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SUSTAINABLE RURAL ELECTRIFICATION:

RESIDENTIAL SOLAR ENERGY ON THE NAVAJO NATION

Nora Y. Cata
San José State University

Org. 06124
Anthony Martino, Manager
Sandra Begay-Campbell, Technical Advisor
Sandia National Laboratories[1]
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ABSTRACT

This paper will examine sustainable rural electrification on the Navajo Nation; specifically, the trends, observations, and input provided by employees of the Navajo Tribal Utility Authority (NTUA) associated with its Solar Energy Program. The environmental and social motivations for research will be introduced followed by a brief background on renewable energy technology and global rural electrification. The research scope will then narrow to a background on energy poverty on American Indian lands, paying close attention to the Navajo Nation. The intern's research will explain the benefits and challenges to Navajo electrification and provide specific details on NTUA's Kayenta, AZ residential Solar Energy Program. A compilation of interviews of NTUA employees, including the Renewable Energy Specialist and Kayenta District Manager, will offer anecdotal insight into how the Solar Energy Program has evolved since its inception and what trends were detected during customer interactions.

[1] Sandia National Laboratories is a multi-program laboratory managed and operated by Sandia Corporation, a wholly owned subsidiary of Lockheed Martin Corporation, for the U.S. Department of Energy's National Nuclear Security Administration under contract DE-AC04-94AL85000.

Particularly, how the following program components have progressed over time: application process, initial site assessment, customer education, customers' reactions to the project, and what is working well or what could be improved. These observations will provide a foundation for future hypotheses and set the stage for subsequent student research on what makes a successful residential solar photovoltaic installation on the Navajo Nation. Further student research will be conducted throughout 2012-2014 to quantify any statistical correlations between success (as defined by below average number and cost of service operations) and NTUA customer applications and operations and maintenance paperwork.

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LIST OF ABBREVIATIONS

CO_2: carbon dioxide

DAS: Data Acquisition System

DOE: Department of Energy

EIA: Energy Information Administration

ERP: Enterprise Resource Planning

GHG: greenhouse gas

HDI: Human Development Index

kWh: kilowatt-hour

LED: light-emitting diode

MW: megawatt

MOU: Memorandum of Understanding

NGS: Navajo Generating Station

NEDP: Navajo Electrification Demonstration Program

NREL: National Renewable Energy Laboratory

NTUA: Navajo Tribal Utility Authority

O&M: operations and maintenance

PV: photovoltaic

RET: Renewable Energy Technology

RUS: Rural Utility Service

SCADA: Supervisory Control and Data Acquisition System

SHS: Solar Home System

SNL: Sandia National Laboratories

SOP: standard operating procedures

SWTDI-NMSU: Southwest Technology Development Institute at New Mexico State University

TEP: Tribal Energy Program

toe: tonnes of oil equivalent

USDA: U.S. Department of Agriculture

WAPA: Western Area Power Administration

Chapter 1: Introduction

Motivation and Scope

Climate Change

Climate change, as a result of anthropogenic greenhouse gases (GHGs), is one of the planet's preeminent challenges. Its direct consequences range from increased drought and intensity of heat waves to a greater risk of flash floods and cyclones.[2] When considering the effects of global warming, one must consider the indirect losses as well. A changing climate affects all types of biodiversity including the number of species found in an Amazonian tropical rainforest to a reduction of agricultural crop productivity in Southern Europe. An often disregarded repercussion is the human economic and social costs associated with climate change. This could be the price for reconstruction after increasing incidences of natural disasters or the relocation of an Inupiat Eskimo village in Shishmaref, Alaska due to sea level rise.

One of the leading causes of climate change is the emission of carbon dioxide (CO_2). The United States is ranked second in the world behind China in global contribution. Of the United States' CO_2 emissions, 81.5% comes from energy-related activities.[3] Fossil fuel combustion from electricity generation is the largest source of CO_2 emissions, making electricity-production a focal point of mitigation strategy. The reliance on fossil fuels for electricity is a compounding problem since energy use is anticipated to accelerate with increased urban migration. Over half of the world population currently lives in cities and this number is projected to reach 60% by

[2] IPCC, *Climate Change 2007: Impacts, Adaptation and Vulnerability*, Contribution of Working Group II to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change, Summary for Policymakers (Brussels, 2007).
[3] U.S. Energy Information Administration, *Emissions of Greenhouse Gases in the United States 2009*, Independent Statistics & Analysis, U.S. Department of Energy (Washington, DC, 2011).

2030.[4] However, it is the potential impact of incorporating those currently without electricity that poses a major problem in our energy future.

Global Energy Poverty

Presently over 1.3 billion people lack access to electricity worldwide.[5] These individuals are said to be living in *energy poverty*, defined as the "inability to cook with modern cooking fuels and the lack of a bare minimum of electric lighting to read or for other household and productive activities at sunset."[6] Expansion of conventional electricity generation and distribution would overload the current grid system and dangerously accelerate world GHG emissions. If the global population were to mimic the energy use of the United States – which is 7.2 tonnes of oil equivalent (toe) per person per year compared to the world's average of 1.7 toe[7] – we would quickly exhaust our resources as more people compete for a limited amount of fossil fuel. Despite the daunting ramifications of rural electrification, the beneficial socio-economic implications are exceptionally significant.

Electricity is arguably the single-most vital component to advancing rural economic development[8] and improving the overall health and well-being of communities. The link between per capita electricity consumption and the Human Development Index (HDI) can be seen in the

[4] UN, Department of Economic and Social Affairs, Population Division, *World Urbanization Prospects: The 2005 Revision*, Working Paper No, ESA/P/WP/200 (New York, 2006).
[5] International Energy Agency, Organisation for the Economic Co-operation and Development, *Financing Access for the Poor – Special Early Excerpt of the World Energy Outlook 2011,* presented at the Energy For All Conference (Paris, 2011).
[6] UN, Development Programme, *Energy Services for the Millennium Development Goals,* in pursuance of UN Millennium Development Goals (New York, 2005).
[7] UN, Development Programme, *Fighting Climate Change: Human Solidarity in a Divided World*, prepared by Amie Gaye in Access to Energy and Human Development Report 2007/2008 (New York, 2007).
[8] Keshab Das, *Electricity and Rural Development Linkage*, No. 172 of Working Paper Series (Gota, Ahmedabad: Gujarat Institute of Development Research: 2006).

graph below. The positive contribution of electricity to the HDI is strongest for the first kilowatt-hour (kWh), suggesting that even minimum electricity could be beneficial in helping to meet basic needs.[9] Furthermore, access to electricity has been reported to increase literacy rates[10] which can spur economic growth, lower poverty and birth rates, reduce crime, promote civic engagement and self-empowerment, and aid in disease prevention.[11] Yet how does the world meet the electricity needs of the rural poor, without compromising the earth's natural resources and global population's longevity? One answer could be by "leap-frogging" beyond fossil fuel and grid expansion to the utilization of standalone renewable energy technology.

[9] Akanksha Chaurey and Tara Chandra Kandpal, "Assessment and evaluation of PV based decentralized rural electrification: An overview," *Renewable and Sustainable Energy Reviews* 14 (April 2010): 2266-2278.

[10] Human Development Research Centre, *Economic and Social Impact Evaluation Study of the Rural Electrification Program in Bangladesh,* prepared by Abul Barkat et al., Report to National Rural Electric Cooperative Association (Dhaka, 2002).

[11] READ Board of Trustees, "Benefits of Literacy Fact Sheet," READ Educational Trust, http://www.read.co.za/index.php?id=42 (accessed October 4, 2012).

