Fall 2011

Residential solar energy in the Valley: A feasibility assessment and carbon mitigation

Deanna Leigh Zimmerman
James Madison University

Residential Solar Energy in the Valley:

A Feasibility Assessment and Carbon Mitigation

Deanna L. Zimmerman

A thesis submitted to the Graduate Faculty of

JAMES MADISON UNIVERSITY

In

Partial Fulfillment of the Requirements

for the degree of

Master of Science

Sustainable Environmental Resource Management AND

Integrated Science and Technology

December 2011

Dedication

This work is dedicated to my parents Kevin and Kathy Zimmerman, who taught me that it isn’t always easy to do the right thing and to Shea' McPeak, without whose never-ending support and love this work would not have been possible.

Table of Contents

List of Tables

List of Figures

Abstract

This project explores whether the Shenandoah Valley can achieve its 25x'25 goals in the residential sector using the two most feasible solar energy technologies, solar photovoltaic electric power production and solar thermal hot water generation. After a review of the barriers to the adoption of solar energy in households, the potential rates of adoption and energy output are estimated using U.S. Census data and Department of Energy data. Multiple scenarios are explored, including the "maximum theoretical" contribution of solar energy to the residential sector as well as scenarios of household behavior under different constraints. With respect to solar photovoltaic, it is argued that the "most likely" theoretical scenario is one in which about 15% of all occupied Valley households adopt a 1 kilowatt system. If that was so, then solar photovoltaic electricity would contribute about 1% of the residential sector's total energy needs in the Shenandoah Valley. Solar thermal would meet 2.7% of the entire Valley's energy needs. The associated carbon mitigation for solar PV is equivalent to about 5,222 passenger vehicles and 9,801 passenger vehicles for solar thermal mitigation potential.

Chapter 1: Introduction

Global warming will affect all of humanity one day, but changes are already being seen worldwide in climate and landscapes. With climate change an imminent and large scale issue, turning toward renewable energy is essential for survival. The scope of this problem scares people into thinking they couldn't possibly make a difference individually, but uniting populations toward the same goal is not an easy task either, so the question becomes how do we begin to solve this issue? The answer lies at the community level. A step in the right direction is investigating the feasibility of renewable technology adoption at the community level and the possible impacts it could have on much larger scale issues. Communities have the power to bring together smaller groups of people and collectively have the potential to make a bigger and positive impact on climate change.

Research Question

This dissertation will aim to identify the opportunities and barriers to achieving the goal of 25% of total energy being derived from renewable sources by 2025 in the Shenandoah Valley region with regards to the residential energy sector, via adoption and diffusion of solar photovoltaic and solar thermal technologies. These two solar technologies will serve as the focus for this investigation because they are easily installed into the current housing stock. New construction homes would certainly benefit from installing solar technologies, but new construction alone will not achieve the goal of 25x'25, which is why retrofitting the existing building stock is critical. Four categories of barriers and opportunities to solar technology adoption and diffusion will be addressed in depth including technical, economic, social, and public policy. The purpose of the analysis will be to thoroughly understand the factors that both enhance and delay the uptake of solar energy technologies in the region. The second part of this analysis is an estimate of the maximum possible adoption of such solar energy technologies and an estimate of their carbon dioxide displacement if adopted. By estimating the amount of electricity generated and offset via solar energy as applied to solar photovoltaic (PV) and domestic hot water respectively, an estimate of carbon dioxide mitigation levels will be determined.

This research question is intricately tied to the residential housing sector and its energy consumption characteristics. The residential sector in the United States accounts for about 22% of the total energy consumption from all sectors (EIA, 2009b). Residential buildings are accordingly responsible for 21% of the total U.S. greenhouse gas emissions as well (Hinrichs & Kleinbach, 2006). Almost one-fourth of the total energy in the United States is produced from the residential sector, which is why the 25x'25 Initiative is an instrumental organization. They strive to promote renewable energy technologies in all sectors, and focus on increasing the adoption of renewable energy. This national initiative has constructed the goal of achieving 25% of all energy from renewable sources by the year 2025. To achieve this goal, widespread changes will need to take place in energy use and correspondingly large amounts of greenhouse gas emissions need to be offset by renewable energies.

The amount of carbon dioxide emitted into the atmosphere in 2009 by the United States was 6.6 billion metric tons (EPA, 2011c). For perspective, this would equate to the annual greenhouse gas emissions of 1.3 billion passenger vehicles (EPA, 2011b). Carbon dioxide, a greenhouse gas (GHG), accounts for 83% of total GHGs that contribute to greenhouse effect, climate change, and global warming (Hinrichs & Kleinbach, 2006). GHGs, including methane, sulfur dioxides, particulate matter, carbon monoxide, and carbon dioxide are a byproduct of almost every activity, from electricity generation for heat and power to transportation to agriculture. Global warming is a concern for everyone because it could result in higher global temperatures, disruption of ocean currents, extreme precipitation, ocean level rise and coastal flooding, droughts, species endangerment or extinction, shifts in agriculture production and countless other issues. In order to slow climate change, major reductions in GHG emissions would need to occur. This could be partially accomplished with renewable energy sources such as solar, wind, biomass, hydro, and geothermal power (Hinrichs & Kleinbach, 2006).

Renewable energy sources such as solar technology have a multitude of benefits including a reduction in GHG emissions, better local air quality, and little operational maintenance. Renewable energies also supply a reliable source of domestic energy. The benefits of choosing renewable energy may seem obvious, yet the occurrence of renewable technologies, especially solar technology in the residential sector is staggeringly low, especially considering that the residential sector in the U.S. alone accounts for 21% of the total carbon dioxide emissions (Hinrichs & Kleinbach, 2006). The low occurrence of solar technology is due to a number of barriers which inhibit homeowners from choosing renewable technology. Currently only 5.4% of the total energy consumed in the United States is derived from renewable sources (Gelman, Hummon, McLaren, & Doris, 2010). Solar technology in particular only accounts for 0.1% of the total energy consumed, even though it has the potential to reach high market penetration which could have a large impact on the reduction of residential GHG emissions (Gelman et al., 2010).

Slowing climate change is not the only reason to choose renewable energies like solar technology though. Choosing renewable energy sources will reduce dependence on foreign oil and provide a reliable alternative to fossil fuels. Renewable energy sources also increase the environmental quality of an area, an externality which is difficult to measure and quantify. This externality is not accounted for in the consumption and real costs of fossil fuel sources. Renewable energies are also inherently localized energy sources which should be consumed close to where they are produced. Their widespread implementation would create local, rural jobs and strengthen local economies. Distributed generation of renewable energy would also increase national security with less demand on foreign fuel sources. With energy demand and prices increasing every year, the role of renewable energy sources in the energy industry has been steadily gaining momentum. As fossil fuel energy supplies dwindle, renewable alternatives will need to rise to the challenge of meeting demand and protecting environmental quality for future generations (25x25 National Steering Committee, n.d.b.).

Background

Uniting regional communities toward a similar goal may sound easier than trying to coalesce an entire nation, but it is still a difficult task. Organizations like the National 25x'25 Initiative help to accomplish this difficult task through regional demonstration projects which exemplify community activity and involvement in renewable energy alternatives. The research conducted for this thesis is an example of progressing toward the national goal with regional level information and community participation.

The 25x'25 Initiative is a voluntary, grassroots, non-profit coalition of over 400 organizations and people from agricultural, forestry, business, labor, and environmental industries that are dedicated to working towards the goal of deriving 25% of all energy from renewable sources like hydropower, wind, solar, and biofuels for the United States by the year 2025. It is an organization which helps coordinate energy efficiency and renewable energy issues on a federal policy level. This Initiative is financed by the Energy Future Coalition, a non-partisan group funded by foundations. The 25x'25 aims to bring new and clean technologies to the energy market (especially residential) and to consumers. Other key goals of the Initiative include increasing national security by reducing dependence on foreign oil from the Middle East, creating local jobs, improving air quality, as well as reducing GHG emissions (25x'25 National Steering Committee, n.d.a.). The United States has an abundance of renewable resources that can be utilized for energy such as wind power, solar, biofuels and biomass, among others. Total energy demand in the U.S. is expected to grow by 24% by 2025 (25x'25 Action Plan, 2007). By investing in clean technologies now, the energy demand for today and the future can be met with less of an impact on the environment and slow global warming (25x'25 National Steering Committee, n.d.c.).

The 25x'25 Initiative was originally focused on achieving its goals within the forestry and agriculture sectors in the western United States. California in particular decided that the 25x'25 goals should be implemented on a smaller scale than the national initiative, and in 2005 the San Joaquin Valley of California was the first regional demonstration project to take the 25x'25 goals to a community level. The San Joaquin Valley Clean Energy Organization (SJVCEO) is comprised of contributors from partnership work groups, educational institutions, community-based organizations, and agriculture and business leaders. (25x'25, n.d.). The SJVCEO and the 25x'25 Initiative decided to lead a regional effort to develop, plan and integrate energy efficiencies and clean energy in the San Joaquin Valley (25x'25, n.d.). A total of eight counties in the San Joaquin Valley joined together to support and encourage energy efficiency measures as well as the adoption of clean and renewable technologies (25x'25, n.d.).

The Valley 25x'25 is a subset of the national organization which is devoted to the same goal but on a much smaller scale: the Shenandoah Valley in Virginia. They are a voluntary, grassroots, non-profit organization. They are promoting a sustainable future through the organization, making it a shared community resource which is focused on helping residents and businesses strive to choose alternative energies and to conserve energy through efficiency measures (Valley 25x'25, 2011a). Following the San Joaquin Valley's example, 25x'25 supporters from the Shenandoah Valley region decided to conduct a demonstration project in the Shenandoah Valley, closely outlining the goals of the national initiative. Funding was sought and received from the 2010 Federal Budget, which allocated a grant of $750,000. This money funds research projects conducted by students at educational institutions, supports an educational campaign to raise awareness about energy efficiency and renewable energy in the Shenandoah Valley, and supports agrotourism (K. Newbold, personal communication, 8 September, 2011). The Shenandoah Valley has a sizeable goal of getting to 25% renewable energy by 2025, which is only 14 years away.

Residential solar was chosen as the focus of this thesis because solar technology offers a reliable and available source of alternative energy regardless of location and the residential sector could potentially save energy and reduce emissions by implementing such technology. The Valley 25x'25 is using all types of renewable energy to get to 25% in the next 14 years, but solar technology in particular is flexible enough to be installed almost anywhere. Virginia's solar resource is strong enough to make solar energy a viable option for almost all homeowners. Even though residential solar will probably not contribute the largest percentage to the 25% Valley renewable goals, it is a contribution that should be given due consideration nonetheless.

Solar Technology in the Residential Sector

The residential sector has the opportunity to make great use of the energy that comes from the sun through solar technology. There are numerous options for homeowners, including solar photovoltaic panels, building integrated elements, solar thermal domestic hot water heating, solar space heating, and passive design. Certain types of solar technology are better suited for new construction or are easier to implement for retrofitting existing homes. Technology which is easily installed as a retrofit will be of high importance, as this research is concerned more with retrofitting the existing housing stock rather than installations in new construction homes. Retrofitting the existing housing stock was chosen as a focal point because of the nature of this project. With 14 years left to make changes, it was decided that the existing housing stock would make more headway toward the Valley 25x'25 goals than new construction homes (which has shown a pattern of decline in the past 5 years). Each type of technology has various price ranges, meets different household needs and has different implications for installation and maintenance. One feature that all solar technologies have in common though, is that they are beneficial for the environment.

Photovoltaic panels use sunlight to generate electricity which can be used to power appliances and other electronic devices. Figure 1 shows the configuration of a typical solar PV system. Sunlight is converted into electricity within the panel and transferred to an inverter, which converts the direct current into an alternating current which is then compatible with the electricity grid and for use in the home.

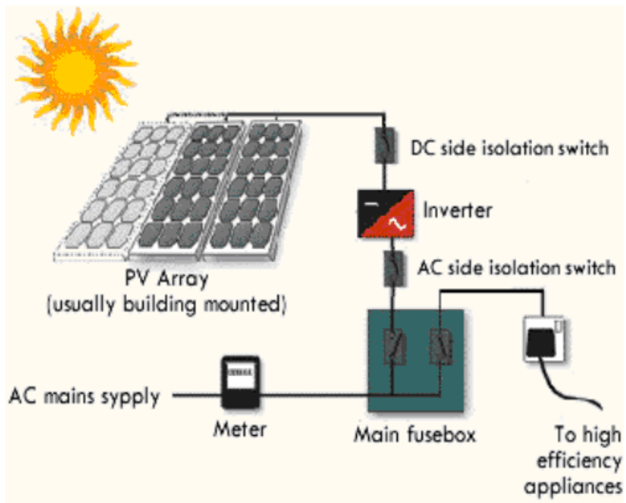

Figure 1. Typical Residential Photovoltaic System Configuration
Source: www.alternativeheatinginfo.com/Solar_Energy_for_Homes.html

Several PV cells combined make up a module, and multiple modules comprise a solar array, or a panel. Multiple solar panels combined create an entire solar PV system. The amount of light energy which can be converted into electricity increases with the size of the PV system. The size of the system needed depends on the amount of energy consumed, the number of people in the household, and operating conditions for the system at a particular geographic location. The typical system size for household energy consumption is roughly a 3 KW system (Yang, 2010). For reference purposes, a personal computer uses 50 watts when in use, or 0.4 kWh for 8 hours. A clothes dryer ranges from 1800 to 5000 watts of electricity use, and assuming 1 hour of use would consume a maximum of 5kWh in that time period. A 16-cubic foot refrigerator would use 725 watts over 24 hours but cycles on and off, and would require about 5.8 kWh of electricity daily (EERE, 2011c). The amount of electricity generated from PV panels differs by geographic location for the same sized system. For instance, in Virginia, a 3 KW system would generate 14.4 kWh per day, given a daily insolation rate of 4.8 kWh/m^2/day, which is the average amount of solar radiation that a solar PV panel in the Shenandoah Valley would receive. A 3KW system in Maine would generate only 12 kWh daily and the same sized system in Arizona would generate 19.5 kWh per day (NREL, 2008).

The cost effectiveness of a solar PV system varies however, depending on the output of the system, consumer rates for electricity, and the availability of subsidies. Depending on various federal, state, and local incentives, the subsidized cost of a PV system could be between $4,000 and $45,000. In 2009, installed PV prices were around $8.60 per watt (NREL, 2011). As prices fall to around $1.50 to $2.00 per watt, solar technologies will likely become competitive with traditional sources and therefore become more familiar and affordable in the residential energy market (Duke, Williams, & Payne, 2005; Yang, 2010).

