Interference	1	1	2	N/A

Table 3 Example Risk Assessment

This is accomplished by informing airport planners to stay away from concentrated solar power systems because they focus the energy of the sun by reflecting it into a central location to produce heat that then turns water into steam and drives turbines for power generation (M. Harris, 2010).

8.4 Cost vs. benefit analysis and involving relevant stakeholders

After choosing the renewable energy technology to be implemented, a cost vs. benefit analysis of the project would be completed by project managers and relevant stakeholders. Cost-benefit analysis compiles all costs and return in order to prove the project worthy of the stakeholder's participation and investment (Watkins, n.d.). The following is a sample of the costs involved with solar energy project.

According to Kandt and Romero, "The cost of PV-generated electricity has dropped 15- to 20-fold in the last 40 years. Grid connected PV systems sell for between 20¢ per kilowatt-hour (kWh) and 32¢/kWh in 2011, or about $5 per (peak) watt (Wp) to $8/Wp, including support structures and power conditioning equipment. Peak-watt is the power rating that a PV system measures under standard test conditions, and under which a panel could be expected to deliver its peak output. An NREL study of 7,074 PV systems installed in 2007 reported a range of total capital costs averaging $8.32/Wp for small systems less than 10 kilowatts (kW) and $6.87/Wp for large systems greater than 100 kW; costs have dropped further since then. Costs reported for PV projects are decreasing rapidly, so a local solar installer may be the best source of current cost information. Operation and maintenance costs are reported at $0.008/kWh produced, or at 0.17% of capital cost without tracking and 0.35% with tracking. The systems are very reliable and last 20 years or longer. Siting PV systems at airports costs marginally more than systems sited in other locations. Additional costs could be incurred for project planning and coordination with FAA and related glare/glint studies." (A. Kandt, 2014, pp. 3,4).

8.5 Return on Investment

Implementation of renewable energy at U.S. airports can be achieved through collaboration with energy utilities and stakeholders willing to invest in a renewable project. This direction often leads to a healthy partnership and provides local stakeholders with access to renewable energy. During implementation, it is important to consider availability of sunlight in a specific geographic location as well as availability of free surface area.

For example, according to Kandt and Romero, “A variety of financing mechanisms exist to help facilitate the installation of PV systems. Third-party financing, in which an entity finances, owns, and operates the system, is a mechanism for installing a PV system for little or no capital and is most often utilized for commercial- or utility scale systems. These mechanisms include power purchase agreements, energy savings performance contracts, and utility energy services contracts. In addition, the FAA operates the Voluntary Airport Low Emissions (VALE) program, which helps airport sponsors meet their state-related air quality responsibilities under the Clean Air Act. Through VALE, airport sponsors can be eligible for funds to help support the procurement and installation of PV systems. The Manchester-Boston Regional Airport (MHT) project, in the city of Manchester, New Hampshire, benefited from VALE funds that covered 95% of PV system costs.” (A. Kandt, 2014).

A return on investment of capital (ROIC) strategy is a must for every project before it even begins. It gives a sense of how well an investor or stakeholder plans to use the resources at hand and cover up the initial capital which in a project like setting up a solar field can be significantly higher. Taking the example of Cochin International Airport where the airport itself was a major stakeholder in the project and it uses the electricity generated by the solar field for its own operations thus saving up on energy bills and estimating a complete return on investment of its initial capital within 6 years. In this case, after 6 years, the revenue thus saved by reduced energy bills could be used to improve existing facilities and technologies used by the airport and further invest in ways to indirectly save natural resources. Following Legal concerns and considerations covered in Section 8.1 of this design, if an airport is allowed to be a stake holder and invest in a such a project, the need for involving external financers reduces and drives implementation at a faster rate.

The ROIC for such a project will thus be a ratio calculated as:

$$Return\ on\ Invested\ Capital = \frac{Cumulative\ net\ annual\ gains\ from\ investment - Total\ Cost\ of\ Investment}{Total\ Cost\ of\ investment}$$

When this ratio reaches a non-negative value, the initial capital investment has been covered and the asset (solar field) is now able to generate revenue/savings. Having a robust return on investment strategy which gives a good snapshot of profitability over the years would also decrease stakeholder liability and attract more investments from the public as well as private sector. This ROIC is not discounted with a time-value of money.

8.6 Post-Implementation Assessment of effectiveness and ongoing evaluation

Monitoring sustainable development and its impact requires identification of operational indicators that provide measurable information on the three pillars of sustainability as defined by Milan (i.e. economic, environmental and social conditions) (Janić, 2007) (Böhringer & Jochem, 2007).