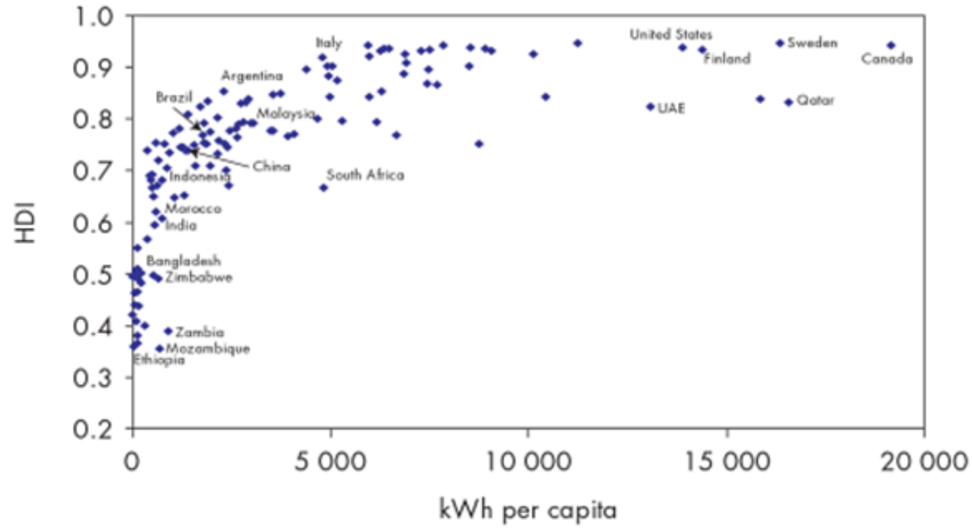

Figure 1: Per Capita Energy Consumption and HDI Value[12]

Decentralized rural applications of renewable energy technology (RET) such as small-scale hydro, wind, and solar have been installed throughout the developing world for the past four decades.[13] Standalone RETs have numerous advantages over conventional energy technology: independence from national grids, the ability to supply electricity to geographically remote populations, and relative benignity to the environment.[14] This access to electricity could allow communities to move up the "energy ladder," where societies have been shown to experience better education and entertainment, higher income levels, and improved economic

[12] United Nations, Development Programme, *Fighting Climate Change - Human Solidarity in a Divided World: Human Development Report*, prepared by Amie Gaye, 2007/2008.

[13] Judith Alazraque-Cherni, "Renewable Energy for Rural Sustainability in Developing Countries," *Bulletin of Science, Technology & Society* 28, no. 2 (April 2008): 105-114.

[14] United Nations, Conference on Trade and Development, *Renewable Energy Technologies for Rural Development*, prepared by UNCTAD Current Studies on Science Technology and Innovation, New York and Geneva: 2010.

development.[15] RETs are sustainable in multiple senses of the word: environmentally, socially, and economically. The proliferation of decentralized RETs to rural communities wanting access to electricity is one viable alternative to establishing fossil fuel dependent power plants and extensive grids.

One of the most promising sources of rural electrification is through the use of solar photovoltaics (PVs). Solar energy is a limitless and readily available resource; enough sunlight strikes the earth in forty minutes to supply the earth with energy for an entire year.[16] The evolution of solar technology has allowed for great advancements in PV efficiency and reduced costs, plus it is 10 times less carbon intensive than conventional energy.[17] In the United States, solar energy is expected to increase from 2.1% to 27.6% of the non-hydro renewable energy resources by 2021 (as of 2011, renewable resources supply 4.3% of the nation's energy).[18] Solar was also one of the first RETs deployed globally as a solution to sustainable development and there are an estimated 3 million PV systems[19] currently installed. Converting sunlight into energy is an excellent solution for sustainably meeting some of the world's rural electrification needs. Off-grid residential projects are poised to take advantage of this technology and promoting future PV deployment could assist energy poverty alleviation.

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[15] United Nations, Development Programme, *Energy Services for the Millennium Development Goals*, prepared by Vijay Modi, Susan McDade, Dominique Lallement and Jamal Saghir, Washington DC: The International Bank for Reconstruction and Development/The World Bank/ESMAP, 2005.
[16] Ken Zweibel, James Mason and Vasilis Fthenakis. "Solar Grand Plan." *Scientific American*, January, 2008.
[17] Benjamin Sovacool and Christopher Cooper, "State Efforts to Promote Renewable Energy: Tripping the Horse With the Cart?" *Sustainabile Development Law & Policy* 8, no. 1 (2007): 5-9.
[18] Federal Energy Regulatory Commission, *2011 Long-Term Reliability Assessment,* SNL FERC Power Report, 2011.
[19] Frans Nieuwenhout, Taric de Villers, Nitant Mate and Miguel Egido Aguilera, "Reliability of PV stand-alone systems for rural electrification: Tackling the Quality in Solar Rural Electrification – Target Action-C Contract No. NNE5/2002/98" (Work Package 1 Literature Findings, April 2004).

Native American Energy Poverty

Energy poverty is not a concept exclusive to developing countries. Within the United States, there are families who are still waiting to flip on the first light switch inside their home. Of the 1.4% of U.S. households without electricity, Native Americans on reservations are disproportionately affected. An analysis by the Energy Information Administration (EIA) determined that 14.2% of households on American Indian reservations have no access to electricity.[20] Of those who did have electricity, Natives paid a greater portion of their income to receive the service compared to the rest of the U.S. It is astounding that many electric utilities and mining firms are dependent upon the resources they obtain from tribal lands, yet pennies on every dollar going to energy corporations ends up on the reservations to support energy infrastructures.[21] A disconnect exists between where the energy is extracted from the earth and to whom, and where, it is routed.

Within the United States, tribal lands cover 5% of the area, yet hold 10% of America's renewable energy potential.[22] The National Renewable Energy Laboratory (NREL) estimates that there is solar energy potential equivalent to 4.5 times the annual U.S. electricity needs on Indian lands in the lower 48 states.[23] There is amazing potential for solar developments, especially in the sunny American Southwest. Despite having these vast energy resources, tribal

[20] U.S. Energy Information Administration, Office of Coal, Nuclear, Electric and Alternate Fuels, *Energy Consumption and Renewable Energy Development Potential on Indian Lands*, Department of Energy, Washington, DC, 2000.
[21] Phil Taylor, "Public Lands: Tribes See Brightening of Once-Bleak Energy Development Prospects," *Environment & Energy Daily* (July 16, 2009), available at, http://www.eenews.net/public/Landletter/2009/07/16/1 (accessed October 5, 2012).
[22] U.S. EIA, *Energy Consumption and Renewable Energy Development Potential on Indian Lands*, 2000.
[23] Douglas MacCourt, *Renewable Energy Development in Indian Country: A Handbook for Tribes*, subcontract report for National Renewable Energy Laboratory, June 2010, NREL/SR-7A4-48078.

lands are the most impoverished and underdeveloped regions in the U.S. There is a vicious circle of energy poverty; a poor resident cannot afford the energy services that could increase productivity and income. Fortunately, there are organizations aiming to help improve the energy situation on tribal lands. For example, the U.S. Department of Energy (DOE) Tribal Energy Program (TEP) has provided financial support to American Indians since 1992 to help develop renewable energy projects on tribal lands. This program, in partnership with Sandia National Laboratories, has funded a 160 megawatt (MW) wind energy project by Campo Kumeyaay Nation and a rural electrification solar energy project on the Navajo Nation, among others.