Solar PV technology is also commonly used in building integrated elements. While it may be more convenient to integrate solar technology into new construction homes, being able to retrofit an existing home is essential because solar technology needs to be implemented without rebuilding an entire housing stock. Retrofitting the existing housing stock is a core component of this thesis because new construction would not be able to achieve the 25x'25 goals. By integrating solar technology into an existing residence, it will help to increase overall efficiency and reduce energy loads for conventional fuels. An example of building-integrated solar technology is solar shingles. Solar shingles can reduce the amount of construction material needed to build or replace a roof, while adding durability and duality to a single building aspect (EERE, 2000).

Photo A

Photo B

Figure 2. Solar shingles

Source: Photo A: Charlotte Solar Power, n.d.
Photo B: Durability and Design, 2010.

The cost of solar shingles varies by brand and size of system, but shingles will generally cost around $7,000 per kilowatt installed (Wood, 2007). A single PV shingle (86"x12") will generate about 17 watts of electricity per square foot. In order to create a 1 KW system, it would require about 60 shingles, and 420 square feet of roof space, which would equate to a roof 42 feet by 10 feet or a roof at least 20 feet by 22 feet. Clearly, solar shingles require significantly more space to generate the same output as about four PV panels which would require about 100 square feet of roof space (Uni-solar, 2003). Compared to typical PV panels, the output for a solar shingle is less per square foot and costs are within a similar range, but shingles are marginally less expensive. Homeowners may find solar shingles more attractive or less obtrusive aesthetically than conventional panels, however replacements are much more labor, time and money intensive. For the purpose of this investigation, PV panels will be focused on because they are easier to implement on an existing home without as much renovation, as well as the fact that they are more familiar to the consumer than building-integrated solar shingles.

Another form of solar technology that is widely used is solar thermal domestic hot water heating. There are two categories of solar hot water systems which can be used for domestic use, active and passive (or thermosiphoning). Active systems utilize pumps and controls; passive systems do not use external sources of energy but rather circulate water by natural means with temperature differentiation (EERE, 2011f; Hinrichs & Kleinbach, 2006). Generically, a solar hot water (SHW) system will have a solar collector and a storage tank. There are options for a one-tank or two-tank solar hot water system. Two-tank SHW systems use one tank to preheat the water with the solar collector before being sent to a conventional water heater, which minimizes additional heating by natural gas or electricity. A one-tank system utilizes the conventional water heater as the storage tank for the water heated by the solar collector (EERE, 2011f).

Domestic solar hot water system prices vary by size and location but will range from $4,000 to $10,000, but will likely be lower with government incentives. Domestic solar hot water system sales are growing slowly at 5% annually even though they have the potential to meet a majority of a household's hot water needs (depending on the amount of daily solar radiation), according to a study done by The Sacramento Municipal Utility District (Hinrichs & Kleinbach, 2006).

Solar hot water in a residential setting varies in usefulness, though. Depending on the amount of solar radiation, type of system, rate of recharge, and the number of household members, a solar hot water system will differ in cost effectiveness. Passive solar hot water systems are best suited for climates where freezing temperatures are rare because such a system is more prone to freezing pipes due to the direct circulation of the water to be consumed in the household. Active solar hot water systems frequently utilize indirect circulation. Indirect circulation often adds an anti-freezing agent (such as propylene glycol) to water which is used as a heating medium that is then circulated through pipes and heats the water to be consumed within the storage tank itself. Indirect circulation in a hot water system is best suited for colder climates where freezing is prone to happen. The typical output for a residential solar hot water system will vary by geographic location. For Virginia, it will be around 4,000 to 5,000 BTU annually, based on calculations from average household hot water use and total state energy consumption per household (EIA, 2005a; EIA, 2005b). The flow rate for a solar hot water system varies between 0.5 to almost 2 gallons per minute (Alternate Energy Technologies, LLC., n.d.). Solar hot water has the potential to meet much if not all, of a household's hot water needs, but the cost effectiveness of such a system will vary by a number of factors.

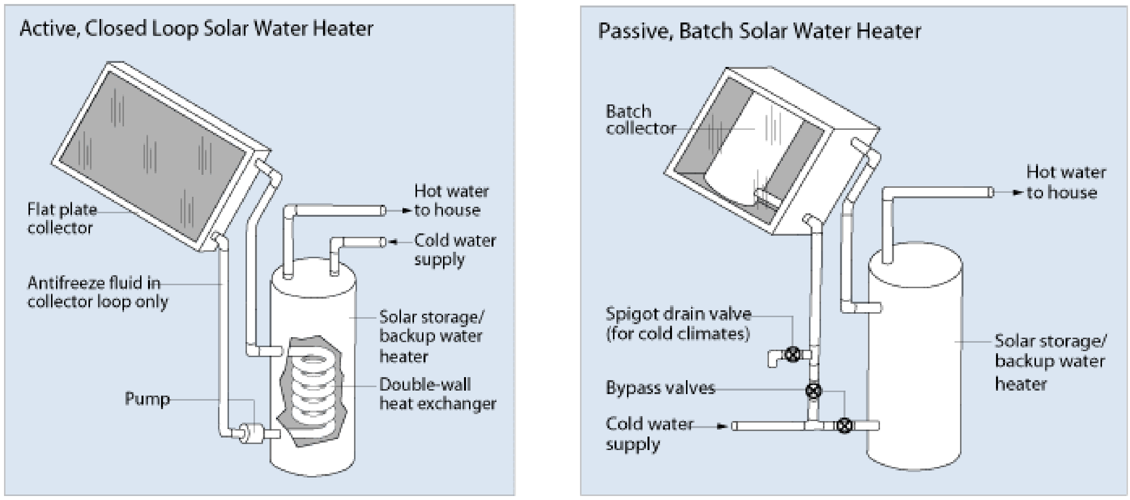

Figure 3. Configuration of Domestic Active and Passive Hot Water Systems
Source: (EERE, 2011f).

Another option for residential solar technology is solar space heating and cooling. Space heating and cooling account for about half of total energy use in a home (EIA, 2010c). Solar space heating works much the same way as solar hot water, except that the medium being heated is air instead of water. Two types of solar space heating include using a fluid as a heating medium or air. Solar air heating systems include room heating and transpired air collectors. A solar air collector can also be used to preheat the air for a heat pump. The air collectors for space heating are usually installed on the roof or a south facing wall of a building. The solar collector with glazing absorbs radiation from the sun and heats the air in an insulated box. A fan, blower, or pump exchanges the hot and cool air via ducts to be distributed throughout the house or to a hot air storage container. Transpired air systems use metal plates installed with a dead space on the south facing wall of a building. Even on cloudy or cold days, the air between the plates and wall can heat up as much as 40°F. Air systems do not degrade over time and do not freeze like liquid systems do, but are less efficient because a liquid is a better heat transfer medium than air (EERE, 2011e).

Liquid systems work very much like a solar hot water system, also heating a non-toxic antifreeze heating liquid such as propylene glycol rather than water, so that the heat can be transferred even in freezing temperatures. The liquid flows from the collector to a storage tank or to be distributed as heat immediately to minimize heat losses from the system (EERE, 2011e). Heat storage for this type of system would be a standard water heater, or it could be piping under the flooring for radiant heating. It is important to consider the storage needs of the home and the size of the system and the tank needed. Radiant flooring is an integrated building technique using solar technology which is efficient, though slow to heat up initially. Another option is to distribute the heat with baseboards or vents though they require higher temperatures to function which would require an additional input of energy from another source (EERE, 2011e). Central forced air can also use a coil but this system would also require additional input from a furnace for example (EERE, 2011e).

Solar space heating and cooling can be very useful in the residential sector, but the construction and implementation of solar in new homes is more likely because much of solar space heating technology is designed to be building-integrated. It is harder to retrofit older homes for solar space heating, even though the technology is attractive to homeowners. Solar walls, for instance (seen in Figure 4), can be installed not only in single family dwellings, but also in apartment complexes. Active solar space heating can be implemented in existing homes, but would require extensive renovation in order for such a system to be operational and efficient. An active solar space heating system will generally cost between $30 and $80 per square foot of collector area (EERE, 2011a). The renovations would then create additional costs for installation of this type of system making it less cost effective and attractive for existing homeowners. Another point of contention for solar space heating in the Valley is that it does not readily fit into the time constraints of the Valley 25x’25 Initiative. The year 2025 is only 14 years away, and to expect widespread installation and renovation for solar space heating for homes in the Shenandoah Valley is unrealistic, even though it could make a small contribution. Solar space heating will not be an area of focus due to the fact that the existing housing stock in the Shenandoah Valley has a greater chance to make a positive impact by retrofitting and making use of solar PV and solar hot water systems.

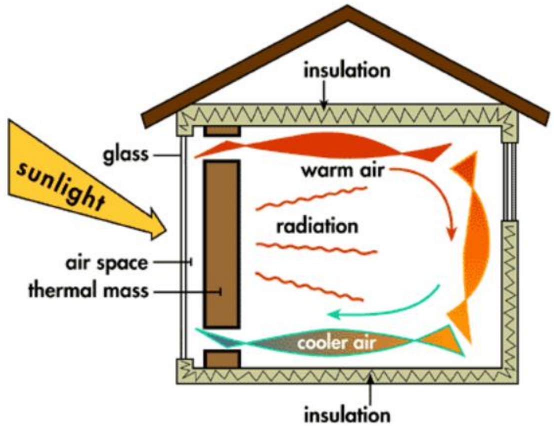

Figure 4. Diagram of a Solar Wall Illustrating the Heat Flow Process
Source: http://www.iklimnet.com/save/passive_solar_heating.html

Figure 5. Photo of a Commercial Solar Heating System on a Roof
Source: http://ircmaine.com/solar/solar-thermal-2

One of the market trends in residential solar technology is to integrate passive design. Passive design is an aspect of solar technology which does not require any mechanical or electrical parts in order to operate, but must be installed when the home is built. Unlike active solar heating, there are no pumps or fans required for passive heating. There are five main elements of passive solar design in a home: aperture, absorber, thermal mass, distribution, and control. Aperture refers to the windows which allow light into the home (EERE, 2011d).

Orientation of a home to the south for instance, may increase the efficiency of PV panels and allow for maximum natural daylight, reducing the heating and lighting demand. South-facing orientation is optimal for most homes (EERE, 2000). The absorber is an element within the home (a wall or floor) which is directly hit with sunlight and transfers the heat to the thermal mass, which stores the energy as heat (EERE, 2011d). Certain materials (such as concrete or brick) can act as insulation on the outside (or inside) of a home, absorbing heat during the day and slowly losing it over night, acting as a buffer to temperature change. This can reduce the need for heating or cooling (EERE, 2000). The distribution of heat is usually achieved through conduction, convection or radiation from the absorber/thermal mass surface. In certain cases, a fan will help the distribution of heat (EERE, 2011d). The control aspect of a passive home refers to the ability to maintain a comfortable temperature. Thermostats are an example of an automatic control which will only operate when the temperature reaches a certain point (EERE, 2011d). Overhangs can shade windows as a cooling mechanism in the summer when the sun is higher in the sky and allowing sunlight through in the winter when the sun path is lower. Shading with deciduous trees or other nearby buildings is also important to consider for minimizing cooling demand (and therefore requiring less electricity) but the shading may also inhibit maximum PV panel functionality. Even a simple act like installing double pane windows with a low emissivity coating can help to reduce heating and cooling loads, while allowing natural light to reduce lighting needs (EERE, 2000). Figure 6 illustrates the elements of passive design.

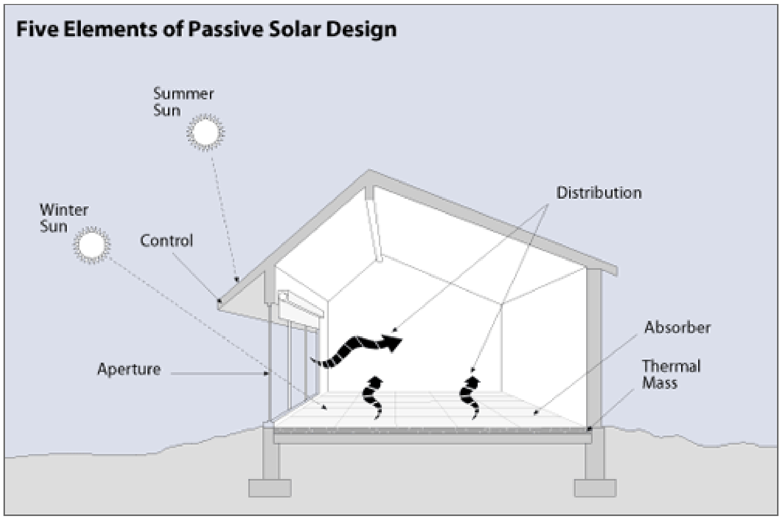

Figure 6. The Five Elements of Passive Solar Design
Source: EERE, 2011d

Passive design elements in the United States housing stock are fairly common. Overhangs and shading, insulation, and a tight building envelope are all factors that are usually considered. These passive design elements are also fairly easy retrofit improvements which can be made to an existing home. However, windows, thermal mass, and orientation are more expensive or harder to renovate (California Energy Commission, 2011). Replacing old windows with newer double or triple pane windows with a glaze or coating can be expensive, or installing new windows to the south facing exposure on a home requires considerable renovation. The thermal mass materials would also be very difficult to replace or renovate, and the orientation of a home cannot realistically be changed once it has been built (California Energy Commission, 2011). The passive design elements of a home that can easily be changed (shading, insulation and building envelope) are more closely related to energy efficiency improvements which will not lend a large addition toward the solar energy contribution from the residential sector's to the goal of achieving 25x'25. Because it will not make a sizeable contribution and due to the fact that extensive renovations could be required for some passive design elements (which are time and money intensive), passive solar design technology will not be included in the analysis.

Shenandoah Valley Demographics

The Shenandoah Valley regional demographics, housing, and social characteristics will influence rates of adoption rates of solar technology. Household distribution among counties and independent cities will also indicate where efforts should be focused for informational campaigns. New construction represents a small portion of the total households, and thus, owner occupied households and the distribution will be of great significance in order to determine potential solar technology adoption rates.