In 1993, Pearce and Atkinson (Pearce & Atkinson , 1993) put forward an index based on the Hicksian income concept (Hamilton, Atkinson, & Pearce, 1997). In 1997, Hartwick later enhanced this concept by using the Hartwick rule, which defines the level of re-investment from resource rents that are reinvested to assure that the societal stock will never decline (Hartwick, 1977). The societal capital stock consists of produced capital, natural capital (resources etc.) as well as human capital (knowledge, skills etc.) where all values are monetized, such that aggregation is again achieved by simply adding up. The Genuine Savings is an indicator that determines that the project is on or off a sustainable development course and is thus an indicator of weak SD. The team adopted a neoclassical stance to assume the possibility between environmental and capital gains in the sense described by Solow (Solow, 1986). We then decide that the project is sustainable and is forecasted to be sustainable if it saves more than the combined depreciation of these two forms of capital.

8.7 Technical Aspects of Design

Choosing a renewable energy source may be a difficult challenge for airport planners. The National Renewable Energy Laboratory (NREL) is an excellent resource for research on this matter. The NREL provides many reports and images that are available to help airport planners visualize the possible energy output of a certain renewable resource near their area.

Introduction of a small power plant on Airport grounds may be a safety concern for travelers and employees at the airport if there are any problems with the renewable grid. Safety should be assessed and addressed prior to, during and after installation.

Glare/glint is a consideration for placement of different types of solar panels. Placement of solar panels on rooftops, which may create the need for an increase in structural supports at the terminal or hangar. This would be an increased cost and many airport authorities may not want to implement solar because of this factor alone. Therefore, it may be more logical to implement solar energy during a renovation of a certain structure and proactively add solar panels to the airports as they are expanded or updated over time.

9 Industry Interactions

9.1 List of companies contacted

9.1.1 Indianapolis Solar Power Companies: (Contact links Hyperlinked)

1. Land Owner - Indianapolis Airport Authority
    a. IAA Contacts: Jeff Dutton
2. Telamon corporation
    a. Media Contact: Alexa Amatulli

3. Johnson Melloh Solutions
4. Utility - Indianapolis Power and Light Company
5. Phase I Owner - General Energy Solutions
6. Phase IIA Owner - WGL Energy
7. Education Partner - Ball State University
    a. c/o The Center for Energy Research/Education/Service (CERES)
        i. Architecture Building (AB), Room 018
        Ball State University
        Muncie, IN 47306
        Phone: 765-285-1135; Email: cote@bsu.edu
8. Contractor - Cenergy Power
9. Panel Manufacturer - Sharp
10. Inverter manufacturer - Solectrica Renewables

9.1.2 Chicago O'Hare sustainability projects:

1. O'Hare Sustainability
2. Contact Us Page

9.1.3 Hangar 25, Bob Hope Airport, Burbank, California:

1. Designer of Hangar 25 - J.R. Miller and Associates - Email: jrma@jrma.com
2. Shangri-la Construction

9.2 Questions asked to Industry

1. What direct role did your company (organization) play in implementation of (solar panels, infrastructure energy efficiency, power distribution, and financial responsibility) at (specific) airport?
2. How much energy does the airport save annually using this system?
3. What is the return on investment for your organization? / How long do you expect it to take for return on investment?
4. What happens to additional energy if any has been left over? Is it sent back to the grid? Other uses?
5. Is everybody pleased with the outcome of the project? Have there been any complaints with regards to the implementation and use of the project?
6. How much energy goes to local use and how much is used by IND?
7. Did you have to make major changes to infrastructure in order to utilize solar power?
8. How involved were you in the solar field project?
9. Were you a part of the original investment?
10. Did the solar farm create any new jobs for your company?
11. Are there any other safety risks to employees using solar?
12. Would it be alright to contact you again if we have any more questions?
13. Are you okay with being cited in our paper?

9.3 Responses from Industry

9.3.1 Indianapolis Power and Light Company (IPL)

We were able to have a phone call with John Haselden, the Principal Engineer at IPL. He was a very helpful source in our research. We were not able to follow our line of questioning exactly, but Mr. Haselden provided us with even more information than we requested, which was extremely important for implementation of our design.

1. What direct role did your company (organization) play in implementation of (solar panels, infrastructure energy efficiency, power distribution, and financial responsibility) at (specific) airport?

   Technical Side:

   - Interconnection agreement
   - Keep up power quality
   - Automatic reclosers
   - Additional equipment needed for distribution

   Financial Side:

   - There needed to be an off taker of the energy produced by the Solar Farm (IPL)
   - Contract Term and Price
   - Feed in tariff
   - Offered attractive enough pricing
   - Attracted investors (without distributor there is no chance of solar farm being created)
   - Regulated the utility only (power produced)
   - 1978 Federal Energy Administration Rule

2. How much energy does the airport save annually using this system?

   Power is purchased by IPL and connected directly into IPL network.

   IND does not necessarily get the energy. IND gets a separate bill entirely.

3. What is the return on investment for your organization? / How long do you expect it to take for return on investment?

   No direct answer, but IPL is involved in a 3-year pilot contract for the project and a 15-year purchase contract for the energy produced by the Solar Farm.