Background

Navajo Nation

The Navajo Nation, or Diné Bikéyah (Land of the People), is the largest Native American reservation within the United States. It extends throughout northeastern Arizona, northwestern New Mexico, and southeastern Utah totaling 27,000 square miles (about equivalent to the size of West Virginia). Located on the Colorado Plateau, the reservation is ecologically characterized as a high plains desert and is spotted with mesas and canyons. With over 270 sunny days a year, the Navajo Nation is the largest contiguous premium solar resource area in the West with over 424 square miles of prime development area.[24]

Currently, the tribe's economic prosperity depends on the coal industry. Peabody Western Coal Company's Kayenta mine, located within the reservation, supplies 7.8 million tons

[24] Arnold Leitner, *Fuel from the Sky: Solar Power's Potential for Western Energy Supply*, report for National Renewable Energy Laboratory, July 2002, NREL/SR-550-32160.

of coal annually to the Navajo Generating Station (NGS), a 2250 MW power plant in Page, AZ. NGS provides electricity to customers in Colorado, Arizona and California and royalties and taxes from coal mining and NGS provide 60% of the Navajo general fund budget.[25] Despite the abundance of energy resources and its subsequent income, the greatest need for electricity is on the Navajo Nation. Of all Indian households without electricity, the Navajo reservation accounts for 75%; in fact, the Energy Information Administration (EIA) estimates that 37% of Navajo homes are left in the dark.[26] Part of this high percentage can be attributed to the cultural history of the nation and its effects on population density. The Navajo people typically practice a herding lifestyle that requires large tracts of land to support grazing livestock such as sheep and cattle. As a result, non-electrified homes exist anywhere from 1 to 45 miles away from the electrical grid since the population is so dispersed.[27]

In order to electrify those homes existing off the grid, line extensions would have to be constructed at a cost of $35,000 single-phase or $60-80,000 three-phase per mile.[28] It has been estimated that it could cost as much as $350 million over a period of ten years to provide electricity to off-grid Navajos.[29] Other United States' regions with similar geographic characteristics are subsidized in order to surmount the normally cost prohibitive construction. Therefore, the Navajo Tribal Utility Authority (NTUA), which services the majority of the Navajo Nation, can only shoulder the cost of construction in areas with a population density of

[25] Navajo Nation, Division of Economic Development, *Comprehensive Economic Development Strategy of the Navajo Nation*, prepared by Trib Choudhary, Window Rock, 2002/2003.
[26] U.S. EIA, *Energy Consumption and Renewable Energy Development Potential on Indian Lands*, 2000.
[27] Paul Denetclaw Jr., "Successful Tribal Programs and Projects in their Communities" (panelist speaking at the Southwest Renewable Energy Conference, Flagstaff, AZ, August 7, 2003).
[28] Battiest 2004
[29] Bain 2004, 73,78

more than eight homes per mile. Below that number, the costs falls on individual families who often can't afford the exorbitant construction prices associated with electrifying their home. The table below illustrates that the percent of people living below the poverty line on the Navajo Nation is at 42.9%,[30] the unemployment rate is 25%[31] (while in the greater U.S. it is 9.1%[32]), and the percent lacking electricity is estimated to be 36.8%.[33]

Demographics				
	Navajo Nation	Kayenta, AZ	Greater AZ	Greater US
Regional Population	180,462 ʃ	5,189 ¤	6,392,017 ¤	311,591,917 ¤
Median Age	24.0 ʃ	21.9 *	35.9 ¤	37.2 ¤
Per capita income	$7,269 ʃ	$10,982 ¤	$25,680 ¤	$27,334 ¤
Median household income	$20,005 ʃ	$31,837 ¤	$50,448 ¤	$51,914 ¤
Unemployment rate	25% *	19.8% *	9.3% ¤	9.1% ¤
Poverty rate	42.9% ʃ	37.9% ¤	15.3% ¤	15.1% ¤
Median value of owner-occupied housing units	$25,000 *	$44,300 *	$121,300 *	$188,400 ¤
Percent lacking electricity	36.8% §	---	---	1.4% ɣ
Housing Units	68,744 ʃ	1,602 ¤	2,844526 ¤	
Key: * 2000 U.S. Census data; ¤ 2010 U.S. Census data; § EIA using 1990 U.S. Census data; ʃ Navajo Nation data from U.S. Census data 2000; ɣ EIA 2000				

Table 1: Demographics of Navajo Nation and Greater U.S.

[30] Navajo Nation, Division of Economic Development, *Navajo Nation Data from the US Census 2000*, prepared by Trib Choudhary, Window Rock, AZ, 2000.
[31] U.S. Bureau of the Census, "Census 2000 Data for the United States," http://www.census.gov/census2000/states/us.html (accessed October 6, 2012).
[32] U.S. Bureau of the Census, "Census 2010 Data for the United States," http://2010.census.gov/2010census/data/ (accessed October 6, 2012).
[33] U.S. EIA, *Energy Consumption and Renewable Energy Development Potential on Indian Lands*, 2000.

Navajo Rural Electrification

Despite considerable hurdles, the process of supplying electricity to the Navajo Nation has pushed forward and has even gained national attention. In 2000, Congress created the Navajo Electrification Demonstration Program (NEDP), which President Clinton signed into law (Public Law 106-511, Section 602). It was intended to fund $75,000,000 - over the course of five years - to assist the tribe in extending electricity to rural residents either through electric line extensions or hybrid photovoltaic solar home systems.[34] As of 2011, only $14,500,000 had been appropriated for the NEDP[35]; however, DOE, Sandia National Laboratories (SNL) and NTUA have continued in a joint-effort to proliferate rural electrification in spite of limited federal funding.

Navajo Tribal Utility Authority

NTUA is a not-for-profit entity, created by the Navajo Nation Council in 1959, and is the sole utility for most of the reservation. The utility operates strictly on revenues generated from its rates. Of those revenues, 50% goes to purchasing electricity from other suppliers as NTUA does not operate any of its own power plants. NTUA is the backbone of electricity distribution on the reservation and supplies 39,400 electric customers and 193 solar PV customers over 7 districts (5 main districts and 2 subdistricts).[36]

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[34] Navajo Tribal Utility Authority, *FY2002 and FY2003 Final Report: Navajo Electrification Demonstration Program* (Fort Defiance, NTUA: 2006).
[35] New Mexico State Senate, *Fiftieth Legislature First Session, 2011,* submitted by Lenore M. Naranjo, Senate Joint Memorial 21, Santa Fe, 2011.
[36] Navajo Tribal Utility Authority, "About Us" and "FAQs," NTUA, http://www.ntua.com/ (accessed October 6, 2012).

NTUA Solar Energy Program

The modest beginnings of the Solar Energy Program began in 1993 when NTUA, in partnership with DOE, signed a contract with Western Area Power Administration (WAPA) for a grant of $350,000. These funds enabled NTUA to purchase 40 stand-alone solar energy units of either 240 Watt or 260 Watt systems. Sandia National Laboratories assisted in the proposal development process, as well as provided technical assistance. As with any pilot project, there was a learning curve; the array output was too small and the maintenance complications were hefty. While these units have long since been retired, the pilot project allowed NTUA to realize the potential of solar energy in its future.

Another 200 units were purchased from Kyocera Solar, Inc. in 1999 using a $2,000,000 loan from USDA's Rural Utility Service (RUS).[37] Learning from the previous deployment, this next generation of 640 Watt units prompted the transition to a customer lease purchase agreement which set the stage for the lease-to-own contract agreement in effect today. NTUA electricians performed operations and maintenance (O&M) procedures for these units and began to establish standard operating procedures (SOP). Sandia also provided additional help by offering up its PV laboratory and technical advice to NTUA's emerging solar energy technicians. The initial installations were a success in that they opened the door to future development for this innovative solution to Navajo rural electrification.