The Shenandoah Valley Region as defined by the Valley 25x'25 Initiative is comprised of 11 counties which include Allegheny, Augusta, Bath, Clarke, Frederick, Highland, Page, Rockbridge, Rockingham, Shenandoah, and Warren. The Shenandoah Valley study area stretches from the northern city of Winchester south to Lexington, including the independent cities of Buena Vista, Covington, Harrisonburg, Staunton, Lexington, Waynesboro, and Winchester.

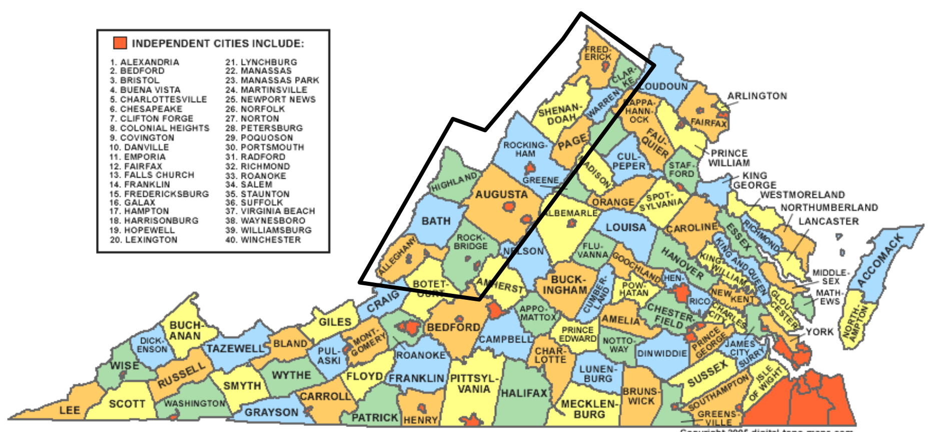

Figure 7. Map of Virginia Counties with Shenandoah Valley Area of Interest
Source: http://www.digital-topo-maps.com/county-map/virginia.shtml

The Shenandoah Valley has a total population of about 382,000 people with an average age of 40 and median annual household income of around $46,000. Generally speaking, the area has a high graduation rate from high school and close to one out of five residents chose higher education. Homeowners account for about 70% of the housing stock (US Census Bureau ACS, 2009). These demographics give a snapshot view of the Shenandoah Valley, which will be significant factors for calculating the maximum possible adoption of solar technology.

The total number of housing units for the Shenandoah Valley is estimated to be 222,983 housing units. The occupied housing units are only roughly 89% of that total, or 199,166 housing units. Owner occupied housing units (OOHU) are approximately 70% of the total occupied housing units, and renter occupied housing units account for roughly 30% of the total housing units in the Valley. These statistics are indicative of the existing housing stock and each year new homes are built in the Valley. In order to follow building laws and codes, a dwelling permit must be issued before a home can be built. Figure 8 below shows the number of single-family housing permits issued by the Shenandoah Valley for the last five years.

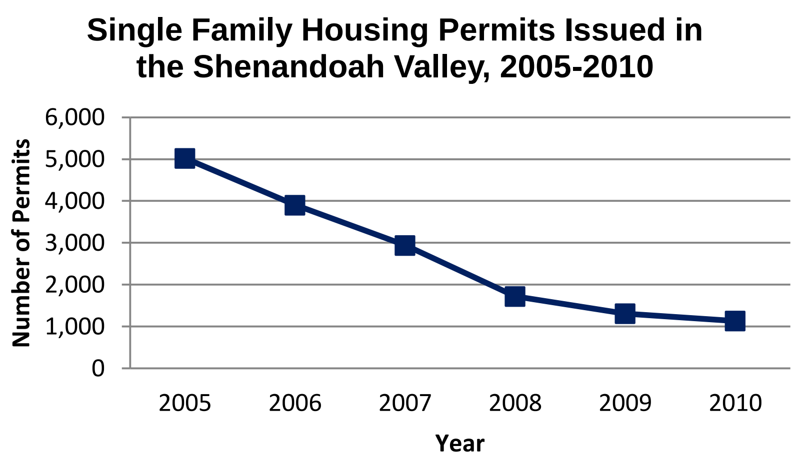

Figure 8. Single Family Housing Permits Issued in the Shenandoah Valley, 2005-2010
Source: U.S. Census Bureau, 1990; and author's calculations. See text.

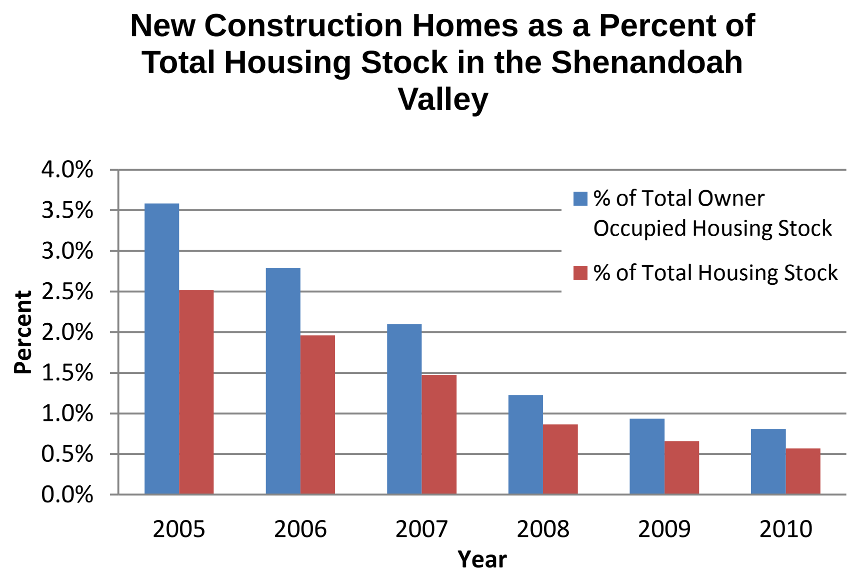

Figure 9. New Construction Homes as a Percent of Total Housing Stock in the Shenandoah Valley
Source: U.S. Census Bureau, 1990; and author's calculations. See text.

Clearly, Figures 8 and 9 demonstrate that the new construction in the Valley is only a small part of the housing stock. In 2010, new construction didn't even account for 1% of the total housing stock. For all five years, new construction single family dwellings accounted for roughly 8% of the current total housing stock. Even making full use of building integrated solar technology elements (including passive design), new construction would only contribute a small portion of solar technology toward the goal of 25x'25. The recent trend in housing clearly shows a downward decline which will probably not improve drastically enough to make the impact needed to achieve 25x'25 in the residential sector in the Valley within the next 14 years.

The Shenandoah Valley shows potential in regards to income, education, geographic location, and housing stock. The median income is around $46,000, with a median age of 40 and about 20% of the populace attending some college. In the last five years, only 8% of the total housing stock was new construction, and while it does not present much of an opportunity to achieve the goal of 25x'25, it does indicate that much of the housing stock will be available for retrofit. Barriers and opportunities to solar technology adoption and diffusion will influence the rates or likelihood of such adoption occurring.

Barriers and Opportunities to Solar Technology Adoption

There are a number of barriers to the adoption and diffusion of solar technology in the residential sector, but fortunately there are also many advantages to help outweigh these disadvantages. Various technical and non-technical barriers are examined at a broader, national scale to give context for smaller community-scale adoption and diffusion issues in the residential sector. Adoption and diffusion factors specific for the Shenandoah Valley region will be explored in Chapter 2. There are four main categories of barriers and opportunities to adoption of solar technology in the residential sector which includes: technical barriers, information and awareness barriers, consumer economic decision making barriers, and difficulty overcoming established systems.

Technical barriers to solar technology adoption usually refer to the effectiveness of a particular technology, such as a solar PV panel. Efficiency is not to be confused with effectiveness of a technology; efficiency is the capacity utilization or maximum possible output under prime operating conditions, whereas effectiveness refers to the maximum possible output given standard or average operating conditions (Hinrichs & Kleinbach, 2006). The effectiveness of a PV panel will vary depending on amount of sunlight and shading, positioning, geographic location, time of year, and topography to name a few. Good planning prior to installation can increase the effectiveness of solar energy technologies. Another technical problem with solar technology is the ability to retrofit existing homes. Some solar technology, such as passive design, needs to be incorporated into new construction which presents issues for the existing housing stock.

The lack of information dissemination, knowledge and awareness of solar technology is considered a non-technical barrier for homeowners or consumers (Margolis & Zuboy, 2006). Information and awareness issues are often correlated with the amount of education attained. Homeowners should not only be educated about solar technologies such as solar PV, solar hot water, and passive design and how it can be implemented in their home, but they should also be educated about electricity needs and their personal consumption trends (U.S. PV Industry Roadmap Steering Committee, 2001). Lack of knowledge and education can also be applied to industry workers as well. A concern for homeowners is the lack of qualified and competent installation technicians, which will also influence the rate of adoption.

One of the most prominent barriers to adoption and diffusion of solar technology in residential homes is the high cost of solar technology, especially when compared to conventional energy sources (U.S. PV Industry Roadmap Steering Committee, 2001). The perceived or real payback period required for a return on investment may deter homeowners from choosing solar energy sources for a number of reasons. Homeowners are also likely to be skeptical about the ease of installation and the capital cost to install a system. Other concerns include the length of time that a resident will be in their home, and whether or not they own their home. These factors greatly contribute to whether or not a homeowner will decide to choose a solar energy system.

Difficulty overcoming established energy systems is a barrier to overcome as well. Electricity grid systems are designed in a way that is practical for large, central power generation plants and distribution. Solar distribution requires a more localized production and consumption system, which is not easily compatible with current systems. Consumers who choose solar energy systems which require connection to the grid are met with interconnection, stand-by, and sell-back policies which mandate charges and fees. Net metering is sometimes required when connected to the grid, yet residential energy producers rarely receive market price for electricity production (Margolis & Zuboy, 2006; U.S. PV Industry Roadmap Steering Committee, 2001).

These four categories of barriers and opportunities outline the factors influencing the adoption and diffusion of solar technology in the residential sector and will help determine the potential of such technology in the Shenandoah Valley. The implications of these barriers and the factors which prove to be more easily surmountable will become clear as the Valley progresses towards the goal of achieving 25% renewable energy by 2025.

Methods and Key Findings

The goals and time frame of the Valley 25x'25 are ambitious to be sure, but projects like this feasibility assessment will help get the Valley moving in the right direction. The residential sector accounts for about 22% of total energy consumed in the United States (EIA, 2009b), and is responsible for 21% of the total U.S. GHG emissions (Hinrichs & Kleinbach, 2006). If the Shenandoah Valley is a representative population, the residential sector in the Valley has the potential to make a substantial contribution to the Valley 25x'25 goals. However, there are barriers which stand in the way of widespread solar technology adoption and diffusion throughout the Valley. Technical issues, lack of knowledge and awareness, consumer economic decision making barriers, and overcoming established systems will all prove to be complex obstacles to the adoption and diffusion of solar technology.

The technologies that have the best chances of high rates of adoption and diffusion in the Valley residential sector are solar PV and solar thermal hot water. The most important factor in this consideration is that they are easily retrofitted into the existing housing stock. Solar PV and thermal are also more likely to be familiar to the average resident than building integrated technologies, such as solar shingles or solar walls. The Shenandoah Valley has a good solar resource, which will lend itself to sizeable outputs and offsets in GHG emissions for PV and solar thermal.

The methodology followed to find the real feasibility included an assessment of the total number of owner occupied housing units and then a process of reducing the maximum number of potential homes by the demographic factors of income, education, and age, which influence adoption rates. The scenario for the maximum theoretical number of homes proved to be very unrealistic, and the most likely solar technology adoption scenario conveyed that solar technology would meet less than 1% of the total energy needs for the Shenandoah Valley.

Overall Structure of Dissertation

The following chapters of this dissertation will aim to explain and establish the real feasibility of attaining the 25x’25 goal for the residential sector in the Shenandoah Valley. Chapter two will give a background and context for the research to be conducted in the Valley. It will also explain the opportunities and barriers for the residential sector in the Shenandoah Valley and define the scope of energy use within the Valley, as well as list the financial incentives available to homeowners for solar technology. Chapter three contains the benefits and costs of solar technology in the Shenandoah Valley, including the maximum theoretical concept, a benefit cost analysis for both solar PV and solar thermal, as well as a carbon dioxide mitigation analysis. Chapter four contains the estimates of rates of adoption of solar technology in the Valley. Various demographic scenarios are examined, and the real likelihood of solar technology adoption is determined. Chapter five is a conclusion which will summarize results, explain the real likelihood of solar technology adoption in the Shenandoah Valley, and analyze the feasibility of achieving the goal of 25% by 2025 for solar thermal hot water and solar PV in the residential sector, as part of the larger scope of the 25x’25goals in the Valley.

Chapter 2: Background and Literature Review

Determining the feasibility of achieving 25% renewable energy in the Shenandoah Valley by 2025 must first start with examining the bigger picture and the larger scope of energy use. This chapter seeks to understand the extent and uses of fossil fuels as well as the role renewables play in the residential sector at the national, regional, state, and community level. The knowledge of energy use at various societal levels will provide context for energy use in the Valley. The demographic and household characteristics will play a vital role in determining the amount of adoption and diffusion of solar technology which can be achieved in the Shenandoah Valley, especially the ease and ability of the existing housing stock to retrofit for solar technology. The Valley demographics will be explored and applied to adoption and diffusion factors, which are extracted from a literature review. Federal, state, and utility financial incentives available for the residential sector will also be examined to determine the role they play in the adoption and diffusion of solar technology for the Shenandoah Valley.

National Energy Use

In 2009 the United States' energy production totaled 73.5 quadrillion BTU. Natural gas accounts for 33% of the total, followed closely by coal which produced 29.7% of the nation's energy. Including hydropower, renewable energy generation for 2009 in the U.S. was 10.6%, with the remainder being generated by crude oil or nuclear power (Gelman, 2010). These figures will be useful when Virginia's energy use is compared to the United States energy use patterns; if they are similar, the role of solar technology in the residential energy may be increased in scale and applied at a national level to increase use of renewable energies and reduce GHG emissions. The 25x'25 Initiative could make an example of the regional demonstration projects which are taking place at the community level and implement them at the national level.