4. What happens to additional energy if any has been left over? Is it sent back to the grid? Other uses?

   All energy is sent to the grid.

5. Is everybody pleased with the outcome of the project? Have there been any complaints with regards to the implementation and use of the project?

   Very pleased with the project. We have 95 MW connected right now to the grid.

6. How involved were you in the solar field project?

   Solar field project would not have gone forward without IPL involvement.

7. Did the solar farm create any new jobs for your company?

   Only one new job was created, and that was a contract position involving study/ coordination with other companies working on the project.

8. Would it be alright to contact you again if we have any more questions?

   Yes

9. Are you okay with being cited in our paper?

   Yes

At this point the line of questioning turned into more of a conversation as Mr. Haselden gave us a description of IPL's involvement and current role in the project, as well as why they had to be a part of the project.

- The contract with IPL was completed by March 30, 2012
- Indianapolis is a poor wind resource and biomass resource
- Rates are normally 8 cents per kwh and this project drives the cost up to 20 cents per kwh
- There is a 1.5% price increase for all local customers
- The energy sold does not quite reach 1% of IPL sales
- We discussed a Renewable portfolio standard - a required amount of renewable energy that must be produced by power companies in some states at 1% or 10% of total power produced. The possibility of this legislation drove IPL to be a part of this project.
- A very large piece of incentive for company's finances is driven by taxes. A 30% federal investment tax credit is given to companies involved in these sort of projects, but not to Airports. Often doesn't make sense for an airport to create a solar farm because of the lack of tax benefits.
- Net metering is done by the utility company, not the other companies involved.

9.3.2 Telamon Corporation

Alexa Amatulli was contacted at Telamon Corporation to help us with our research. She is a Marketing Lead that is referenced on an IND Solar Farm press release. She replied to our requests extremely quickly and was very easy to communicate with.

1. What direct role did your company (organization) play in implementation of (solar panels, infrastructure energy efficiency, power distribution, and financial responsibility) at (specific) airport?

   Telamon served as the co-developer, so we managed the project and finalization of the deal by making sure all parties were on the same page (i.e. – City of Indianapolis, Federal Aviation Administration, Indianapolis Power & Light, airport, & the engineering, procurement, and Construction Company).

2. How much energy does the airport save annually using this system.

   The airport indirectly utilizes the energy produced by the solar farm. The solar farm is not specifically for the airport's use – all of the energy produced feeds into the Indianapolis Power & Light power grid and is distributed to homes throughout Marion County. The airport is able to garner non-airline generated revenue with the IND Solar Farm through a 15-year land lease agreement with the owners. GES (General Energy Systems) owns Phase I, Washington Gas & Electric owns Phase II, and Johnson-Melloh Solutions owns Phase III.

3. What is the return on investment for your organization? / How long do you expect it to take for return on investment?

We already received our return because we sold the solar farms to the outside parties mentioned above.

4. What happens to additional energy if any has been left over? Is it sent back to the grid? Other uses?

   All of the power is sent to the grid.

5. Is everybody pleased with the outcome of the project? Have there been any complaints with regards to the implementation and use of the project?

   Yes – everyone is pleased with the outcome of the project. We have not received any complaints regarding the project. One of the major challenges throughout the project was having to work with the Federal Aviation Administration to ensure that there weren't any glare issues for incoming and outgoing aircraft, however, the tower at IND has never received any complaints in terms of glare issues.

6. How much energy goes to local use and how much is used by IND?

   All of the energy is used by the local consumer – the airport indirectly uses the energy as mentioned above. The solar farm creates 20 MW AC of energy, which means it has the capacity to annually produce 36.1 million kilowatt hours of electric energy, which is the equivalent of powering approximately 3,650 average-sized American homes.

7. Did you have to make major changes to infrastructure in order to utilize solar power?

   Are you talking about the airport specifically? If so, no, the solar farm was placed on land that couldn't be used for anything else due to height restrictions for incoming & outgoing aircraft.

8. How involved were you in the solar field project?

   As the co-developer, Telamon was extremely involved in the day-to-day operations during pre-development and construction.

9. Were you a part of the original investment?

   Yes – the solar farm is all privately funded.

10. Did the solar farm create any new jobs for your company?

    No – it did create new jobs for the engineering, procurement, and construction firm though --- their name was Cenergy.

11. Are there any other safety risks to employees using solar?

    I don’t think they are any safety risks to employees using solar. Of course during the construction phase, just need to ensure that proper handling is utilized with the solar panels.

12. Would it be alright to contact you again if we have any more questions?

    Sure

13. Are you okay with being cited in our paper?

    Sure

9.3.3 Ball State University

Dr. Robert Koester from Ball State University was contacted to help us answer some of our questions. He is a Professor of Architecture, Director at the Center for Energy Research/Education/Service, Chair for the Council on the Environment, and a University Liaison for ACUPCC, IGCN, ISCN, STARS, USGBC. Although Ball State University's involvement was limited to research, Dr. Koester supplied us with very helpful information.