The evolution of the Solar Energy Program continued and in 2000, NTUA, DOE and Sandia National Laboratories signed a Memorandum of Understanding (MOU) premising their

[37] Sandra Begay-Campbell, "Native American Sustainable Energy Systems - Navajo Solar Electric Case Study," presented at the Arizona Governor's Tribal Energy Meeting, Arizona, 2005.

current active relationship. The MOU authorized a technology transfer from Sandia to the Navajo Nation and emphasized collaboration on energy, economic development and technology deployment within the region.[38,39] The passage of NEDP as a law in 2001 solidified the Solar Energy Program as a viable option for bringing basic electrical service to those in need and NTUA has continually built upon the program. Since then, the utility has deployed numerous 880 W hybrid units and several 1080 W hybrid units that include a small energy-efficient refrigerator. The following table illustrates the evolution of the program up through its current 1080 Watt solar/wind hybrid unit.

Dates	Funding	Amount	Customer Price/Month	Array Output	Total kWh/day	# of Units	Manufacturer (Integrator)
1993	DOE - WAPA	$350,000	$40	240 W 260 W	1.3	40	Solar Mart
1999 - 2001	USDA – RUS	$2,000,000	$95	640 W	1.6	200	Photo Com. / Kyocera
2002-2003	DOE – NEDP	$800,000	$75	880 W hybrid small wind (Phase I)	2.0	40	SunWize (NADAC)
			$145	880 W hybrid LP gas generator (Phase I)	2.0	4	SunWize (NADAC)
2003-2010	DOE – NEDP	$1,150,000	$75	880 W hybrid small wind (Phase II)	2.0	63	SunWize (Ducommon Tech.)
2010 – Present	DOE		$75	1080 W hybrid small wind + refrigeration unit	~3.0	65	Sacred Power

[38] Shaun Tsabetsaye, "Navajo Tribal Utility Authority: Electrification Demonstration Program Developing a Sustainable Tribal and Rural Cooperative Solar Program," Tribal Energy Program intern research paper, Sandia National Laboratories, 2003. SAND #2003-3202 P.
[39] Jennifer Coots, "A Decade of Changes to an Alternative Power Source for a Rural Utility," Tribal Energy Program intern research paper, Sandia National Laboratories, 2004. SAND #2004-5102 P.

Table 2. Evolution of NTUA Solar Energy Program[40]

[40] Coots, Jennifer. "A Decade of Changes to an Alternative Power Source for a Rural Utility." Tribal Energy Program intern research paper, Sandia National Laboratories, 2004. SAND #2004-5102 P.

Chapter 2: Literature Review

Navajo Rural Electrification

Benefits

A common misconception is that development somehow takes away the authenticity of a tribe's culture. Yet, renewable energy benefits the community and aligns with Navajo values. Solar photovoltaics are a good option because they are a clean, quiet and sustainable source of electricity that is in harmony with the Native American Philosophy of Seven Generations.[41] Solar PVs also benefit tribal sovereignty by furthering self-sufficiency and self-determination. Moreover, solar energy has the potential to strengthen the Navajo economic, social and cultural integrity.

Economic

The Navajo Nation is facing a major need for employment. The current lack of jobs leads residents to pursue employment off the reservation, essentially creating a "Brain Drain."[42] By creating a Solar Energy Program to implement RET, there will be a greater need for Navajo technicians and engineers to develop skills for installing and maintaining PV systems. There is also the potential to spur entrepreneurial ideas and catalyze a rural energy market.[43] Substance abuse is often cited as a symptom of joblessness, and alcoholism and drug addiction are much

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[41] Sandra Begay-Campbell in "Making Decisions for Seven Generations," *Sandia Technology: A Quarterly Research & Development* Journal 3, no. 4: 2001.
[42] Craig Bain et al., "Navajo Electrification for Sustainable Development: The Potential Economic and Social Benefits," *American Indian Culture and Research Journal* 28, no. 2 (2004): 67-79.
[43] Y. Mulugetta, Y. Nhete, T. Jackson, "Photovoltaics in Zimbabwe: lessons from the GEF solar project," *Energy Policy* 28, no. 14 (2000): 1069-1080.

higher than the national average within the Navajo Nation.[44] The creation of additional jobs increases individual productive daily activity and provides a steady income, thereby serving as an alternative to idleness.

The Nation is also facing stunted economic growth. The installation of PV systems may indirectly spur the local economy by allowing residents to purchase television sets that frequently advertise local goods. Experiences of rural electrification in Kenya and Zambia have found that TV is the main driver for demand since it allows business advertisers to reach a wider audience.[45] Additionally, retailers and manufacturers could grow as a result of a new demand for items like refrigerators, fans and computers.[46] While increased commercialism has its pitfalls, access to improved lighting, heating/cooling, and communication could allow residents more time to dedicate to employment, education or entertainment.[47]

Educational and Cultural

Electrification of a home can create further educational opportunities by allowing a child to complete homework after dark or raise their computer literacy level. The following anecdote illustrates the importance of electricity in advancing a Navajo child's education:

> "Imagine a schoolchild trying to complete homework by the light of a kerosene lamp. Consider too, that the child woke up at 5:00 a.m. to catch a bus and begin a sixty-mile ride to school, with two-thirds of that distance on an unimproved road. After a full day of school and a long drive home, the young child is responsible for various household chores, and then she sits down to try her

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[44] Larry Hendricks, "Navajo Nation: Rez Alcohol Abuse Fueled by No Jobs," *AZ Daily Sun*, March 6, 2005.
[45] Chaurey, *Renewable and Sustainable Energy Reviews,* 2010.
[46] Bain et al., *American Indian Culture and Research Journal,* 2004.
[47] Heather Scofield, "Reservation's remotest corners get light with small-scale, solar-wind systems," *The Durango Herald,* April 1, 2012.

> homework. Already this child is placed at a disadvantage in a very competitive Western society."[48]

The addition of timesaving devices may also play a role in how much effort and time a child can dedicate to their studies or interact with elders. Lighting could allow Navajos to engage in weaving, beading, smithing, and other culturally significant Hogan-based artistic activities past sunset.[49] By providing the same comforts that other American students are afforded, this child will have a better chance of competitive employment and cultural entrepreneurship in the future.

Health

Health-wise, electricity is extremely valuable as it allows for the refrigeration of food and medication, enables telemedicine, and improves indoor air quality. The variety of food consumed increases with refrigeration, especially in the availability of fresh fruits, vegetables, and milk. Replacing the quantity of canned food (which generally have lower nutritional value) consumed with healthy dietary staples could help avoid causes of diabetes and other medical conditions.[50] Additionally, rural electrification could help in the treatment process of those afflicted with diseases that require refrigerated medication, such as insulin. Also valuable would be the ability to electronically transmit data to a health clinic via telemedicine.[51]

Lastly, electrified lighting would make kerosene lamps (the primary source of off-grid lighting on the reservation) unnecessary, consequently improving indoor air quality. Kerosene lanterns have been linked with long-term health risks and respiratory ailments because of the

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48 Bain et al., *American Indian Culture and Research Journal,* 2004.

49 Dean Howard Smith, *Paths to Self-Sufficiency and Cultural Integrity in Indian Country* (Walnut Creek: AltaMira Press, 2000).