The residential sector in the United States consumes roughly 22% of total energy consumed in the nation each year (EIA, 2009b). As seen in Figure10, natural gas accounts for the largest share of energy consumption, followed closely by electricity. Fuel oil and propane together account for less than 15% of all energy consumed in the United States. The residential sector includes energy consumption only for stationary combustion used in built structures, and does not include energy consumption from any other sector, such as commercial buildings or transportation. Since the residential sector consumes almost one-fourth of the total energy consumed in the nation, it has great potential to reduce energy consumption and GHG emissions by implementing renewable energy alternatives. Because natural gas and electricity are also used heavily in the Shenandoah Valley residential sector the potential to reach the 25x'25 goals is hopeful.

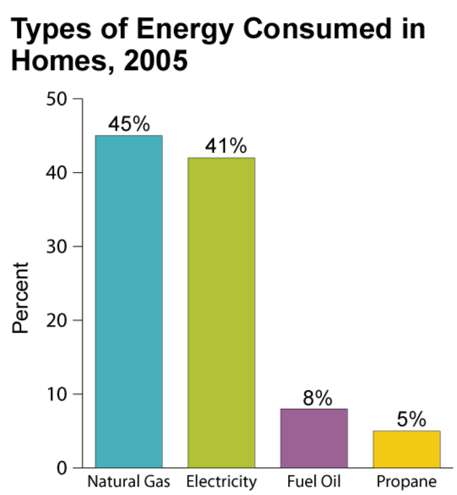

Figure 10. United States Share of Total Energy Use by Fuel Type in the Residential Sector
Source: U.S. EIA, *2005 Residential Energy Consumption Survey*

The biggest contributors to household energy consumption are space heating, lighting, and hot water heating, as can be seen in Figure 11. Combined, they account for 87% of all household energy use. Lighting (26%) and water heating (20%) account for nearly half of all residential household energy consumption (EIA, 2010b). According to the Residential Energy Consumption Survey (RECS) from 2009 produced by the EIA, the average household in the United States consumes about 95 million BTU of energy each year, an average of almost 8 million BTU each month (with expected fluctuations for heating and cooling seasonally) (EIA, 2011c). Also according to the survey, natural gas is the most prominent home heating fuel, used in nearly half of the homes. Use of electricity for heating also increased, and fuel oil use declined by about 4% for the same year (EIA, 2011d).

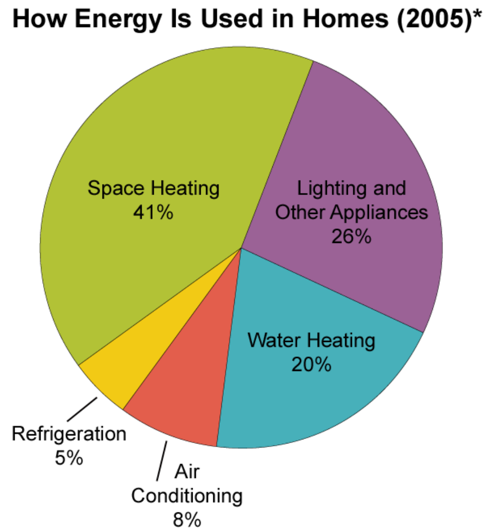

Figure 11. United States Household Energy Use
Source: U.S. Energy Information Administration, 2005 Residential Energy Consumption Survey

The 2009 RECS also supplies statistics for energy efficiency measures, which help to lower heating/cooling and lighting costs. Of all occupied houses in the United States, 58% had energy efficient multi-pane windows, 35% weatherized their home to prevent air leaks, 23% added insulation and roughly 37% purchased energy efficient appliances, including refrigerators and washing machines. Sixty percent of the households in the U.S. invested in CFL or LED lighting (EIA, 2011d). Energy efficiency measures are an easy investment to make when trying to lower utility bills which also explains the high acceptance percentages, but these measures alone will not be enough to reduce GHG emissions or any of the other benefits which come from renewable energy alternatives. The average national energy consumed in homes broken down by use provides context which can be compared to state and regional energy use. If the Shenandoah Valley were to implement energy efficiency measures such as those listed above, combined with installing solar technologies, the potential for energy savings would be even greater. If this took place, the goals of getting to 25% renewable energy in the next 14 years would be more easily achieved.

Shenandoah Valley Scope of Energy Use

The residential sector in Virginia consumed 289.2 trillion BTU of end-use energy (EIA, 2009c). Virginia also consumed 152.7 trillion BTU of electricity in 2009, which equates to about 53% of all Virginia residential energy (EIA, 2009c). To find the average household energy consumption, the total energy use in BTU was divided by the 2009 estimate of Virginia population, which totaled about 8 million people (U.S. Census Bureau, 2011b). This calculation resulted in 36,150,000 BTU per capita, which was then multiplied by 2.36 to represent the average number of household residents in the Shenandoah Valley. The result was an annual household consumption average of 85,314,000 BTU which can be used in calculations to determine the total percent of energy use which solar technology generates. This is a limited estimation technique, due to the number of calculations required to move from the state level to the community level, to the household level. Households will also vary by individual consumption characteristics.

The residential sector in Virginia accounted for 12.1% of total energy consumption in the state in 2009 (EIA, 2009b). This percentage accounts for energy actually consumed in the home, and does not account for energy losses through electricity transfer. If the losses are included in this figure, the figure changes to 25.6% of Virginia's total energy consumption. Virginia's residential sector consumes more energy by about 4% when compared to the national average. This is a substantial difference when 4% is measured in trillions of BTUs. This difference could be accounted for by the presence of the nuclear power plants which are energy intensive, and are used to generate electricity that supplies half of the energy consumed in the residential sector. Kentucky, which has no nuclear power plants, only consumes 19% of the total energy in the state in the residential sector. North Carolina, which has eight nuclear power plants, consumes roughly 28% of the total energy in the state in the residential sector (NRC, 2011). Residential energy use in Virginia comes from a variety of sources but is provided primarily by electricity, accounting for 53%. Natural gas (29%) and petroleum (14%) are also big contributors for providing energy to the households in Virginia (DMME, 2010). Virginia has two nuclear power plants which supply electricity to about 1/3 of the entire state. Virginia relies heavily on coal fired power plants for electricity, which typically provide about half of the state's electricity generation (EIA, 2009d). Because Virginia residential energy use (including losses) accounts for a higher percentage the national average, the state will have to work harder than other states to achieve 25% of its total energy from renewables by 2025.

The Shenandoah Valley currently uses electricity to meet roughly 43% of home heating needs, followed by utility gas, which makes up another 20% (U.S. Census Bureau American Community Survey, 2009). Other fuels used in home heating in the Valley are fuel oil or kerosene (17%) and liquid propane gas (11%). Less than 1% of heating comes from solar sources (U.S. Census Bureau American Community Survey, 2009). Table 1 shows the fuel type used for home heating and percentage of homes that utilize each fuel. Clearly, if solar is only being used for less than 1% of home heating fuels, then there is a long way to go to reach the 25x'25 goals for residential home heating. However, because a large percentage of the homes in the Valley use electricity for home heating, the adoption potential for solar PV is greater than for those homes which use fossil fuels, because a retrofit will be easier. A home using electricity will only need to install the solar equipment because it is already designed for heating with electricity whereas a home making use of oil will require more alterations. The average electricity rate for Virginia homes is 10.61 cents per kWh as of May 2011. Virginia's residential electricity rate is lower than the average U.S. rate of 12.03 cents per kWh (EIA, 2011c).

Table 1. Percent of Homes Using Various Home Heating Fuels in the Shenandoah Valley

Home Heating Fuel	
Occupied Housing Units	Percent of Homes Using Fuel Type
Utility gas	20%
Bottled, tank, or LP gas	11%
Electricity	43%
Fuel oil, kerosene, etc.	17%
Coal	< 1%
Wood	8%
Solar energy	< 1%
Other fuel	< 1%
No fuel used	< 1%

Note: Percentages may not add up to exactly 100% due to rounding.
Source: U.S. Census Bureau American Community Survey, 2009, and author's calculations. See text.

Demographics and Household Characteristics

Demographics

The demographics of the Shenandoah Valley are of interest to this research because the quantity and distribution of social, educational, and housing characteristics will influence the adoption rates of solar PV and solar thermal in the residential sector. The demographics of income, education, and age, will shape scenarios which will ultimately determine the likelihood and feasibility of adoption for the Shenandoah Valley.

The Shenandoah Valley has a population (16 years and older) of over 411,000 people within its 11 counties. Of the 411,527 residents age 16 or over living in the Shenandoah Valley, 246,652 are employed in the civilian labor force (not in the armed forces) and 12,270 are unemployed. The 12,270 people who are unemployed are defined by the U.S. Census Bureau American Community Survey (ACS) as without a job but looking for work. There are also 152,083 people which are included in the population which are not in the labor force. Included in this category are those that are not looking for work, students, homemakers, retirees, seasonal workers, etc. The unemployment rate in 2009 for the Shenandoah Valley is 4.73%, which is lower than the national unemployment average of 9.3% for the same year (BLS, 2009).

The age groups for the Shenandoah Valley population have a normal distribution. From younger than age 5 to 15 the range varies between 30,000 and 31,000. The population per age group increases with age until age 54, after which it declines drastically. The median age for residents in these counties was estimated by the U.S. Census Bureau American Community Survey at around 40 years old. This information is valuable because generally speaking, people at this age are typically established and stable with housing and career choice which could indicate a larger audience which may be more open to solar technology implementation than a population with an average age of 25. The age distribution for the Shenandoah Valley is essential to understanding adoption patterns because certain age groups will be more likely to adopt renewable technologies than others. The population aged 45 to 54 years has the highest numbers of people, at 74,821 people. Depending on the barriers present for the region, it could be a favorable or unfavorable fact.

There are 338,044 people in the Shenandoah Valley age 25 or older. Of these, 149,262 or 44% have attended at least some college, or have a degree. Close to 22% of the population over age 25 has achieved a Bachelor's degree or higher, and for the entire Valley, over 80% of residents are at least high school graduates (or equivalent). The amount of education directly correlates with income, which will indicate the amount of disposable income and therefore the affordability of solar technology for the "average" Shenandoah Valley resident. Almost 20% of the population age 25 or over, however, never finished high school (U.S. Census Bureau ACS, 2009). This information will be important in correlating the education and awareness levels which are influential to renewable technology adoption.

One of the most important factors to consider about the Shenandoah Valley population is household income. The amount of income will directly affect the amount of disposable income which will in turn affect the ability of a homeowner to purchase a solar system. The income data acquired from the American Community Survey is reported in 2009 inflation adjusted dollars. There are ten income brackets, which are not evenly distributed. It should be noted that the data was normalized by the Census to create a normal distribution. The following table shows the distribution of income for the Shenandoah Valley.

Table 2. Income and Benefits in 2009 Inflation Adjusted Dollars for the Shenandoah Valley

Income and Benefits	Number of Households	Percent of Total Households
Total Households = 199,166		
Less than $10,000	13,306	7%
$10,000 to $14,999	12,253	6%
$15,000 to $24,999	22,423	11%
$25,000 to $34,999	23,064	12%
$35,000 to $49,999	31,370	16%
$50,000 to $74,999	40,428	20%
$75,000 to $99,999	25,913	13%
$100,000 to $149,999	20,527	10%
$150,000 to $199,999	5,901	3%
$200,000 or more	3,981	2%

Source: U.S. Census Bureau American Community Survey, 2009, and author's calculations. See Text.

It is easily seen that the highest number of households earn between $50,000 and $74,999 annually. There are almost twice as many households that earn less than $50,000 than households that make more than $74,999 (102,416 compared to 56,322). The median income of all counties was determined and then averaged together to find that the average median household income for the Shenandoah Valley was $46,140.

Home Ownership and Household Characteristics

The Shenandoah Valley has 199,166 total occupied households. Multiple dwelling apartment buildings were excluded in this analysis because apartment buildings are often rented and therefore occupants would not have ownership of the roof. There are 174,663 units which are either one unit attached or detached buildings. These homes were selected because it was assumed that they would have the right or ability to install solar technology (i.e., landlord owned or owner occupied), whereas apartment buildings would require permission from a higher authority, such as an apartment building supervisor or landlord. If mobile homes are included, the total increases to 190,895 homes. This only gives a picture of the total occupied housing units, and not ownership status, which will affect the ability to install solar panels. The 190,895 homes may include owner occupied as well as renter occupied housing units, so this number assumes that some landlords would be willing to install solar technology if they pay the utilities (namely water and electric). Not all landlords pay utilities however, because it would not be cost effective or attractive to renters if the price of rent were to increase to cover the cost of the installed solar system. For this study, renters and landlords will be excluded and only owner occupied dwellings will be studied.

The owner occupied houses in the Shenandoah Valley totals 139,990 households (59,176 renters). This information can lead to the assumption that 70% of the housing stock in the Shenandoah Valley will be the maximum number of housing units which might adopt solar technology (U.S. Census Bureau ACS, 2009). It is assumed that owner occupied houses are either stand alone dwellings (one unit detached), 1 unit attached (for example, duplexes) or mobile homes and not located in a multi-dwelling apartment building. The owner occupied dwellings will be used as the baseline to determine the maximum possible adoption. The 70% of the housing stock offers a baseline maximum adoption, but doesn't infer a *realistic* maximum possible adoption due to other factors which must be considered, such as income and economics of the region.

Two factors closely related to income are whether or not a homeowner has a mortgage, and monthly home costs for a homeowner. Out of 139,990 owner occupied homes in the Valley, 63% (88,161) of homeowners have a mortgage on their home, and 37% (51,829) do not (own it free and clear). The U.S. Census ACS reports data on the selected monthly costs for both homeowners with and without a mortgage. The selected monthly owner costs include "everything paid to the lender including principal and interest payments, real estate taxes, fire, hazard, and flood insurance payments, and mortgage insurance premiums" (2009 ACS Subject

Definitions, pg 24). The 'selected monthly owner costs with and without a mortgage' will help to determine the amount of disposable income available to homeowners. It does not take into account considerations such as maintenance, repairs, or utility bills for homes. Figures 12 and 13 below show the percentages of homes and the associated selected monthly owner costs.