1. What direct role did your company (organization) play in implementation of (solar panels, infrastructure energy efficiency, power distribution, and financial responsibility) at (specific) airport?

   We are the Education Partner for the project and continue to advocate for the public understanding of the technology and its social, economic and environmental impact. We did not play a role in design and/or implementation.

2. How much energy does the airport save annually using this system?

   The website provides a real time display of that production.

   Complete Project information is available here: http://indsolarfarm.com/

   See real-time energy data from the IND Solar Farm installation.

3. What is the return on investment for your organization? / How long do you expect it to take for return on investment?

   Check with Telamon and Johnson Melloh for these numbers.

4. What happens to additional energy if any has been left over? Is it sent back to the grid? Other uses?

   Yes it is exported to the grid.

5. Is everybody pleased with the outcome of the project? Have there been any complaints with regards to the implementation and use of the project?

   General feedback has all been positive.

6. How much energy goes to local use and how much is used by IND?

   Check with Telemon, Johnson Melloh and the Indianapolis Airport Authority

7. Did you have to make major changes to infrastructure in order to utilize solar power?

   The technical hookups were engineered by Johnson Melloh.

8. How involved were you in the solar field project?

   As Education Partner we have continued to develop web based and mobile learning based information/instructional packages; available here:

9. Were you a part of the original investment?

   No.

10. Did the solar farm create any new jobs for your company?

    Not employment per se, but yes, new educational opportunities for our students in the development of the web content cited above.

11. Are there any other safety risks to employees using solar?

    Check with Johnson Melloh.

12. Would it be alright to contact you again if we have any more questions?

    Sure.

13. Are you okay with being cited in our paper?

    Sure.

10 Projected Impact of Project and Conclusion

The ability to systematically and more easily analyze the possibility to incorporate a renewable energy source at airport facilities, as seen when following the proposed implementation method, has far more positive than negative impacts on the pillars of aviation sustainability, as well as positive secondary commercial potential.

10.1.1 Commercial Potential

Though this design is not a commercial product, a large benefit to the proposed implementation process is that it requires no additional monetary investment from the organization using it. Using this method, a reusable power project can be strategically planned with estimates of cost and risk prior to breaking ground on the technology installation.

10.1.2 Operational Impact

The designed procedure will allow renewable energy sources to be installed at airport with more precision and efficiency. It will cut down on the negative operational impacts that normally follow system change by enabling airport leaders to anticipate any problem areas or challenges prior to installation of the renewable energy source such as flight, air traffic control, or ground operations interference. Another major consideration to operational impact are safety hazards produced by renewable energy. Wind power has the obvious danger of large spinning turbines, which cannot be situated near the airport because of the chance of collisions. For solar panels, as long as the glare/glint studies done at the airport show that there are no danger to existing routes and the approach/take-off of an aircraft, there should be no operational impact.

10.1.3 Economic Impact

With the increased ease of renewable energy source installation and usage many more airports will have the ability to undertake these projects, which will create business opportunities for renewable energy equipment manufacturer's, energy infrastructure installation companies, and maintenance technicians to keep the system in order after installation is complete. The airport will also likely have new need for airport planners during the preparation process. In direct relation to the solar panel example followed throughout the project, even small solar panel installations have been found to produce a significant amount of full time positions (The Centre for Local Economic Strategies (CLES), 2012).

The airports themselves also see economic gain from renewable energy systems. Not only do the new systems reduce energy costs, but research also shows that on average those who contribute to renewable energy sources see a $2.90 return for every $1 invested. Renewable energy projects also provide skill development for current management staff and employees in the supply chain (The Centre for Local Economic Strategies (CLES), 2012).

10.1.4 Environmental Impact

"All energy sources have some impact on our environment. Fossil fuels — coal, oil, and natural gas — do substantially more harm than renewable energy sources by most measures, including air and water pollution, damage to public health, wildlife and habitat loss, water use, land use, and global warming emissions" (Union of Concerned Scientists, 2016).

The expected increase in renewable energy installation with the use of this planning process has the obvious positive environmental impact of not burning as many fossil fuels in order to create energy, which can instead be created cleanly. Regarding solar energy sources, a typical 2,000kWp system can save over 1 ton of CO_2 per year (The Centre for Local Economic Strategies (CLES), 2012). Any negative impacts due to the placement of energy systems in natural habitats will be considered on a case-by-case basis depending on the location and type of system.