50 Sandra Begay-Campbell, interview by Bain et al. in *American Indian Culture and Research Journal,* 2004.

51 Craig Bain et al., *American Indian Culture and Research Journal,* 2004.

high concentration of particulate matter inhaled.[52] The EPA found that more than twenty dangerous compounds were released in significant quantities during the burning of kerosene lamps such as acetone, benzene and lead.[53] The resultant particulate matter inhaled from burning one liter of kerosene is the equivalent of inhaling two packs of cigarettes per day.[54] A displacement study of PV lighting units in Ghana found that households reduced the amount of fire hazards, the adverse health effects of indoor air smoke, and proportion of people who got blackened nostrils from soot associated with kerosene lanterns.[55] The substantial health advantages of rural electrification for Navajo families could change the quality of life for many children and elders alike.

Environmental

Solar energy is around 10 times less carbon intensive than conventional energy while each liter of kerosene emits approximately 2.5kg of CO_2. Minimizing the use of kerosene lanterns would aid in the displacement of fossil fuel and reduce greenhouse gas emissions. Kerosene is inherently energy inefficient; in fact, a PV compact fluorescent lighting system is 100 times more efficient than a kerosene lantern also making it cost-effective.[56] Studies of the impacts of solar home systems (SHS) found that they can displace as much as 15.2-21.3 liters of kerosene

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[52] J. Apple et al., "Characterization of particulate matter size distributions and indoor concentrations from kerosene and diesel lamps," *Indoor Air* 20, no. 5 (2010): 399-411.
[53] Twine Bananuka, “Reducing Health Problems – Solar-powered LED Lights-Flexiway Solar,” AllAfrica.com (accessed February 6, 2012).
[54] Jennifer Perry, "Lighting up the World," Engineers Without Borders, http://www.ewb-international.org/pdf/Lighting%20Up%20The%20World.pdf (accessed October 6, 2012).
[55] Obeng, G.Y., F.O. Akuffo, I. Braimah, H.D. Evers and E. Mensah. “Impact of solar photovoltaic lighting on indoor air smoke in off-grid rural Ghana.” *Energy for Sustainable Development* 12, no. 1 (2008): 55-61.
[56] Richard L. Ottinger and Rebecca Williams, "Renewable Energy Sources for Development," *Environmental Law* 32, no. 2 (2002): 331-368.

per month in Argentina, 12.0 liters per month in Burkina Faso, and 5.0 liters per month in Bolivia.[57] A study in 2003 found that over 70% of SHS have an emissions reduction potential of over 200kg CO_2 a year.[58] If each of the 18,000 Navajo households reduced their kerosene lantern usage for four hours a night, net GHG emissions would decrease by 1.8 million kilograms per year which is the equivalent of driving over 4 million miles in the average car.[59] Moreover, the dispersion of renewable energy technologies may have a positive impact on attitudes towards the technology if the programs are implemented successfully.

Negative Impacts

The possibility of negative impacts as a result of rural electrification on the Navajo Nation should not be abandoned. Access to the internet may have a destructive effect on traditional lifestyles and those wishing to preserve their culture might find American pop culture damaging. Besides cultural preservation, decisions to abstain from solar panels might be that they appear too flashy, the application process looks daunting, or the unit appears too overwhelming to maintain. Not all people need or want electricity; it is important to respect those families who choose to live in un-electrified homes as an individual lifestyle choice.

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[57] Chaurey, *Renewable and Sustainable Energy Reviews,* 2010.
[58] R. Posorski, M. Bussmann and C. Menke, "Does the use of solar home systems (SHS) contribute to climate protection," *Renewable Energy* 28. no. 7 (2003: 1061-1080.
[59] David Tarasi et al. "18,000 Americans Without Electricity: Illuminating and Solving the Navajo Energy Crisis." *Colorado Journal of International Environmental Law and Policy* 263 (2011): 1-12.

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Chapter 3: Problem Statement

Objective

The objective of this research is to examine the current state of NTUA's Solar Energy Program in Kayenta, AZ and to evaluate its effectiveness as determined by: its ability to maintain financial security, establish standard operating procedures, train qualified employees, satisfy customer needs and deliver quality service. Identifying key trends (strengths, weaknesses, opportunities and threats) will help ensure PV unit longevity and lasting success of the program. This paper will set the foundation for future student research by determining specific components of success in order to quantify the progress of the Solar Energy Program over time.

Research Questions

- How has the program evolved since its inception in terms of standard operating procedures, customer relations, and delivery and maintenance of the technology?
- What are some challenges inhibiting the program's effectiveness?
- What are some key components to the success and longevity of the program?

Hypotheses

- Developing standard operating procedures has increased program efficiency.
- Developing standard operating procedures has helped the program weather challenges.
- The program continues to face ongoing challenges such as financial security and maintaining a solid customer base.

- Maintaining strong customer relationships are key to ongoing success.
- Employees will have a positive attitude and outlook towards the program and its future.

Chapter 4: Methods

Study Site

The study site for this research paper is the NTUA District in Kayenta, AZ. The incorporated township of Kayenta is located 25 mi south of Monument Valley and has the largest number of PV units among all the NTUA districts. As of 2007, there were 299 PV systems owned by NTUA, of which Kayenta had 100. There were 83 units of the 640 W system and 17 units of the 880 W system. Each Solar Home System contains PV modules, a frame for the modules, a battery bank, a battery charge monitor/controller, an inverter and a load center. The following table provides a quick overview of regional demographics.

Kayenta, AZ	
Population, 2010	5,189
Persons under 18 years, percent	38.9%
American Indian persons, percent	92.3%
Language other than English spoken at home, percent	80.6%
Households	1,277
Persons per household	3.87
Per capita money income in the past 12 months (2011 dollars)	$10,452
Persons below poverty level, percent	42.3%
Land area in square miles	13.17
Persons per square mile	393.9

Table 3. Kayenta Township 2010 Census Data[60]

Study System

[60] U.S. Bureau of the Census, "Census 2010 Data for the United States," http://quickfacts.census.gov/qfd/states/04/0436990.html (accessed December 1, 2012).

The study system for this research included an initial comprehensive review of previous Sandia intern research pertaining to NTUA's Solar Energy Program. The analysis of prior student essays was then used to uncover key program themes, which were then divided into the following focus areas: customer reactions, customer education, business processes, application process and initial site assessment.

These five focus areas were then applied to the second portion of this study during employee interviews. Interview questions were shaped with the intention of uncovering program challenges and successes within the five key focus areas. Close attention was paid to the current state of the program (as of 2012) and how it has evolved since its inception.

Data Collection

Interviews were conducted throughout the summer of 2012, which were transcribed and analyzed in the Fall. There were twelve main interview questions posed and included employee thoughts on what was going well within the program, what could be improved upon, its progression, overall trends, and input on future research. All questions can be seen in Appendix A. A list of those interviewed includes the Kayenta District Manager, a Renewable Engineer, a Field Superintendent, an electrician, and the Renewable Energy Specialist.

Chapter 5: Results

Program Trends as Found in Prior Intern Research, 2003-2009

Previous SNL TEP intern research was an integral part of this study since it shed light on the evolution of the NTUA Solar Energy Program from its inception to the last NTUA intern project in 2009. Extracting reoccurring themes and recognizing consistent challenges in the development of the SEP is a necessary step to identifying important focal points for future student research. Therefore, a brief explanation of student topics will be introduced and a compilation of their arguments will be examined. Paying close attention to how certain program components have evolved will allow the most recent NTUA employee interviews to be evaluated within the greater context of time. These components, such as including the development of a business model, customer education, and identifying consistent challenges, improved upon the program's success.