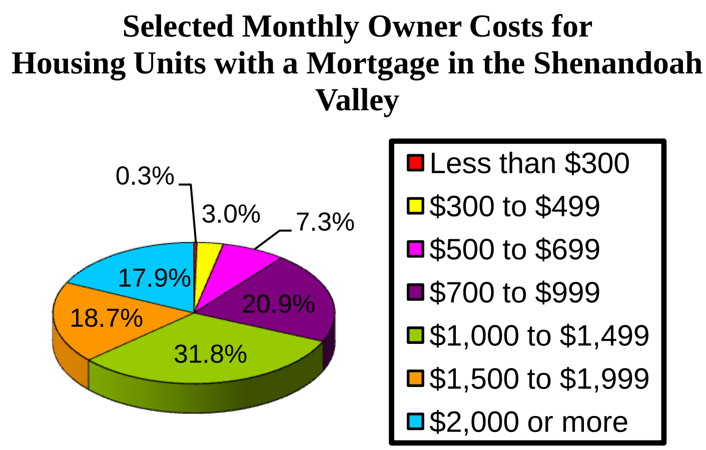

Figure 12. Selected Monthly Owner Costs for Housing Units with a Mortgage in the Shenandoah Valley
Source: U.S. Census American Community Survey, 2005-2009, and author's calculations. See text.

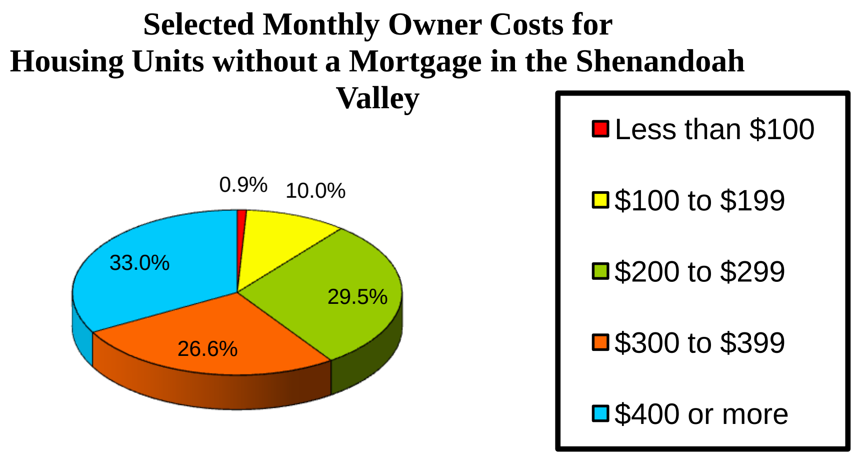

Figure 13. Selected Monthly Owner Costs for Housing Units without a Mortgage in the Shenandoah Valley
Source: U.S. Census American Community Survey, 2005-2009, and author's calculations. See text.

From these graphs, it can be seen that for housing units with a mortgage, almost 1/3 of the homes spend between $1,000 and $1,499 each month. Another 36% of the homeowners with mortgages spend more than $1500 on selected monthly costs. For homeowners without a mortgage, the selected monthly costs are drastically less, with over 60% of all homeowners without mortgages spending less than $400.

Another set of data available from the Census which is closely related to selected monthly costs for homeowners with or without a mortgage is 'selected monthly costs as a percentage of income.' This information will show the percentage of a household's income that goes to housing costs. It would also be a good indicator for how much disposable income is available, excluding utility and maintenance cost considerations. This information is broken down by housing units with a mortgage and housing units without a mortgage. Figures 14 and 15 below show the selected monthly owner costs (taxes, insurance, interest payments, etc.) as a percentage of household income for homeowners with and without a mortgage.

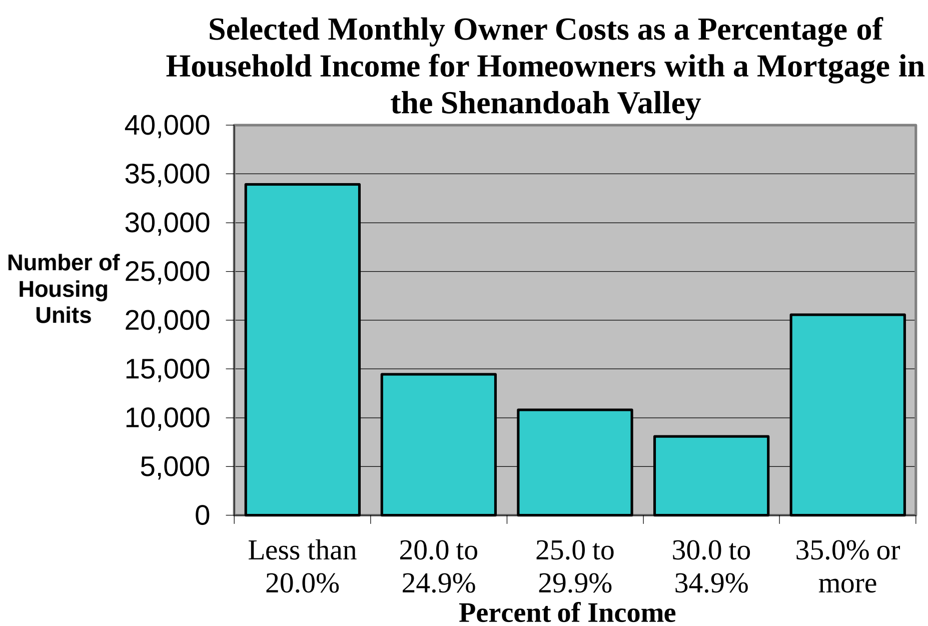

Figure 14. Selected Monthly Owner Costs as a Percentage of Income for Homeowners with a Mortgage in the Shenandoah Valley
Source: U.S. Census American Community Survey, 2005-2009, and author's calculations. See text.

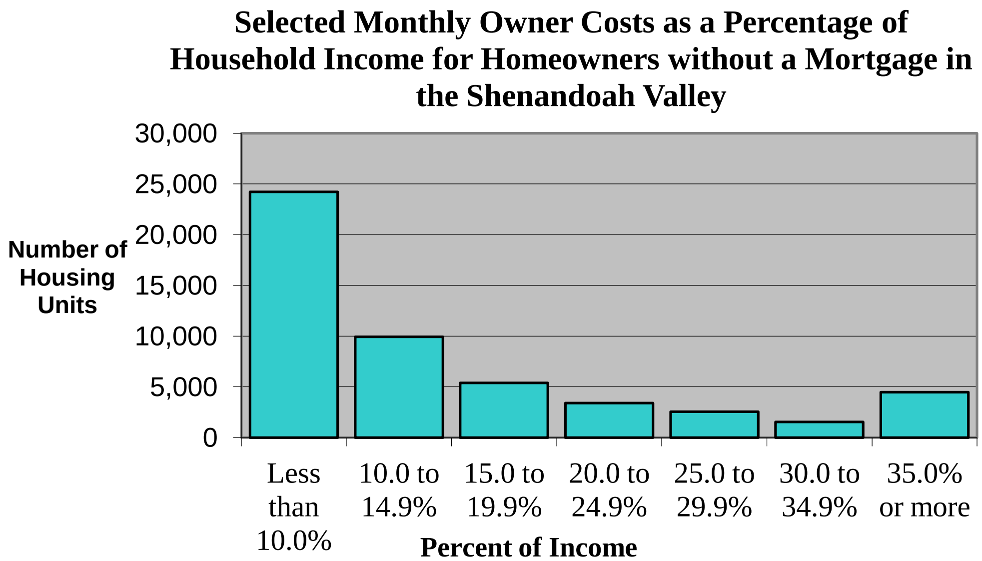

Figure 15. Selected Monthly Owner Costs as a Percentage of Income for Homeowners without a Mortgage in the Shenandoah Valley
Source: U.S. Census American Community Survey, 2005-2009, and author's calculations. See text.

Figure 14 shows that almost 35,000 owner occupied housing units with a mortgage spend less than 20% of their annual income on housing costs. However, a little over 20,000 OOHU spend 35% or more on their housing costs alone. Over 1/3 of total annual income for a household being spent on housing does not leave much disposable income with which renewable energy technology could be purchased. Figure 15 shows that a majority (almost 25,000) of homeowners that do not have a mortgage spend less than 10% of their income on housing expenses. This implies that there is more disposable income available to homeowners who do not have a mortgage.

On average, 64% of the households in the U.S. that had discretionary income earned over $24,300 each year per household (Summers, 2011). For the Shenandoah Valley, that would equate to 151,184 homes, or 76% of the households. Disposable income is defined as personal income minus income taxes. As a general budgeting rule, it is unwise to spend more than 30% of total income on housing expenses (Foreman, 2005). Due to the larger scope of this project, additional monthly expenses (such as food or transportation) will not be included in calculations for disposable income because an average of these expenses would be not accurate for the each household in the Shenandoah Valley. The selected monthly owner costs from the U.S. Census American Community Survey as a percentage of income will be used however, as a guideline for disposable income. Any housing costs which are more than or equal to 30% of total income will be excluded for the potential adoption of solar technology because it would not be economical or feasible for those households.

Figure 16 below shows the total number of owner occupied households in each county or independent city for the Shenandoah Valley. This information will be essential for the Valley 25x'25 Initiative so that efforts to educate homeowners about solar technology can be concentrated in locales where it will make the most impact. Figure 16 shows that efforts concentrated in Augusta, Frederick, Rockingham, Shenandoah, and Warren Counties have the greatest likelihood for success. This graph does not reflect the owner occupied homes which could afford this technology, but it is an excellent guideline for educational and informational purposes. Total population per county or independent city is also a good factor for determining where concentrations of people are located within the Valley, but for residential solar technology adoption, the number of owner occupied housing units will serve the same general purpose in a more concise manner.

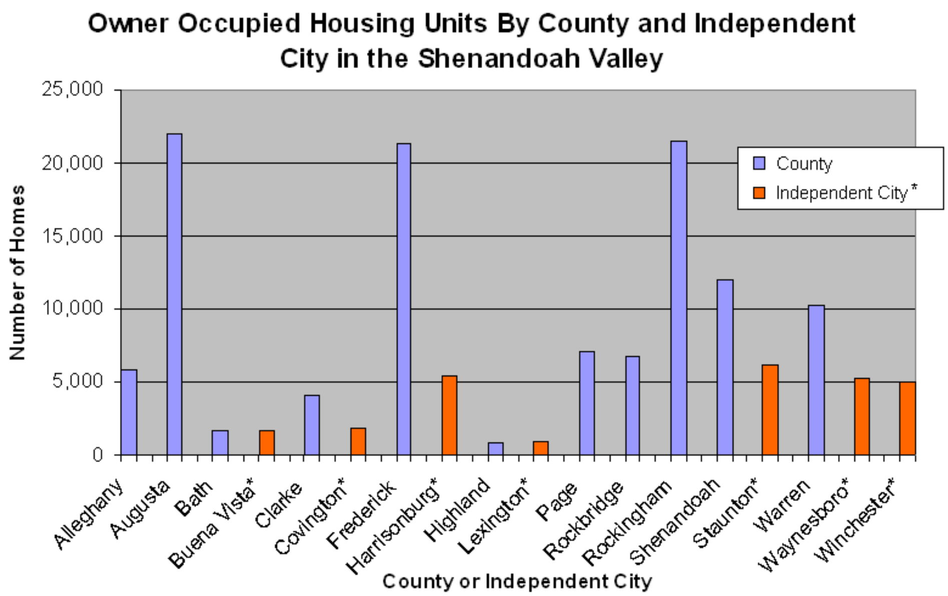

Figure 16. Owner Occupied Housing Units by County and Independent City in the Shenandoah Valley
Source: U.S. Census American Community Survey, 2005-2009, and author's calculations. See text.

The implications of demographic and household characteristics indicate some essential points to remember. First, there is a total population in the Shenandoah Valley of 411,000, of which 44% have attained higher education of some kind. Education and income are closely correlated, and the average household annual income is around $46,000. The selected monthly owner costs as a percentage of income data is valuable because it allows the determination of average household annual disposable income which will later be used in calculations to determine the affordability of solar PV or solar thermal hot water systems.

The household distribution and educational characteristics are significant because they will serve as a guide for the Valley 25x'25. With the average amount of household disposable income (household income minus housing costs) of about $32,000 (not including any other bills or financial responsibilities), the geographic distribution becomes very important. A total of 139,990 owner occupied housing units, or 70% of all occupied housing units are equipped with a relatively small annual disposable income, so making the location and effectiveness of education and awareness campaigns a high priority for the Valley 25x'25 means that the efforts will be concentrated where they can make the most impact. From Figure 16, it can be seen that educational or informational efforts in Augusta, Frederick, Rockingham, and Shenandoah Counties will reach the highest number of homeowners. The target of getting to 25% renewable energy by 2025 is ambitious considering 2025 is only 14 years away, so the Valley 25x'25 needs to concentrate on locales which are most likely to succeed in this goal.

Adoption and Diffusion Factors

The synthesis of the adoption and diffusion factors as applied to the Shenandoah Valley demographics is the analysis that will determine the real feasibility of adoption. By combining all of these aspects together, scenarios can then be created which demonstrate options and alternatives for the amount of adoption and diffusion which could take place. The adoption and diffusion factors delineated in this chapter will guide the Valley 25x'25 on which areas are laden with obstacles and those that have barriers which can be more easily overcome in order to accomplish the 25% renewable energy goal faster and more efficiently. There are four overarching categories for adoption and diffusion rates in the residential sector which include: technical barriers, information and awareness barriers, consumer economic decision making barriers, and difficulty overcoming established systems. Listed below are the major categories and barriers or opportunities which fall under each category.

- Technical
  - Household orientation and characteristics
  - Geographic location
  - Ease of retrofit
- Consumer economic decision making
  - High capital cost
  - Disposable income
  - Length of payback
  - Return on investment
- Information and awareness
  - Education
  - Workforce skills
  - True cost of clean/conventional energy
  - Social responsibility
  - Consumer perceptions

- Difficulty overcoming established systems
  - Net metering
  - Grid connectivity
  - Government policy
  - Financial incentives

Technical

The effectiveness of any given solar system varies greatly by numerous factors. Whether or not a resident owns or has control over their roof is an issue, and if the roof is available then the amount of space available will limit the size of the solar PV system that can be installed. Roof ownership is an issue for multi-home dwellings, which is why this barrier dictates that only owner occupied housing units be used. Shading of the panels from trees or surrounding buildings is a technical concern as well, but can be more easily overcome than the amount of sunlight available at a geographic location. Geographic location plays a role in the effectiveness of a PV panel. For instance, a panel installed in Maine will get less solar radiation than a panel in Virginia, which would mean increased output for the panel. One of the major concerns with technical barriers is the ability to retrofit a home with solar technology. The chosen technologies of solar PV and solar thermal are inherently easier to integrate into existing homes than active space heating or certain passive design measures. The technical barriers to adoption and diffusion in the Shenandoah Valley are partially overcome by focusing on the technologies which will lend themselves to ease of retrofit.