10.1.5 Social Impact

The ability to implement a source of renewable energy gives airports the opportunity to receive the positive social reaction that often follows such projects. In general, renewable energy sources are perceived as positive and likeable projects which surrounding communities feel good about seeing and enjoy being a part of. One negative social impact noted on renewable energies is the lack of aesthetic appeal depending on the renewable energy source, although solar panels are often enjoyed aesthetically. Another social issue may be the initial cost of the renewable energy resource to the surrounding energy consuming community. Currently solar energy may cost a consumer $0.08 per kwh, while solar energy may cost a consumer $0.20 per kwh (Kandt & Romero, 2014, p. 3), but as renewable technologies become more common place and are manufactured and installed at a cheaper cost, the price should drop over time.

10.2 Conclusion

Airports account for 5% of the aviation sector's global carbon emissions per year (Alliance to Save Energy, 2012). Many airports around the world are already implementing innovative operational changes in order to lower these emissions and increase aviation sustainability. By using the recommended process, the selection, placement, installation, and long-term use of renewable energy sources on airports will be more efficient and effective. As the implemented renewable energy sources increase surrounding economic growth, operational efficiency, community perception and reduce environmental impacts, aviation sustainability as a whole is increased.

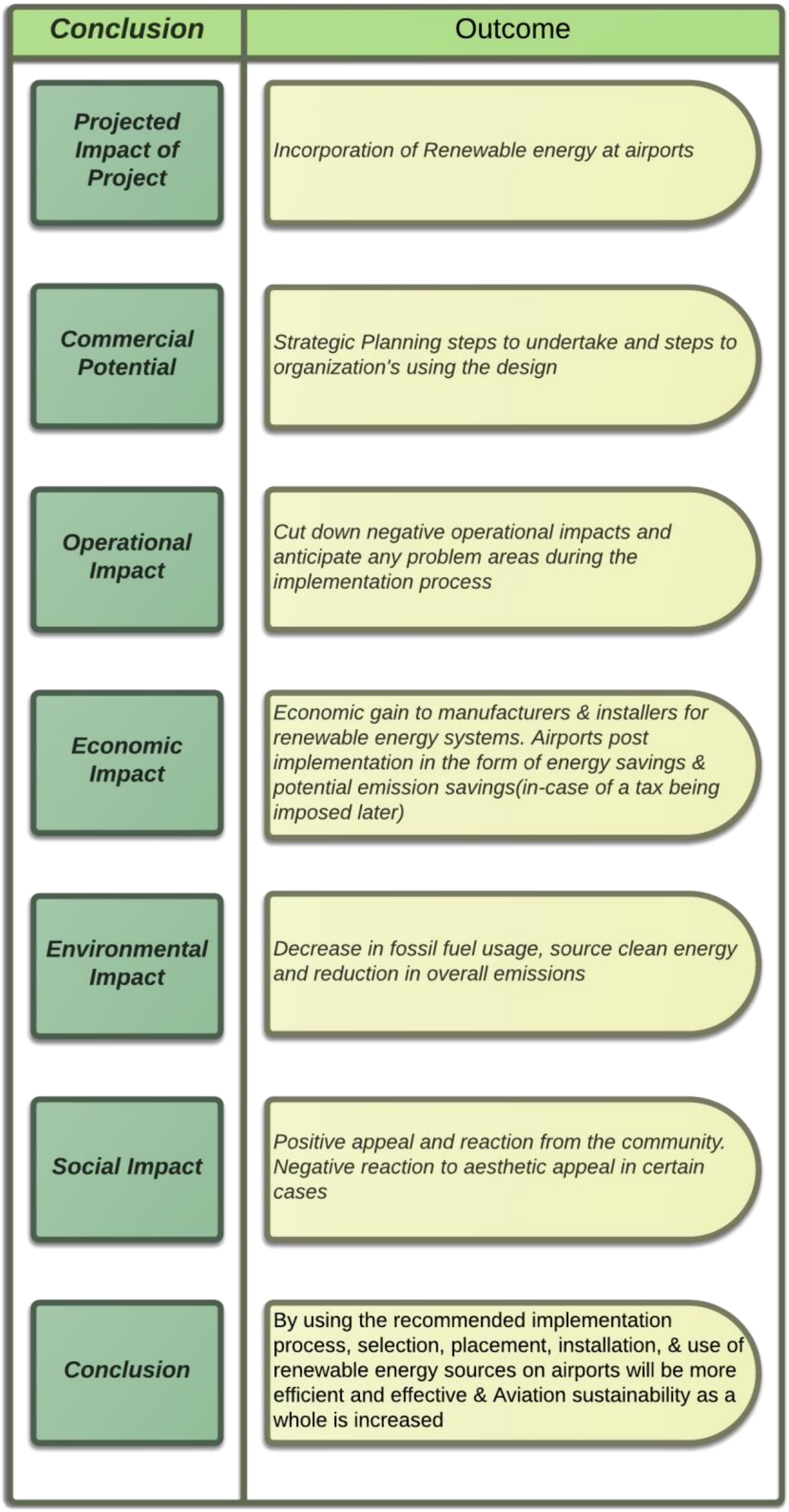

Figure 5 Conclusion

11 Appendix A: List of complete contact information

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12 Appendix B: Description of the University

About the University:

Purdue University, the land, sea grant University in Indiana, is a vast laboratory for discovery. Purdue is a public university known not only for science, technology, engineering, and math programs, but also for our imagination, ingenuity, and innovation. It's a place where those who seek an education come to make their ideas real — especially when those transformative discoveries lead to scientific, technological, social, or humanitarian impact.