Standard Operating Procedures

The first contribution was written in 2003 by Shaun Tsabetsaye and detailed the inception of the Solar Energy Program, related legislature and associated federal funding. It stressed the benefits of developing a sustainable rural cooperative solar program that could serve as a model for other tribal governments. Former Renewable Energy Specialist Larry Ahasteen was interviewed and asserted that operating a Solar Energy Program under a business model would be the most viable solution for longevity. Ahasteen elaborated on the economic value of keeping close tabs on all costs associated with deployment and maintenance of the units. The paper also recognized the importance of establishing standard operating procedures. In 2003, the installation process for the PV units had been documented but the operations and maintenance processes had not yet been solidified. Tsabetsaye and NTUA employees developed workflow diagrams to remedy this problem and set the precedence for Troubleshooting and O&M procedures.

Customer Relations

Keith Candelaria also contributed insight in 2003 by focusing on the customer-side of the program. His interactions lay emphasis on customer education and creating trust between the electricians and residents. Customer education began emerging as one of the most important factors to success and his paper shed light on its beginnings. A twenty-minute video titled "Power from the Sun," was created in 2002 and is available in both Navajo and English. It briefly explains to customers how sunlight is converted to useable energy and includes a quick overview of how the PV system functions. Taking cultural subtleties into account, Candelaria also explored employee-customer relationships. NTUA set strict standards for employing a bilingual staff that could understand cultural nuances. He learned this allowed for heightened trust from rural residents and created better customer bonds and open lines of communication.

Streamlining

The technical and economic drivers for adopting four generations of PV units were addressed in a paper by Jennifer Coots in 2004. Financially, this paper was enlightening; it revealed NTUA's average capital cost per PV unit to be just over $15,000, and the monthly cost of O&M maintenance to be higher than that charged to the customer per the lease-to-own agreement[61]. The utility was struggling to balance the costs and revenues of the program so NTUA found other ways of improving efficiency. During the deployment of the 640 Watt units, SNL's Renewable Energy Department conducted extensive training with NTUA electricians, engineers and technicians. The employees gained valuable technical experience that could save future time and money. Continuous improvements were also seen within the PV units and adjustments were made to the array positioning and battery box. All 640 Watt units were made identical in order to ease training, sales, distribution, installation, and maintenance services. The newly deemed "drag and drop" design was a testament to the PV unit's increased mobility.

Unfortunately, batteries were still proving to be a formidable hurdle in service calls. The root of the problem was identified to be excessive loads in combination with inadequate recharging by the customer.[62] NTUA worked to remedy the problem by installing LED DOD-meters inside the houses to alert the residents of low battery and Morningstar TS45 charge controllers to equalize the batteries at regular intervals. Coots also unearthed a new issue: vandalism was on the rise. Vandalism occurred in the form of larceny and property damage; however, more often it was the case of residents trying to 'fix' the unit themselves or attempting to use the batteries for other purposes. In the above cases, improved customer education was recommended to alleviate the problem.

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[61] Coots, Jennifer, "A Decade of Changes to an Alternative Power Source for a Rural Utility," Tribal Energy Program intern research paper, SNL, 2004. SAND #2004-5102 P.
[62] Southwest Technology Development Institute, "PV Hybrid System Second Performance and Data Report: Three Kyocera 'Sun-Pak' Solar Electric Power Systems owned by Navajo Tribal Utility Authority Ft. Defiance, Arizona," January 2001.

By 2004 it was clear that the new O&M process had made a significant impact in identifying key technical issues. SNL intern Benjamin Mar attests that it allowed the PV program to evolve into a more powerful, sustainable and efficient system. For example, by using the O&M forms, NTUA was able to determine that 880 Watt phase I charge controllers were failing due to the cloud edging effect maxing out the PV current limit. This led to a design correction to the 880 W phase II charge controllers in order to withstand the current at peak conditions.

Customer Education

It was also apparent that financial imbalance was still lingering and NTUA was facing higher costs than the monthly customer payments afforded. Extraneous expenses continued rolling in despite the utility's inability to increase monthly fees due to the previously agreed upon lease-to-purchase contract. Vandalism had become a noticeable occurrence since 2001 so NTUA hoped to ebb associated costs by creating a vandalism policy. Additionally, inadequate battery care still dominated the service calls and added the financial burden of replacement parts. Therefore, a new customer education process was implemented to help with PV system longevity. Electricians began consistently advising customers, pre-reviewing load potential within the household, and providing newly created handouts listing appropriate appliances under "OK" or "not OK" headings. The educational handouts also included information sheets illustrating correct usage of the battery capacity meter, inverter remote switch and load center. The electricians were doing more customer education than ever before during their initial site assessments to ensure longevity of the unit.

Automated Tracking

As with many aspects within the program, standard operating procedures were maturing. In 2004 NTUA was not yet tracking the frequency of PV system failures. Customer Outage Reports were implemented in order to track trends within the different systems, furthering the program's business-model attributes. The utility began utilizing an Enterprise Resource Planning (ERP) system and automating notifications for bi-annual maintenance. Ben Mar argued that one of the most important aspects of the sustainability of the Solar Energy Program was the efficiency of its operating processes, of which NTUA consistently strived to improve. In addition to the advancements already made, he suggested it would be beneficial for the utility to maintain complete and efficient documentation in order to create consistency throughout all districts. Unfortunately, the ERP system had its limitations. The program was overly-complicated and detailed cataloguing was still proving too time-consuming. The utility was still searching for an appropriate software platform.

In 2005, the Southwest Technology Development Institute at New Mexico State University (SWTDI-NMSU) developed a Data Acquisition System (DAS) for monitoring nine remote PV sites on the reservation. The purpose was to determine why systems were not being properly utilized or why some batteries reached end-of-life more rapidly than others. Sandia intern Tanya Martinez explored the potential to add DAS to NTUA's supervisory control and data acquisition system (SCADA). If monthly energy reports could be generated for PV customers that visually documented their overuse, perhaps the number of service calls could be reduced (Martinez reported that NTUA received approximately 15 calls per month, most often related to failure due to over-usage)[63]. The takeaway lesson learned from Martinez' paper was that the DAS output pinpointed unit failures mainly as a result of customer over-usage as opposed to technical component failure. As of November 2012, the status of these DAS is unknown to the author.

State of the Program, 2007

With a greater hold on standard operating procedures, NTUA was now "actively seek[ing] ways to improve system performance, increase the number of systems and customers for the program, and improve its financial position."[64] NTUA had adopted SAP as their ERP platform to track customer service requests and to generate cost reports for service orders. They had also demonstrated strong workflow processes by setting up a Customer Service Call Center where all troubleshooting calls were routed. The Service Orders were queued to the Service Planning team and the Financial Team used the O&M forms to determine the costs incurred by each call.