Consumer Economics

It is often assumed that the only barrier to implementing residential solar technology is the price of a system. While it is a very important barrier, it is not the only one. The largest barriers to technology adoption are both social and economic. The amount of income, level of education of a homeowner, and the high capital costs of installed solar PV in particular are the greatest barriers to residential adoption. The amount of education and income are directly associated; Sawyer (1982) uses education levels as an indicator for income attainment. Therefore, the connection can be made that the higher the education level attained, the greater the income. The higher the levels of both education and income indicate a higher likelihood of renewable technology adoption and energy efficiency measures in the home (Nair, Gustavsson & Mahapatra, 2010).

A study on the geographic distribution of household solar energy in the United States by Zahran, Brody, Vedlitz, Lacy & Schelly (2008) also indicate that there are positive associations between the amount of wealth or income a homeowner has and solar energy adoption due to the fact that wealthier households can more easily absorb the capital costs of a system. They are able to wait a reasonably longer amount of time for a return on investment (ROI) compared to a home which falls into a lower income bracket (Zahran, et al., 2008). The current cost of installed solar in Virginia is around $8.60 per watt, which would equate to a total cost of between $4,300 and $43,000, assuming between a 0.5 KW and 5 KW system which is a typical range for residential systems. Adachi (2010) states that a clear barrier to the adoption of residential solar PV is the high capital cost of a system, as well as lengthy payback periods.

Conversely, the high cost of a solar system can be overcome by saving money, rebates and incentives, to name a few. Median home value, for instance, is often used to assess solar system affordability because it represents a source of capital which could finance solar technology (Zahran, et al., 2008). Other economic barriers which need to be considered by homeowners are the amount of time it will take for a return on investment (ROI), and the length of a payback period. Leidl & Lubitz (2009) found that when comparing domestic water heating technologies, a long payback period was a significant barrier and subsidies were needed in order to gain acceptance by consumers. If a consumer will experience a return on investment which suits their financial needs, the payback period could be considered an opportunity for adoption. On the other hand, a long payback period means a long-term investment which some homeowners might not be willing to make. Combs, et al, (1983) explain that a complication for solar technology is that it requires a long-term commitment with no real possibility for a low-risk trial period.

Information and Awareness

An obstacle which is closely related to these economic benefits and barriers is the knowledge and awareness of residential solar technology, which is directly associated to the amount of education attained. Residential solar technology is not a new concept; this technology has been around for decades, yet some homeowners are unfamiliar with it as an option for their home. If homeowners are uneducated or unaware about a technology, it is unlikely they will be willing to install it in their home. Duke, Williams, & Payne (2005) also state that people may be reluctant to gain the necessary knowledge to be a solar system owner because it may seem complicated. Education and awareness programs for homeowners would ease negative associations about solar technology and with the perceived complexity of the operations and maintenance of solar equipment as well. A social science study on residential solar technology conducted in the U.S. and France also found that adequate comprehension of solar technology is a factor for determining potential diffusion (Warkov & Monnier, 1985). Teaching homeowners that it can save energy to run appliances (washer, dishwasher, etc.) during off-peak hours would also make a big difference in overall energy consumption. Stakeholder familiarity with solar energy technologies could facilitate the adoption and diffusion through the residential sector. Building integrated materials and installation will also help to alleviate negative perceptions (*aesthetics or otherwise)* (U.S. PV Industry Roadmap Steering Committee, 2001).

Another facet of the education barrier is the education of workers in the solar technology installation and maintenance field. Inadequate workforce skills and training may not seem like a significant barrier to solar adoption and diffusion throughout the residential sector, but it is. Scientific, manufacturing, and labor skills are currently lacking in the solar technology industry, which directly slows the adoption of this technology. Professionals need to be familiar with solar energy system components to be able to perform installation, maintenance, and inspection services skillfully. Educational services are also lacking in this industry for training skilled laborers (Margolis & Zuboy, 2006; US PV Industry Roadmap Steering Committee, 2001). As the penetration of solar technology occurs within the energy sector, more laborers will become trained and skilled in the profession.

A barrier which is both economically and socially related to solar technology adoption (or any renewable energy) is the failure to account for all costs and benefits of energy choices (Margolis & Zuboy, 2006). The full value of clean energy is not realized because intangible costs (GHGs, air pollution, emissions, etc.) are externalities, and therefore are not seen, felt, or accounted *(or even sometimes acknowledged)* for by the consumer. Fossil fuels do not account for these externalities and clean technologies do. This increases the costs of solar technologies, but they are "hidden" costs. Good air quality and a clean environment are difficult to internalize or to even assign a monetary value (Reddy, 2010).

There are a few intangible social factors which are significant to solar technology adoption and are both economically and educationally related. Multiple authors agree on the fact that feelings of environmental concern or social responsibility drive whether or not a consumer will chose renewable energies (Sawyer, 1982; Adachi, 2010). While environmental concern or feelings of social responsibility (for the environment, neighbors, future generations, etc.) are a propellant for adoption, these intangibles alone are generally not enough to drive adoption for homeowners. Consumers thinking about purchasing solar technology must be motivated by a number of factors (ideally, economic and social), such as monetary benefits in terms of monthly utility savings, affordability of upfront costs via rebates or incentives, and social/environmental responsibility (Sawyer, 1982). It is a factor which increases the likelihood of adoption, but is not a driver alone. People generally are not willing to strain themselves financially if it means only a negligible change in environmental condition. Other social factors to consider are the age of the home and homeowner. Consumption of expensive durable goods often peaks during midlife, ages 40-49 which is fairly predictable, independent of other factors such as family size, education, occupation, etc. (Zahran, et al., 2008). This could lead to the assumption that areas with populations in this age range will be more likely to purchase solar technology regardless of other social influences.

An additional influential adoption factor is a homeowner's perception of solar technology. Two common perceptions are that solar equipment on a roof will affect the aesthetics of a home, and the other is that a particular region or locale doesn't receive enough sunlight for solar technology to be cost-effective (Zahran, et al., 2008). These perceptions by homeowners could be an opportunity or a barrier to adoption. If a homeowner believes that the aesthetics will be enhanced on the home or if it will improve the homes' status or environmental image, then it would be a beneficial factor. Likewise, if a consumer believes that the amount of sunlight they receive in a day would result in large energy savings then the perception (not necessarily the actuality) of the amount of sunlight would be positive. However, the actual amount of solar radiation a place receives is significant because it will determine the cost effectiveness of installing solar technology. Additionally, homeowners in cold climates are less likely to adopt due to fear of damage to the equipment, such as snow or ice weight, or freezing pipes (Zahran, et al., 2008). The counterargument applies to both of these ideas held by consumers as well, which would make them more of a hindrance to solar adoption. The amount of insolation and aesthetics are not as influential on consumers' decisions to purchase solar technology however, as the high capital costs or amount of disposable income.

There are a few social factors which are questionable among authors for the adoption of solar technology. The presence of a technical occupation in the home (29% of the total Valley population) is said to be positively associated with solar technology adoption due to the understanding of how the equipment operates and how to maintain it (Nair, Gustavsson, & Mahapatra, 2010). It could be seen as an offset to the group of homeowners which lack adequate knowledge and awareness of solar technology; though no substantial correlations can be made between the two. The other factor which may or may not influence adoption rates of solar residential systems is the presence of an environmental leader in the community. In the context of the Shenandoah Valley, James Madison University could be considered an environmental leader based on its sustainability campaign, however, there are no instances of installed solar within Harrisonburg city limits.[1] Rockingham County has 25 installed solar systems for home heating, but no strong association can be made between the two (U.S. Census ACS, 2009).

Overcoming Established Systems

More often than not, electricity grid systems are designed for large power plants in a central generation and distribution location, which is contrary to the needs of residential solar generation and distribution. Utility companies almost always require consumers to connect to the grid for safety purposes, but conversely, also require fees, charges, and permits to connect to the grid (SEIA, 2011). There can sometimes be lengthy interconnection procedures; however, the option to connect to the grid is much cheaper than storing the solar energy produced in batteries for later use. Utility companies are not required by law to provide or incentivize net metering (SEIA, 2011). Net metering is a policy which allows energy consumers to sell back excess electricity generated from their system to the utility company. Net metering might create a quicker return on investment for a homeowner, but it could also be a considerable hindrance if a homeowner considers all the rules, regulations, and formalities of connecting to the grid prior to installing solar technology. Another aspect of this hindrance is that residential energy producers rarely receive market price for electricity production, so the return on investment time period with net metering might not meet homeowners' expectations.

Government policies could be implemented to make the symbiotic relationship between utility companies and residential energy producers more equal. Both parties benefit from grid interconnection and net metering; utility companies receive a good image for incorporation renewable energy into their profile while gaining electricity reliability, and producers sell

[1] One homeowner in Harrisonburg now owns a solar PV system.

unneeded power to accelerate the payback process (Margolis & Zuboy, 2006; U.S. PV Industry Roadmap Steering Committee, 2001).

Another barrier related to overcoming the established system is the lack of or inconsistencies of government policy supporting renewable energies. This includes any policies or regulations supporting research and development of solar technologies, or policies which hinder the R&D. Regulations which make zoning or permitting processes for solar technology difficult are also an obstacle. This barrier also includes the policies which support conventional fuel sources, such as subsidies for fossil fuels. Creating policies to incentivize the R&D and installation of solar technology can help to overcome this barrier (Margolis & Zuboy, 2006; U.S. PV Industry Roadmap Steering Committee, 2001). Local incentives by utility companies may also support solar technology adoption rates.

Inadequate financing options for solar technology projects are yet another concern for the diffusion and adoption of solar technology. Solar energy systems are not yet competitive with conventional sources. There are some federal and state programs which supply incentives and rebates for installing a solar energy system, but even after incentives and rebates, the cost is still high to consumers. Until the cost of conventional energy and solar energy systems balance out a little more, programs which provide financial aid are needed if solar energy technology has a hope of diffusing in the residential sector (Margolis & Zuboy, 2006; U.S. PV Industry Roadmap Steering Committee, 2001).

Based on the barriers and opportunities found from the literature review as applied to the demographics of the Shenandoah Valley, the biggest barriers (or opportunities) to residential solar adoption will be the high capital cost of solar equipment, income, education, age of homeowner, and length of payback period. The literature review revealed the recurring theme of high capital costs for solar PV, income and education of consumers are the biggest influences on whether or not a homeowner will decide to install solar technology. The demographics of the Shenandoah Valley suggest that the average resident in the Valley is a middle class, working homeowner in middle age with little extra money (roughly $32,000 per year disposable income) to spend. With a small amount of money remaining at the end of each month, the average homeowner would probably not be inclined to purchase a solar PV system which is seen as a long term investment and perhaps risky. Consumers are concerned with the economic bottom line and the bottom line for solar at this point in time is that it is not easily affordable and has a lengthy return on investment period, which is does not seem attractive or advantageous for homeowners. Ease of financing could also be a significant factor to consider because it could outweigh the high capital cost barrier.

Education was chosen as a factor of focus because it equally poses as an opportunity or barrier for adoption. Almost 45% of the population in the Valley currently has at least some college education, and educational and awareness campaigns could potentially increase this number so that more residents are informed about solar and other renewable technologies and the implications in their own home. The average homeowner however may not understand the implications and importance of global warming, climate change, or GHG emissions, but chances are they have at least heard of solar panels.

The average age for a resident in the Valley is around 40 years old. This could potentially be an excellent opportunity because it is in the low end of the age range of the group that consumes the most durable goods regardless of other factors. These people will remain in the group most likely to purchase solar PV systems for the next few years. This age for the average resident could also be a barrier to adoption because within the next decade, that group of people will be looking forward to retiring and not investing in a solar PV system which currently takes longer to pay off than the life of the system. High PV system costs, income, education, and age were chosen from the literature and demographics of the Valley review because they deserve further evaluation and analysis to fully determine their impact on the Shenandoah Valley and solar technology adoption rates.

Financial Incentives

Financial incentives often discern if a renewable technology will be affordable or not. There are a number of options for financial incentives for residential solar technology, including those supplied by the federal and state governments and local rebate and financing options from utility companies. Federal and state incentives are most commonly tax rebates or credits, while utility rebates often include financing options or some variance of net metering.

The rate at which electricity is credited to homeowners for their renewable electric power production is also a factor that significantly affects payback periods and life cycle costs. In Europe, “feed-in-tariffs” are used extensively and usually reflect a preferential rate for renewable energy production (in other words, the “price” at which electricity is purchased from a renewable energy source is higher than from conventional fossil fuels). In the U.S., “net metering” is required by federal law for all electric power utilities except municipal utilities. Each state decides the exact terms of the net metering provisions, which include the maximum size of the systems that may be net metered, the rate at which the electricity is to be credited to the owner, the rate at which excess generation is to be purchased, and the terms of service of interconnection.

In a net metering environment, electricity is actually purchased from a renewable system owner ***only*** when there is net excess generation at the end of the year (e.g., the system has generated more electricity than the owner uses in their home). When there is no excess generation, electricity is credited at the full retail rate to the owner’s electric bill. In Virginia, if there is excess generation at the end of the year, the owner may sell this to the utility at the utility’s “avoided cost” rate for purchasing electricity, which is close the wholesale rate for electric power (currently about 3.5 cents per kilowatt hour).

The main federal incentive available currently is a residential renewable energy tax credit. It is available for solar PV and solar thermal, as well as other renewable technologies. It allocates a personal tax credit for 30% of the total installed costs for the solar system. In order for solar thermal to be eligible, it must be used to heat at least half of the dwelling's water needs (DSIRE, 2011). For the Shenandoah Valley, this tax credit is beneficial, but does not bring the costs of solar technology into the realm of affordability for all homeowners.

There is also a federal financing option, which is a federal loan program. Homeowners can opt for an energy efficient mortgage which can finance renewable energy technologies to improve an existing home. The U.S. federal government guarantees these loans through the Federal Housing Authority (FHA). The loan has certain restrictions based on county, state, and number of occupants in a dwelling, but allows for the least of 5% of either: the value of the property, 115% of the median area price of a single-family dwelling, or 150% of the Freddie Mac conforming loan limit. One restriction which applies is that the loan may not exceed the projected savings of the installed technology (DSIRE, 2011). The average median home value for a Shenandoah Valley home is about $187,600. If the first financing option was utilized, 5% of $187,600 is $9,380 available to finance a system, which would allow only the purchase of a 1 KW system. The problem with the financing options is that the loan amount may not exceed the savings of the system. It will later be determined in a benefit cost analysis that a 1 KW system does not generate a savings of over $9,000.