Founded in 1869 in West Lafayette, Indiana, the university proudly serves its state as well as the nation and the world. Academically, Purdue's role as a major research institution is supported by top-ranking disciplines in pharmacy, business, engineering, and agriculture. More than 39,000 students are enrolled here. All 50 states and 130 countries are represented. Add about 950 student organizations and Big Ten Boilermaker athletics, and you get a college atmosphere that's without rival.

School of Aviation and Transportation Technology Mission Statement:

The mission of the School of Aviation and Transportation Technology is to support the missions of the Purdue Polytechnic Institute and Purdue University in serving the citizens of the State of Indiana, the nation, and the world, through learning, scholarship (discovery), and engagement activities that extend aviation technology education, aviation technology discovery efforts and technology transfer, and implementation (application) of emerging technology for the global aviation industry. Student learning is advanced by discovery and engagement activities that enhance economic and social development.

13 Appendix C: Description of Non University Partners involved in the Project

N/A

15 Appendix E: Evaluation of the educational experience provided by the project

15.1 Students

The team members worked together to come up with common answers to the questions stated below:

1. Did the Airport Cooperative Research Program (ACRP) University Design Competition for Addressing Airports Needs provide a meaningful learning experience for you? Why or why not?

→Yes, the team agreed that the competition provided a meaningful learning experience since it involved interacting with industry representatives and allowed us to apply knowledge learned in class with respect to aviation sustainability initiatives.

2. What challenges did you and/or your team encounter in undertaking the competition? How did you overcome them?

→One of the largest challenges that we faced was reaching out to industry experts on the matter and receiving replies from them. Fortunately, the industry contacts that did reply to the questions provided us with a substantial amount of information.

Another challenge that the team faced was legislation that was brought to our attention by one of the industry contacts, which led us into factoring legislative changes in our design, and slightly change the direction of our project.

3. Describe the process you or your team used for developing your hypothesis.

→From our studies in sustainability, we noticed a lack of renewable energy projects at U.S. airports and wanted to tackle one of the issues faced by creating a design that may help airport planners to think about implementing renewable energy for their facilities.

4. Was participation by industry in the project appropriate, meaningful and useful? Why or why not?

→Yes, without the knowledge that industry contacts shared with us, our project would have been incomplete. Certain components would not have been factored into our design without the additional information provided by Indianapolis Power and Light regarding renewable energy legislation.

5. What did you learn? Did this project help you with skills and knowledge you need to be successful for entry in the workforce or to pursue further study? Why or why not?

→The team agrees that we learned a great deal about sustainable energy in general as well as the difficulties of the implementation process that airport planners face for such a large project at an airport. Additionally, the topic we chose is forecast to be the future for airports as the FAA and other government agencies push renewable energy, therefore this knowledge gives us a competitive edge for entry into the workforce.

15.2 Faculty

1. Describe the value of the educational experience for your student(s) participating in this competition submission.

   →The educational value for the students is immeasurable. The process of reading the guidelines for the design challenges, generating ideas, developing the ideas into a design, and preparing the technical report helped the students take a vague idea of a problem existing at airports into a designed solution. The student team completed this project as their required course project for an aviation sustainability graduate class that I teach. The team is comprised of three graduate students that come from different educational backgrounds.

Two of the graduate students are from the Purdue BS in Aeronautical Engineering Technology and the third graduated with a BS in Aeronautical Engineering in India. The team formed quickly, and then learned what the strengths are of each team member.

I am particularly proud of how they came together as a team to develop a creative approach to address aviation sustainability at airports by developing a process for airports to use to evaluate the incorporation of renewable energy generation on airport property. They had to use all of their existing knowledge and skills, and figure out what new knowledge would be required to address a need in airport management and planning. Members of the team contacted experts involved in the Indianapolis International Airport's solar energy arrays. For instance, when speaking with the Indianapolis Power and Light engineer, the team found out that there was a federal law that applied to power generation at an airport. I helped them find the law, and then they read the law and asked experts questions to understand more about how this law applied in this particular situation. Cold-calling these experts was an experience that will help them throughout their future careers. Overall, this educational experience was beneficial to the team, and to me because I can see their growth and because I learned a lot from them about renewable power at airports in our 'backyard' in Indianapolis and all over the world.