By 2007, there was enough data held within the SOP forms to quantify trends within the workflow processes. Using this information, SNL intern Terry Battiest studied 48 O&M service requests of the 880 Watt units and tracked battery, inverter and array voltage, system amperage and current over time. He also determined the average cost for an O&M call to be $130.19 per

[63] Martinez, Tanya, "Remote Monitoring System Design – Sustainable Systems for the Navajo Tribal Utility Authority," Tribal Energy Program intern research paper, SNL, 2005. SAND #2005-6027 P.
[64] Battiest, Terry. "NTUA Solar Program System Data and O&M Initiative for DOE Solar Technologies Database." Tribal Energy Program intern research paper, SNL, 2007. SAND #2010-7617 P.

event ($21.70 monthly per unit),[65] down from NTUA's 2004 $75 monthly per unit assessment.[66] In addition to these valuable insights to the program, Battiest also identified several ongoing challenges. Bi-annual O&M service visits are held in March and September, but electricians were having difficulty keeping to schedule. Travel to remote residences was sometimes postponed due to impassible roads, ice, and flooding. Payment delinquency was a regrettable but unavoidable problem among customers and NTUA was still burdening the ownership liability under the lease-to-own purchase agreement. Battiest made the astute observation that program longevity was determined by the following facets in order of importance: nature and the elements, the customers, the program model.

The most recent student publication concerning NTUA investigated how renewable energy can be an avenue for sustainability and self-determination on the Navajo Nation. Gepetta Billie's 2009 student essay provides an enlightening overview of how to evaluate current renewable energy projects on the reservation, and how energy development on tribal lands is a complex and multi-dimensional issue.

Program Trends as Found in Employee Interviews, 2012

The following section contains a compilation of NTUA employee responses to the interview questions posed during the summer of 2012. The interview questions (found in Appendix A) were a reflection of important focal-points found in prior-intern research which have been categorized into the following areas: customer reactions, customer education, business

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[65] Battiest, "NTUA Solar Program System Data and O&M Initiative for DOE Solar Technologies Database," 2007.
[66] Coots, "A Decade of Changes to an Alternative Power Source for a Rural Utility," 2004.

processes, application process, initial site assessment, and other noticeable trends. The answers provided also demonstrate the radical progression of the Solar Energy Program from 1993 to present. One interviewee shared that when they began their involvement with the program (from the 240 W unit to present), there were no standard operating procedures, no technical manual for the unit, nor any guide on how to troubleshoot the system. In fact, the employee had only a basic diagram and self-taught themselves how the components worked together. These next sections (summarized in the bullet points below) will shed light on how much the program has advanced since that employee's first introduction to the technology within NTUA.

- **Customer reactions** were initially associated with "sticker shock" and mistrust of the technology's reliability. Awareness of benefits to the program has improved reactions.
- **Customer education** was once a focal point during the 880 W unit deployment and had made a positive impact on customer usage habits. Since then, the program has stagnated.
- **Business processes** now revolve around customer satisfaction, streamlining operations and maintenance procedures, and making the program financially sustainable.
- The **application process** works to ensure customers have adequate income and housing accommodations for installation. It uses the same application as grid-tied electricity.
- The **initial site assessment** has evolved based on the specific needs of each unit. Due to wait list length, the time and order of site evaluations has not always been consistent.

Customer Reactions

Most customers who adopt the technology are under a lot of financial and economic pressure. They believe solar and wind are good options because residents predominantly see the sun and the wind as free resources. Yet, as Terry Battiest (NTUA Renewable Engineer) explains, "technology to capture the power has a price tag, which can be a shock to customers." Additionally, investments in this technology by residents are different from the costs associated with line extensions. With line extensions there is a one-time, explicit cost for extending a line to a home. With solar, the customer recovers the investment price over time and occasionally faces unexpected costs. However, according to Battiest the initial "sticker shock" eventually wore off and most customers were appreciative once they acclimated to using the solar technology.

Another prominent customer reaction was that residents assumed there were no limits to electricity loads or length of use once the unit was hooked up – similar to grid-tied residential use. This was a common belief before the 880 W units, wherein proper instruction began. As a result, the systems failed and customers were either wary of the dependability of the technology or of being blamed for the failures themselves. It became apparent that customers often shared their experiences of the solar unit with friends and family members, so when these over-use failures became a trend, NTUA stepped in with proper instruction. Now, the communication has moved towards the benefits of installing a unit at one's house. One NTUA employee received compliments because elders were able to spend an extra couple of hours on their weaving at home without experiencing the smell of a lantern or noise of a generator. As demonstrated, the utility has been reactive to customer input so feedback has consistently become more positive.

Customer Education

A disadvantage to the 240/260 and 640 W systems was that temporary personnel were hired to connect the unit; as a result, there was no formal usage education to customers. During the 880 W unit deployment (years 2001/2002), customer education was coordinated and became a focal point of business processes. Electricians began demonstrating to solar customers how much power was being used by hooking up kilowatt readers to appliances and doing comparisons between incandescent and fluorescent bulbs. The Kayenta office created handouts illustrating which appliances were "OK/not OK" to use (however it took several years before the handouts were fully accurate). The journeyman also began stressing electricity conservation and usage time as the most important owner responsibilities. This included equalizing the system twice a month, of which NTUA employees recommended owners complete while they are away from their home for a full day. Many customers took the initiative to educate themselves further, especially if they were rural and needed to maintain the unit themselves. After the initial rollout of customer education, the processes have remained stagnant and may be due for adjustments.

Business Processes

It was apparent during interviews that customer satisfaction has evolved into one of the cornerstones of NTUA's Solar Energy Program. For example, if a unit failed and NTUA couldn't fix it within the month, there would be no monthly charge even if the failure was the customer's fault. To ensure this policy is financially feasible, the utility has the customers call immediately once the unit stops working. Despite the risk of NTUA losing profits, the company feels it is their responsibility to ensure extra parts are always available and the system works at all times.

NTUA believes customer satisfaction will set them apart from competitors. Grassroots initiatives (however benign) have threatened NTUA's pricing by charging up to $50 less per month. Customers are expecting to get the same service for cheaper, but are finding that competitor repairs and maintenance leave much to be desired. In fact, NTUA receives calls to fix competitor units and residents even offer to pay for transportation costs. Unfortunately, NTUA must decline because of the danger and liabilities associated with repairing a unit their employees are unfamiliar with.

As it currently stands, the Solar Energy Program is losing money due to the inconsistencies in its tiered pricing and expenses associated with replacement parts. The majority of 'out of service' units need replacement parts, but the incoming parts are few and far between. With every new influx of parts from grants or loans, the supplies drain quickly. In order to improve efficiency and shave costs, the company looked towards streamlining processes and making O&M plans consistent. If NTUA is able to find additional funding, the Renewable Energy Coordinator would like to increase site visits from biannually to three times a year, plus add an installation follow-up visit. This will help ensure the units are operating correctly and catch any misuse early on.

Application Process

The application for solar energy is the same as that for grid-tied electricity. The customer fills out the standard forms, answers general questions about home site leases, house wiring, etc. and then NTUA creates a work order notification. The customer is then put on a waiting list based on preferred unit size. Waiting times vary since most customers prefer to use the larger units like the 1080s. One employee observed, “People gravitate to what the largest size is. The 680 W customers want the 880 W, and then the 880 W [customers] want the 1080… especially because they pay the same ($78/mo) for the 880 W and the 1080 W.” The variability in price and unit size causes the applicant waiting list to fluctuate in length considerably.

Applicants must first and foremost have adequate housing units. Internal electrical wiring is required and the home assessment plays a large role in selection. The ‘ideal’ household (though not used as part of the selection process) would have three or fewer rooms with approximately eight or fewer outlets. A secondary factor in applications is income. NTUA asks that customers pay $250 in advance in order to offset any possible future financial trouble such as missing a monthly payment. Despite the deposit, defaulting on monthly payments is consistently a problem and there is almost always a resident on the late paying customer list. NTUA actively works towards contacting customers in order to get them caught up on payment or else to notify them that the system will be removed.