A state incentive option is a property tax exemption for solar in the residential sector. The state of Virginia (only selected counties) allows solar energy equipment to be exempted from local property taxes. The only county in the Shenandoah Valley in which this applies however, is Warren County (DSIRE, 2011). This incentive, while useful for over 10,000 homeowners in Warren County, will not be effective enough to cause widespread implementation of solar technology, especially considering it only affects one out of 11 counties striving for the 25x'25 goal.

There are four main utility companies which service the Shenandoah Valley, including Dominion Virginia Power, Shenandoah Valley Electric Cooperative, Rappahannock Electric Cooperative, and BARC Electric Cooperative. Dominion Virginia Power offers net metering for the residential sector for systems which are no larger than ten kilowatts. To take advantage of this option, homeowners with a system must complete an application and have an inspection by the company (Dominion Virginia Power, 2011). Like Dominion Virginia Power, the Shenandoah Valley Electric Cooperative also offers net metering in the residential sector to homes which have a system no larger than ten kilowatts. An application must be submitted to the company. Avoided cost rates for residential solar producers are not listed (Shenandoah Valley Electric Cooperative, 2011). The other two utility companies, Rappahannock Electric Cooperative and the BARC Electric Cooperative serve a smaller portion of the Valley and both have net metering programs, though the Rappahannock Electric Cooperative also offers energy audits for homeowners (Virginia Energy Sense, 2011).

The financial incentives listed above are certainly helpful if the decision to install a solar PV or solar thermal system has already been made by a homeowner, but the incentives are not strong enough to invoke homeowners in the Valley to adopt solar technology. The incentives are not enough to create a quick return on investment or an attractive up front cost for the homeowner. This reaffirms the fact that homeowners will not install solar technology unless they are motivated by a number of factors, and in this case, savings from financial incentives would not be enough.

Conclusion

Currently, the Shenandoah Valley uses less than 1% of solar power to heat homes compared to 43% of electricity which is used for home heating. This will have implications for the adoption of solar thermal water heating systems, as the fuel for water heating is generally electricity or natural gas. The payback periods will be different for each fuel, and depending on the ease of retrotfit, may be more or less attractive to some homeowners. The spatial distribution of households within the Valley indicates that there are a key number of counties/independent cities where the Valley 25x'25 Initiative should focus its campaign and educational efforts. The factors of income, amount of education attained, and the age of the homeowners within these counties/independent cities should be considered for these educational efforts as well. These factors are the biggest barriers to residential solar technology adoption, along with the high up front costs of a system. Valley homeowners will benefit from the federal tax credit of 30% of total installed costs of a solar PV or solar thermal system, but the incentive is not enough to make this technology very attractive in the residential sector.

Chapter 3: Benefits and Costs of Solar Technology in the Shenandoah Valley

Introduction

Solar technology is clearly an environmentally friendly energy choice, but the costs associated with solar technologies in the home must be first taken into consideration before installation occurs. A maximum theoretical concept will be used to determine the maximum possible number of housing units which could install solar PV or solar thermal hot water systems in their home. The cost effectiveness of these systems will be influenced by a number of factors, including the amount of annual solar radiation the Shenandoah Valley receives. A life cycle cost-benefit analysis will be conducted to determine the most cost effective choice for an average Valley homeowner, while taking into account the impact that the length of payback period has on homeowner purchasing decisions. Greenhouse gases will also be examined to establish the possible impact homes in the Valley could have on a larger scale.

Maximum Theoretical Output Concept

The maximum theoretical output concept is used in this research to quantify the maximum number of households which are able to install solar technology in the Shenandoah Valley. The maximum technical output for each size solar PV system is calculated, assuming optimal operating conditions. The technical output of energy is reported in kWh of electricity for each system. Using Census data, the number of households which are able to adopt the technology is determined, and in the Shenandoah Valley the number of owner occupied housing units totaled 139,990. The maximum theoretical concept assumes 100% adoption of the technology for owner occupied housing units. Housing units which are rented could not realistically be included in the maximum theoretical output because the likelihood of a renter installing solar technology is not probable.

In order to facilitate meeting the 25x'25 goals, a maximum theoretical yield for possible residential solar adoption was calculated using the Shenandoah Valley social, economic, housing and demographic characteristics. The maximum theoretical potential adoption for solar PV was then broken down into more realistic scenarios based specifically on values for the Shenandoah Valley. Barriers and opportunities were applied to the scenarios to provide a more realistic picture of the likely adoption which could take place for the Valley. Electricity generation is a key component of the maximum theoretical yield which was calculated as well, which will later be used to help determine the maximum possible (and likely) carbon dioxide mitigation.

Solar PV

Technical Output

In order to determine how much electricity any given PV system will generate, the daily insolation rate must also be established. The map in Figure 17 shows the PV Solar Resource for the United States to give a general idea of how much sun Virginia receives. The amount of solar radiation that the Shenandoah Valley receives is not very distinct, so weather data was acquired from the Weather Bureau Army Navy (WBAN), specifically, the Roanoke meteorological station. The Roanoke weather station was the closest geographically to the Valley with the specific information that was required. The Roanoke station supplied information on 30-year averages of monthly solar radiation between the years 1961-1990. The average solar radiation this location receives is 4.8 kWh/m2/day with +/- 9% uncertainty (WBAN Identification Numbers, 1990).

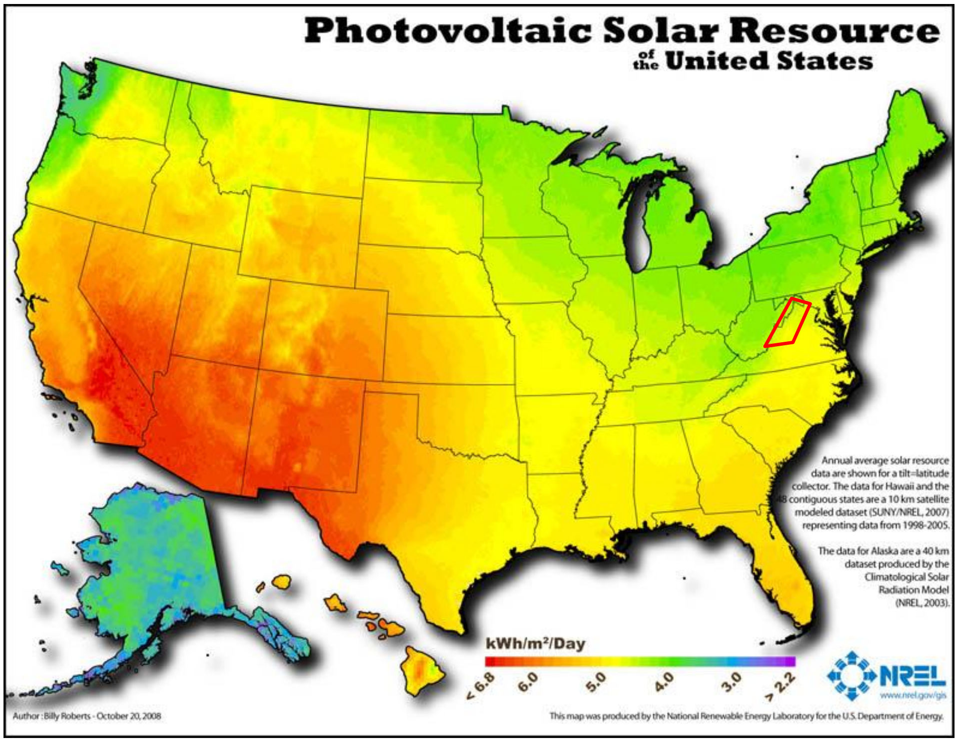

Figure 17. Photovoltaic Solar Resource of the United States
Source: NREL, 2008

The equation which will be used to determine the annual electricity output for various sized PV systems in a given scenario is as follows:

(# of owner occupied housing units x size of PV system (KW)) x daily insolation rate (4.8 kWh/m2/day) x 365 days/year = kWh/year of electricity generated

Table 3. Annual Output for Various Sizes of Solar PV Systems in the Shenandoah Valley

Size of PV System (KW)	Annual Electricity Generated (kWh)
0.5	876
1	1752
3	5256
5	8760

Source: Author's calculations. See Text.

Maximum Theoretical Output

The maximum theoretical potential for the Shenandoah Valley will use the total number of owner occupied housing units (with the assumption that they have control over the roof or adequate ground space for a solar system) which is 139,990 households. For alternate scenarios, barriers such as income, age and education will be applied to the total OOHU. Using the above equation for calculations, the following table shows the theoretical maximum possible annual outputs generated by PV technology.

Table 4. Maximum Possible Solar PV Electricity Generation in the Shenandoah Valley

Number of Housing Units	kWh Generated Annually	Size of PV system (KW)	Percent of Total SV OOHU Electricity Need Met by PV	Percent of Total SV Household Energy Need Met by PV
139,990	122,631,240	0.5	6%	2%
139,990	245,262,480	1	12%	5%
139,990	735,787,440	3	37%	15%
139,990	1,226,312,400	5	62%	25%

Source: U.S. Census Bureau, ACS 2005- 2009 and Author's calculations. See text.

Using the monthly consumption values for the average Virginia household, it can be determined that annual consumption for a *single* household is about 14,040 kWh. If this number is multiplied by the total number of owner occupied housing units in the Shenandoah Valley, the total kWh consumed can be found, which is 1,965,459,600 kWh, or almost 2,000 Gigawatt hours each year. Compared to the electricity generation from maximum adoption, the 0.5 KW system would only provide 6% of the consumption needs, the 1 KW would provide 12%, the 3 KW system would supply over one third, and the 5 KW system would come the closest with 62% but still falls short of the Valley's total electricity consumption needs. To find the percent of total energy consumed, the kilowatt hours generated for each system was multiplied by 3412.1 to convert kWh to BTU. This number was divided by the total number of occupied houses which as multiplied by the average energy consumption per household (BTU). The result is the percentage of need met by PV for all occupied housing units in the Valley. This clearly shows the need for energy efficiency and conservation measures in addition to the need to transition toward renewable energies because even if every homeowner in the Valley installed a 5 KW system, it would generate enough electricity to meet 60% of the total electricity needs, and roughly 40% would be generated from other sources, likely fossil fuels. If all owner occupied housing units installed a 5 KW system would generate about 24.6% of the total energy needs, which is a substantial percentage, and close to the Valley's goal of 25%.

Solar Thermal Hot Water

Technical Output

The solar thermal system for domestic hot water which will be used for this research is a system which utilizes a flat plate collector and one hot water storage tank. Figure 18 below shows a schematic of the solar thermal hot water system which will reasonably be considered typical for the Shenandoah Valley in this research. A drainback system refers to a system which uses gravity instead of pressurization, and usually water is used instead of a glycol-water mix for a heating medium (Patterson, 2011). The temperature differential dictates when the water is pumped to the collector. In times of freezing, cold, or non-sunny weather, the water drains from the collector back into the internal storage unit, preventing the system from freezing (Patterson, 2011). For this reason, a drainback system is well suited for cold climates which are prone to freezing.

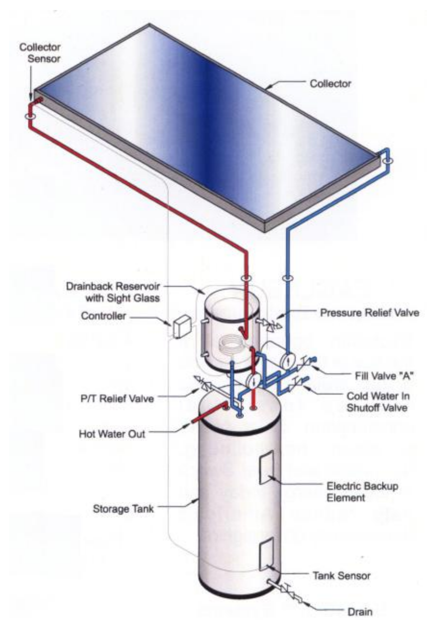

Figure 18. Schematic of a Drainback Solar Collector System
Source: http://www.homefreesolar.com/water-made-hot-by-the-sun.html

Since the Shenandoah Valley has an average household size of 2.36 people, it can be generously estimated that the hot water needs of an entire household can be met with one domestic solar thermal system. This assumption is generous but not unreasonable considering that seasonal fluctuations and changes in hot water demand will vary, but it is important to analyze the potential adoption of solar thermal hot water systems under the best possible circumstances. Due to the assumption that the solar thermal water system will meet 100% of the household needs, the calculations required to determine the maximum output become minimal.

Maximum Theoretical

The maximum theoretical scenario for the case of solar thermal hot water assumes that all household hot water needs are met by one system. Because of this assumption, average household consumption averages for the state of Virginia can be used. The average total household energy consumption in Virginia is 1.65 quadrillion BTU (EIA, 2005b). The average household consumption of energy for hot water heating in Virginia is equal to 0.30 quadrillion BTU (EIA, 2005a). If the household hot water consumption is divided by the total energy consumed, the result is average BTU used in Virginia to heat hot water as a percentage of total energy consumed. This resulted in 18.2% of total energy use being used for hot water heating. As previously explained, the estimated total BTU of energy consumption for a Shenandoah Valley household was 85,314,000 BTU (EIA, 2005a; EIA, 2005b). Thus, the average household in the Shenandoah Valley will use roughly 15,527,148 BTU of energy, or about 4,550 kWh of electricity annually to heat water. See the equation below for further clarity.

*(Estimated energy use in BTU per Valley household * State estimate of percent of total energy used for hot water heating)/ Conversion factor for kWh = kWh per household consumed for hot water heating*

The maximum theoretical output for the solar hot water system in the Shenandoah Valley will therefore be 15,527,148 BTU of energy or 4,550 kWh of electricity per household. If this number is multiplied by the total number of owner occupied housing units, the result is 637,052,493 kWh of electricity. To find the equivalent in natural gas, BTU are converted to cubic feet of natural gas instead, which equals 15,060 cubic feet of natural gas consumed for hot water heating per household annually. The conversion is 1,031 BTU per cubic foot of natural gas. This would equate to a maximum theoretical offset of 2.1 billion cubic feet of natural gas.