2. Was the learning experience appropriate to the course level or context in which the competition was undertaken?

   →Yes, this learning experience was appropriate for the course level. This is a one semester course that starts in January. The team had to decide the challenge and their approach very early.

3. What challenges did the students face and overcome?

   First, these students have had little education in airport operations or management as undergraduate students. The students had to learn many details related to placing solar arrays on airport property such as safety of array placement and mitigation of impact to pilots due to glare. They pored over airport management texts, regulations and websites.The additional challenge for the team was to address aviation sustainability specifically in the design and report. This is not a requirement of the ACRP competition, but it is a requirement for the course. Each student developed their own definition of aviation sustainability based on extensive reading and study. The ACRP, ICAO, FAA and IATA reports on aviation sustainability were used in addition to company websites and academic texts and articles. They had to overcome the lack of a unified definition in the literature and develop their own definition that had meaning to them. Then, as a project team, they developed a consensus definition of aviation sustainability for this project. I am very pleased that their definition is thoughtful, well-grounded, and innovative.

4. Would you use this competition as an educational vehicle in the future? Why or why not?

   →In the future, I do plan to use this competition as an educational vehicle. Most of the time in my graduate classes, the students prepare a technical report or paper. The difference in this competition is that the fact that there is a competition, that there are numerous design challenges and project ideas, and that the submission will be judged by aviation experts is very inspiring to the team.

5. Are there changes to the competition that you would suggest for future years?

   →Please keep doing this competition. I realize that it must take countless hours of dedication from dozens of people to read and judge these entries. I do not have any changes at this time.

16 Appendix F: Reference List

A. Kandt, R. R. (2014). *Implementing Solar Technologies at Airports.* U.S. Department of Energy. Golden: National Renewable Energy Laboratory.

Airport Sustainability. (2015, October 5). Retrieved from FAA: http://www.faa.gov/airports/environmental/sustainability/

Alliance for Sustainable Energy, LLC. (2015, Februrary 2). *Solar Maps*. Retrieved from NREL - National Renewable Energy Laboratory: http://www.nrel.gov/gis/solar.html

Alliance for Sustainable Energy, LLC. (n.d.). *NREL's PVWatts® Calculator*. Retrieved from NREL - National Renewable Energy Laboratory: http://pvwatts.nrel.gov/index.php

Alliance to Save Energy. (2012, November 1). *Air Travel And Efficiency: How U.S. Airports Are Saving Energy*. Retrieved from Alliance to Save Energy: https://www.ase.org/resources/air-travel-and-efficiency-how-us-airports-are-saving-energy

Berrios, J. (2014). World's first 'green' aviation hangar touted in Burbank. *Los Angeles Daily News*. Retrieved Februrary 2, 2016, from http://www.dailynews.com/article/ZZ/20081210/NEWS/812109917

Böhringer, C., & Jochem, P. E. (2007, May 4). Measuring the immeasurable — A survey of sustainability indices. *Ecological Economics*, pp. 1-8. Retrieved April 4, 2016, from http://www.sciencedirect.com/science/article/pii/S0921800907002029#

Cochin International Airport Limited. (n.d.). *Kochi airport becomes world's first to completely operate on solar power*. Retrieved from CIAL - Cochin International Airport Limited: http://cial.aero/Pressroom/newsdetails.aspx?news_id=360

Egere-Cooper, M. (2015, August 4). *This airport runs on wind*. Retrieved from Cable News Network - Business Traveller: http://www.cnn.com/2015/08/04/travel/galapagos-ecological-airport-wind-and-solar-power/

European Commission. (2014, July 23). *CASCADE: reducing energy use by airports*. Retrieved from Digital Single Market: Digital Economy & Society: https://ec.europa.eu/digital-single-market/en/news/cascade-reducing-energy-use-airports

Federal Aviation Administration. (2007). *Introduction to Safety Management Systems (SMS) for Airport Operators.* Washington, DC: U.S. Department of Transportation.

Federal Aviation Administration. (2010). *Technical Guidance for Evaluating Selected Solar Technologies on Airports.* Washington, DC: Office of Airports.

Grose, T. K. (2013, April 23). *Reshaping Flight for Fuel Efficiency: Five Technologies on the Runway*. Retrieved from National Geographic: http://news.nationalgeographic.com/news/energy/2013/04/130423-reshaping-flight-for-fuel-efficiency/

Hamilton, K., Atkinson, G., & Pearce, D. (1997). Genuine Savings as an Indicator of Sustainability. *'CSERGE' Working Paper GEC97–03*, 3-7. Retrieved from http://www.cserge.ac.uk/sites/default/files/gec_1997_03.pdf

Hartwick, J. M. (1977). Intergenerational equity and the investing of rents from exhaustible resources. *American Economic Review*, 972–974.

iSixSigma. (2016, April 4). *Pugh Matrix*. Retrieved from iSixSigma: http://www.isixsigma.com/dictionary/pugh-matrix/

Janić, M. (2007). *The sustainability of air transportation: A quantitative analysis and assessment.* Aldershot, Hants, England: Ashgate.