Initial Site Assessment

The initial site assessment consists of several measures. As previously mentioned, the house must have the proper wiring and a serviceable entrance. The plot where the unit will sit is chosen according to its East to West positioning and on the proper latitude and longitude. Unit placement is marked before contractors arrive so that it can quickly be ‘dropped’ and hooked up. Copper grounding rods and appropriate depth of insertion are taken care of when the unit arrives. NTUA recommends that fences be installed 5-10 ft away from the unit for added safety in order to protect children or livestock, and to protect against theft.

Site assessments have grown increasingly thorough. Beginning with the 880 W units, the surrounding area of the home had to be surveyed for shading from trees or other obstructions. Another new measure since the addition of refrigerator units is an appliance check. The electricians will conduct a visual assessment of the number and type of appliances inside the household. They also use this time to have a conversation with the residents about the technology and its limitations. One NTUA employee said it can be explained by comparing it to planning ahead for a shopping trip: "It's like going to the store with $20 to buy groceries… how are you going to divide up your money for the week?"

Due to the fluidity of site requirements based on unit size/specifications in conjunction with varying wait list times, site assessment processes have never been solidified. One employee observed, "It's never been clear whether it's required that a customer has a completed application first or if the inspection occurs when the system becomes available." Because of the long waits for larger units, some districts don't see value in conducting an early site assessment if the environment is going to change in a year or two. The order of these procedures is actively being discussed.

Noticeable Trends

The following are a list of observations made by employees that do not fit into the above prescribed categories.

- The number one reason for removing a solar unit in the Kayenta District is due to power line extensions as they happen to target the same areas where PV customers are already in place. The second reason for removal is non-payment.

- Elders tend to maintain PV units better than a younger demographic. This is attributed to them growing up without grid-tied power and thus accustomed to fewer appliances.
- There are seasonal trends in the number of service order calls. Most calls occur during the winter, followed by summertime. This is most likely due to the influx of family members like kids returning home for school breaks.
- Usage reports can read like a timeline since loads change based on family activity. Here are examples provided by an employee: a refrigerator goes online (increases load), a child goes off to school (decreases load), a family installs an AC water pump (increases load), a family converts to a DC pump or disconnects (decreases load), or coolers and fans are used during summertime (increases load).

Chapter 6: Conclusions

Program Challenges

NTUA's Solar Energy Program would not have progressed to the level that it is operating at now without its personnel tackling the challenges they faced. It is up to NTUA to continue improving the efficiency and quality of the program by perpetually working to solve the problems associated with operating the SEP. Some examples of issues brought up during interviews are:

- Lack of renewable energy initiative as a corporate-wide policy.
  Interviews shared the difficulty faced by some personnel in committing to the renewable energy program. This was due primarily to the fact that their skills are in other areas. Additionally, some projects (such as grid-tied) take priority over an individual customer's PV system just based on overall customer impact.
- Inconsistency of site assessments.
  The time at which point site assessments are made has varied over the years and throughout the application process based on employee schedules and district. Ensuring assessments are consistent could avoid problems associated with wiring and appliances.
- Customer confusion and dishonesty.
  NTUA has to burden the costs of customers not using the system properly. For example, customers have told NTUA that their houses are wired but the electrician will find the opposite. Customers are also consistently overloading the system and not equalizing it properly.

- Pricing disincentivizes installation of some units.

  The Kayenta District is looking to implement tiered pricing of the different sized units. Currently all three smaller systems (640-W, 880-W and 1080-W) are priced the same. As one employee put it, “Everyone of course wants more power for their dollars and so they try to get the 1080-W.”

- Lack of payment assistance.

  Selling solar energy as an electricity option is difficult because many people can’t afford it. If a resident without electricity makes $250 a month as a basket-weaver, $78 takes up a large portion of their income. There is an inherent disparity between those who need the technology and those who can afford it. However, there is currently no loan, grant, or payment assistance program in place for residents wishing to implement solar.

Program Successes

Interviewees elucidated on how, through trial and error, NTUA’s Kayenta District began experiencing more successes within the Solar Energy Program. There has been an extensive leap in the amount of employee technological knowledge and inter-personal communication and education with customers from whence the program first started. Having to work through program glitches and challenges enabled the SEP to grow and evolve into a more efficient service. One example shared by an employee was the need to change PV providers early-on. During the 640-W system, NTUA was getting a lot of service calls concerning faulty modules. Investigations into the technology unearthed a defect in the soldering of the silica cells which caused post-production melting. The subsequent switch to a new PV provider forced NTUA’s technicians to research all aspects of a quality module, thereby educating them of the current technology.

Communication about the service has also improved over time. Several employees stressed the importance of basic one-on-one interactions and establishing a good connection with individual customers. According to the District Manager, "we have folks who have built long-term relationships." One technician even tells customers, "call me on my cell phone and I can walk you through [the process]." An added benefit is NTUA's employment of personnel who have a cultural understanding of how the users live without electricity. One interviewee felt this added an extra level of empathy for customers within the personnel, since they know what residents' are going through.

Opening the lines of communication has allowed for more focused customer education. One employee recognized that the success of the unit was dependent on getting customers acclimated to the system. The following quote demonstrates the role NTUA plays in ensuring residents are able to keep units functioning in the field:

> "The customers have to make choices. We're there to help them make those choices. Over time, the folks who are smart about their systems, they start to understand. It's like [having] a car… it only burns out if [you] don't maintain it. It's not a smart or not smart thing… it's if [the customers] are smart with the system."

The combination of customer education and proper design (meaning correct installation of appropriate PV components) play a huge role in the success of the system. One employee stressed how the combination of these two initiatives determines how beneficial a system is going to be in reducing operation and maintenance costs, and improving service quality and satisfaction of the customer. As seen in the interview results, NTUA has consistently focused attention on how to expand and improve upon district-wide projects that raise the bar on education and implementation.

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Appendix A: Interview Questions Asked of NTUA Employees

1. Could you please provide background information yourself?
    - Name
    - Title at NTUA, years of service, duties, etc.
    - Where are you from, brief information on upbringing and education?
2. How has the Solar Energy Program progressed over time?
    - What are the main difference between when the program first started and how it operates today?
3. How has the customer education progressed over time, with each of the PV units?
4. What is working really well in the Solar Energy Program?
5. What is not working so well, what could be improved upon?
6. How have the customers reacted to the program?
    - Since its inception
    - Currently
7. What is the application process like?
    - Is there an 'ideal' customer? How are they chosen?
    - Do you ever disqualify applicants for any reason, what makes a poor applicant?
8. Is there an initial site assessment, and how does that go?
9. What trends have you noticed? For example, with:
    - Customer demographics
    - Service calls
    - Financial/access to spare parts

- Performance of specific types of PV units

10. I would like to conduct further research for my graduate thesis; however, I need to formulate an objective and hypotheses. What are your reactions to these:

    - **Objective**: Determine what components make a *successful* off-grid residential renewable energy installation in the NTUA Kayenta, AZ district.
        - *Success* defined by: Below average number of service calls and cost of repairs over a period of time (TBD).

    - **Hypotheses**:
        - Customer sense of ownership of PV units leads to fewer service orders [How would I test this based on service form, application, etc. – is it testable?]
        - Elders will maintain PV units better than a younger demographic
        - The more education provided to customer, the fewer # of service orders
        - A more thorough initial site assessment will lead to fewer service orders
        - Selective decision of applicants based on parameters (like optimal family size and income) will lead to fewer service orders [How would I test this – is it testable?]

11. Do you have any hypotheses to add?

12. If you were to decide my research area, what would you like to know more about?