Kandt, A., & Romero, R. (2014). *Implementing Solar Technologies at Airports.* Golden, CO: Office of Energy Efficiency & Renewable Energy, National Renewable Energy Laboratory.

Koshy, S. M. (2015, September 8). *The World's First Solar Powered Airport Now in Kerala's Kochi*. Retrieved from NDTV: http://www.ndtv.com/kerala-news/the-worlds-first-solar-powered-airport-now-in-keralas-kochi-1215395

M. Harris, S. B. (2010). *Technical Guidance for Evaluating.* Federal Aviation Administration, Office of Airports, District of Columbia.

Pearce , D. W., & Atkinson , G. D. (1993). Capital theory and the measurement of sustainable development: an indicator of “weak” sustainability. *Ecological Economics, 8*, 103-108. Retrieved from http://www.sciencedirect.com/science/article/pii/0921800993900399

Public Utility Regulatory Policies Act of 1978. (1978, November 9). Retail Regulatory Policies for Electric Utilities. *PUBLIC LAW 95-617*. U.S.A.: 95th Congress. Retrieved March 24, 2016, from https://www.gpo.gov/fdsys/pkg/STATUTE-92/pdf/STATUTE-92-Pg3117.pdf

Ridal, J., Garvin, S., Chambers, F., & Travers, J. (2010). *Risk assessment of structural impacts on buildings of solar hot water collectors and photovoltaic tiles and panels.* Livingston (Scotland, UK): Building Standards Division, Directorate for the Built Environment.

Schluneger, M. (2014, September). *Optimise Electricity Usage In Airports*. Retrieved Februrary 16, 2016, from RemakeElectric.com: http://blog.remakeelectric.com/optimise-electricity-usage-and-energy-efficiency-in-airports/

Sierra Research, Inc. (1999). *Technical Support for Development of Airport Ground Support Equipment Emission Reductions.* Sacramento, CA: EPA.

Solow, R. M. (1986). On the Intergenerational Allocation of Natural Resources. *Scandinavian Journal of Economics, 88*(1), 141-149.

Sustainable Aviation Guideline Alliance (SAGA). (n.d.). *Measure*. Retrieved from Sustainable Aviation Guideline Alliance: http://www.airportsustainability.org/measure

The Centre for Local Economic Strategies (CLES). (2012). *Powerful impacts:Exploring the economic and social benefits of renewable energy schemes.* Manchester, UK: The Association for Public Service Excellence (APSE).

The World Bank. (2012). *Air Transport and Energy Efficiency.* Washington, DC: The International Bank for Reconstruction and Development / The World Bank. Retrieved from http://siteresources.worldbank.org/INTAIRTRANSPORT/Resources/TP38.pdf

U.S. Department of Energy. (2012, June). *A Comprehensive Analysis of the Potential for U.S. Solar Electricity Generation.* United States Department of Energy. Retrieved Februrary 01, 2016, from http://www.nrel.gov/docs/fy12osti/54294.pdf

Union of Concerned Scientists. (2016). *Environmental Impacts of Renewable Energy Technologies*. Retrieved from Union of Concerned Scientists: http://www.ucsusa.org/clean_energy/our-energy-choices/renewable-energy/environmental-impacts-of.html#bf-toc-2)

United States Department of Transportation. (2016, January). *Airline Fuel Cost and Consumption*. Retrieved Februrary 1, 2016, from TranStats: http://www.transtats.bts.gov/fuel.asp

Velasco, H. (2015, July 18). *Galapagos airport evolves to renewable energy only*. Retrieved from Business Insider: http://www.businessinsider.com/afp-galapagos-airport-evolves-to-renewable-energy-only-2015-7

Watkins, T. (n.d.). *An Introduction to Cost Benefit Analysis*. Retrieved March 25, 2016, from San José State University Department of Economics: http://www.sjsu.edu/faculty/watkins/cba.htm

Wind Energy Development Programmatic EIS Information Center. (n.d.). *Wind Energy Basics*. Retrieved Februrary 15, 2016, from Wind Energy Development Programmatic EIS Information Center: http://windeis.anl.gov/guide/basics/

Wolf, H. (2015, April 17). *sUAS NPRM Draft Advisory Circular (Hidden Treasure)*. Retrieved April 4, 2016, from wolfuas: http://wolfuas.com/2015/04/17/suas-nprm-draft-advisory-circular-hidden-treasure/

Zielinski, S. (2014, September 5). *Seven Unexpected Ways We Can Get Energy From Water*. Retrieved from simthsonian.com: http://www.smithsonianmag.com/science/seven-unexpected-ways-we-can-get-energy-water-180952625/?no-ist