Economic Benefits and Costs

In order to determine real feasibility and affordability of solar PV adoption in the Shenandoah Valley, a benefit cost analysis needs to be completed. There are a number of analytical options for benefit cost analyses, but the one which will be used for this thesis is termed life cycle costing and it is commonly used to evaluate investments for renewable energy and energy conservation technology over the life of the product or service. Life cycle cost (LCC) analysis has several advantages to other types of benefit cost analyses. An LCC can answer how savings can be compared to costs, how large of an investment to make, how much overall costs will be lowered by increased conservation, and how to compare competing projects for the same purpose (Marshall & Ruegg, 1980). The total life cycle costs for a product or system can be used to compare products for the same purpose at a per unit price to determine which is the smartest investment economically. The disadvantages of such an analysis are that it does not allow the rate of return on investment to be determined, nor does it take into account the real time value of money (Marshall & Ruegg, 1980).

Life cycle costing provides a clear analysis which allows simple comparison of various products or services; however it does not take into account the time value of money and therefore is considered to be a simple payback period calculation. If a product has a long payback period (many years), generally the assumption is that the value of money will be reported in present value, which is defined as "the equivalent value of past and future dollars corresponding to today's values" (Marshall & Ruegg, 1980). Essentially, the life cycle benefit cost analysis does not take into consideration discounting of money, or the fact that electricity (and natural gas) prices are expected to rise over the next 15 to 20 years. The costs could also be reported in annual value, which indicates that all past, present, and future dollar amounts are converted into an equivalent, constant amount for the given time period. This is also called discounting. The benefit cost analysis which follows will assume present values for each scenario evaluated.

The life cycle costing process will be applied to each of the four sizes of a solar PV system to determine which system size is the most cost effective investment. The following equation will be used:

Life Cycle Costs *= Purchase & Installation costs – Salvage value + Maintenance and Repair costs + Replacement costs + Energy costs*

The purchase and installation costs include the total cost of a solar PV system and all components installed, including labor costs and any installation fees. If a tax credit or rebate is applicable, it is subtracted from the purchase and installation costs prior to calculating the life cycle costs. The purchase and installation costs in Table 5 include the 30% available to homeowners. The purchase and installation cost for a solar PV system in the Shenandoah Valley is $8.60 per watt (NREL, 2011). This amount assumes labor costs are included.

Salvage value refers to the value of a system which could be gained from selling it at the end of its useful life. The average life for a solar PV system is 30 years. Salvage value is difficult to pinpoint for residential systems, so a variety of scenarios will be discussed. Maintenance and repair costs include any cost incurred over the life of the product (PV system). For the purpose of this analysis, maintenance and repair costs will be $0 because very little maintenance is required for PV systems.

Replacement costs for a solar PV system would most likely be incurred from the system components rather than the actual panels. Inverters generally need to be replaced every 10 years, because that is the length of the warranty on many types of inverters. There is an option for consumers to buy an additional 10 year warranty which is sometimes equal to the cost of a new inverter, but for this investigation it will be assumed that the inverter will last ten years, the additional warranty will not be purchased, and that the inverter will need to be replaced twice over the life of the solar PV system (30-year life cycle). On average, a typical inverter will cost $0.70 per watt. This number was calculated by averaging the cost per watt for SMA Solar Technology AG inverters, which is an American subsidiary of the German solar technology manufacturing company and the most widely used inverter manufacturer (SMA America, LLC., 2011).

The energy costs related to the life cycle of a product include the cost to operate the system over its lifetime; therefore the cost to operate a solar panel would be $0 since the energy comes from the sun. It can be compared to grid connected electricity, which would be equal to the amount of electricity multiplied by the amount of electricity consumed (in kWh) per household and multiplied by the evaluated time period. It is assumed that the price of electricity will not increase over the 30-year life cycle of the solar PV system. While this may not be realistic, it provides an estimate for the length of the payback period.

Another assumption in this LCC is that the solar PV system payback period will be determined using only from the savings from using solar power compared to grid connected electricity. It should also be noted that all of the chosen PV systems will not provide 100% of household electricity needs and therefore the solar electricity generated would only serve as a supplement and grid electricity would still be required. Table 5 shows the cost of each factor in the LCC equation for each size solar PV system, with a salvage value of $500. This value was used because an accurate value could not be determined for salvage values of residential systems, and thus several scenarios were proposed. The $500 value was estimated to be a moderate salvage value. Residential systems are smaller compared to commercial or utility sized PV systems so the residual value or salvage value would also be less, but the value is difficult to determine, especially considering a 30-year life cycle.

Benefit Cost Analysis for Solar PV

Table 5. Life Cycle Costs for a 0.5, 1, 3, & 5 KW PV System

Life Cycle Costing[2]	**0.5 KW System**		**1 KW System**		**3 KW System**		**5 KW System**	
	PV System	Grid-tied electricity	PV System	Grid-tied electricity	PV System	Grid-tied electricity	PV System	Grid-tied electricity
Purchase and Installation	$4,300	$0	$8,600	$0	$25,800	$0	$43,000	$0
Cost after 30% Tax Credit	$3,010	$0	$6,020	$0	$18,060	$0	$30,100	$0
Salvage	$500	$0	$500	$0	$500	$0	$500	$0
Maintenance and Repair	$0	$0	$0	$0	$0	$0	$0	$0
Replacement Costs	$710	$0	$1,420	$0	$4,260	$0	$7,100	$0
Energy Costs	$0	$2,788	$0	$5,577	$0	$16,730	$0	$27,883
*Annual Energy Savings	$93	$0	$186	$0	$558	$0	$929	$0
Total Life Cycle Cost	**$3,220**	**$2,788**	**$6,940**	**$5,577**	**$22,260**	**$16,730**	**$37,100**	**$27,883**
$ Difference between Solar and Grid Electricity (30 years)	N/A	$432	N/A	$1,363	N/A	$5,090	N/A	$8,817
Payback Period (years)	35	N/A	37	N/A	40	N/A	40	N/A

Source: Author's calculations. See text.

[2] The sensitivity of the life cycle cost analyses to cost estimates will be addressed in the final conclusions.

Table 5 shows that the total life cycle cost for a 0.5 KW system would be about $3,220 over 30 years, compared to almost $2,800 for grid electricity. This is a difference of $432, which indicates no savings at all even for a small residential solar PV system. However, because $432 is not an exorbitant amount of money, a savings may occur with the expected increases in the cost of electricity over 30 years. A 0.5 KW system would provide very little of a household's electricity needs, however. Another scenario is shown below using a salvage value of 15%, which is more generous but perhaps not as realistic. In comparing the higher kilowatt systems and the smaller sized systems, it shows that a $500 return for salvage value is negligible. From the literature examined, it was found that a commercial system (around 500 kW or half of a Megawatt) will draw a 20% salvage value at the end of 30 years. Twenty percent was thought to be too generous for a residential sized system and the $500 is a moderate estimate which was why 15% was used for an alternate salvage value. Table 6 shows the total life cycle costs for a system which would receive 15% of the initial purchase cost as a salvage value at the end of its life.

Table 6. Life Cycle Costs for a 0.5, 1, 3, & 5 KW PV System

Life Cycle Costing	**0.5 KW System**		**1 KW System**		**3 KW System**		**5 KW System**	
	PV System	Grid-tied electricity	PV System	Grid-tied electricity	PV System	Grid-tied electricity	PV System	Grid-tied electricity
Purchase and Installation	$4,300	$0	$8,600	$0	$25,800	$0	$43,000	$0
Cost after 30% Tax Credit	$3,010	$0	$6,020	$0	$18,060	$0	$30,100	$0
Salvage	$452	$0	$903	$0	$2,709	$0	$4,515	$0
Maintenance and Repair	$0	$0	$0	$0	$0	$0	$0	$0
Replacement Costs	$710	$0	$1,400	$0	$4,260	$0	$7,100	$0
Energy Costs	$0	$2,788	$0	$5,577	$0	$16,730	$0	$27,883
*Annual energy savings	$93	$0	$186	$0	$558	$0	$929	$0
Total Life Cycle Cost	**$3,268**	**$2,788**	**$6,537**	**$5,577**	**$19,611**	**$16,730**	**$32,685**	**$27,883**
$ Difference between Solar and Grid Electricity (30 years)	N/A	$480	N/A	$960	N/A	$2,881	N/A	$84,802
Payback Period (years)	35	N/A	35	N/A	35	N/A	35	N/A

Source: Author's calculations. See text.

The 15% salvage value showed a slight reduction in the length of payback periods for the three larger PV systems, but extended the amount of time required to pay off a 0.5 KW system. The annual energy savings shown in both LCC tables is a figure derived from the cost of grid electricity. It was found by multiplying the current electricity rate with the hours of insolation, days per year, and the size of the system. Essentially, it is what a homeowner's electric bill would be using grid electricity annually. If the salvage value were to be $0 after 30 years, the payback period would increase to 40 years. The life cycle costs for systems with $0 acquired from salvage would be $3,720 for a 0.5 KW system, $7,217 for a 1 KW system, $21,651 for a 3 KW system, and $36,085 for a 5 KW PV system. A $0 return for salvage value is a conservative estimate but not entirely unrealistic. As seen in all of the above scenarios for life cycle costs, the savings derived from the system never exceed the costs, therefore indicating that they never pay for the system. The payback periods in all cases are longer than the expected life of a system.

In order to determine affordability, the most likely demographic scenario was used, which was the maximum likely adoption for households restricted by income and education, as explored in Chapter 4. The total number of households able to adopt solar PV which were restricted by income and education was 46,205.

First, the median household income for the Shenandoah Valley was established, which was $46,140 annually. Then, 30% was subtracted to determine the average amount of disposable income per household. Thirty percent was used because it was previously established to be the maximum allowable percentage of income which could go toward housing costs. For the purpose of this thesis, any money remaining after housing costs is considered disposable income. This calculation resulted in an average disposable income for the Valley of $32,298. The average disposable income for the Shenandoah Valley automatically eliminates all 5 KW PV system options because they are all at least $36,000, as found from the LCC. Regardless of whether or not a homeowner would choose to finance a PV system or incur the costs upfront, they would need at least a sizeable portion of the income to cover installation costs. The affordability for the remaining sized solar PV systems was determined using the ACS Census data. The Census data was referenced to determine the percentage of households which made at least $33,000 which resulted in 64% of total OOHU. It is assumed that the homeowners restricted by income and education are a representative portion of the population with respect to income. The 64% was then applied to the OOHU restricted by income and education and the result implies that only 29,530 households would be able to afford a 3 KW system or smaller because they have at least $33,000 in disposable income annually.

The difference between average household disposable income and costs for a 3KW system with varying salvage values ranges from $8,000 to $10,600. This is the portion of annual income which would remain after the purchase of such a system. This is likely not enough to cover annual expenses for an average family of 3-4 (car payments, groceries, bills, etc.). Thus, it would not be likely that a 3 KW system would be installed either, but that a 1 KW PV system would appear more attractive financially to homeowners.

By using a life cycle benefit cost analysis, it appears that the most likely scenario for solar PV adoption in the Shenandoah Valley is a scenario which is restricted demographically by income and education and economically by the high cost of a PV system. This results in 29,530 OOHU able to afford a 3 KW system but unlikely to install it; it is more likely that homeowners would install a 1 KW system because it is more affordable and would generate a quicker return on investment. This benefit cost analysis is limited because it does not consider the time value of money which makes it difficult to determine the actual length of payback for a system and provides a generous estimate on the length of payback. However, it does indicate that a 1 KW system would be most beneficial because it would meet more of a households electricity needs than a 0.5 KW system while being more affordable than a 3 or 5 KW system. A 3 KW system may be the most economical if the time value of money was considered; discounting and its associated implications will be explored later.

Benefit Cost Analysis for Solar Thermal

The benefit cost analysis for solar thermal hot water has similar implications as a solar PV system; it is assumed that a solar thermal hot water system has a 30-year life, and little to no maintenance and repair costs. The typical drainback solar system is a reliable design that often out performs its pressurized counterparts (Patterson, 2011) so replacement costs will also be assumed to be $0 over the life of the system. The annual energy costs for the solar thermal hot water system are also assumed to be zero, since 100% of a household's hot water needs are being met with solar radiation. For conventional heating, an installation cost of $500 is assumed for the cost of a new hot water heater. Tables 7 and 8 below show the life cycle costs for a solar thermal hot water system compared to grid electricity and natural gas.

Table 7. Life Cycle Costs for a Solar Thermal Hot Water System Compared to Electricity

Solar Hot Water	One size meets 100% of hot water need	
Life Cycle Costing for Electricity	**Solar Thermal Hot Water System**	**Grid-tied Electricity**
Purchase and Installation	$8,795	$500
Cost after 30% Personal Tax Credit	$6,157	N/A
Salvage	$0	$0
Maintenance and Repair	$0	$0
Replacement Costs	$0	$0
Energy Costs*	$0	$982.83
Annual energy savings	$482.83	N/A
Total Life Cycle Cost	$6,157	$982.83
Difference between Solar and Grid Electricity	$5,174	
Payback Period (years)	**12.8**	

Source: Author's calculations. See text.

Table 8. Life Cycle Costs for a Solar Thermal Hot Water Compared to Natural Gas

Solar Hot Water	One size meets 100% of hot water need	
Life Cycle Costing for Natural Gas	**Solar Thermal Hot Water System**	**Natural Gas**
Purchase and Installation	$8,795	$500
Cost after 30% Personal Tax Credit	$6,157	N/A
Salvage	$0	$0
Maintenance and Repair	$0	$0
Replacement Costs	$0	$0
Energy Costs*	$0	$289.46
Annual energy savings	$289.46	N/A
Total Life Cycle Cost	$6,157	$789
Difference between Solar and Natural Gas	$5,367	
Payback Period (years)	**21.3**	

Source: Author's calculations. See text.

As can be seen above, the payback periods for a solar thermal hot water system compared to solar PV are staggeringly smaller, even with comparable purchase and installation costs (of a 1 KW PV system). This life cycle cost analysis is more straight-forward than solar PV because it is assumed there is one typical system that can be installed which will meet 100% of a homes hot water heating needs. Based on the current price of electricity, the payback period for solar thermal hot water heating with electricity is almost half of that compared to heating water with natural gas. A payback period of 12.8 years for the system which offsets electricity consumption is still a long payback period for a homeowner, especially when outside factors are considered. The payback period for a solar hot water system which replaces natural gas heating is 21.3 years, which is considered a long payback period.

These payback periods have difficulty competing with the low costs of conventional fuels in addition to the fact that homeowners may not want to make a long term investment for hot water heating. The cost of electricity per month to heat water in a Valley home according to the above calculations is roughly $40, and for natural gas the cost per month is about $24. A homeowner comparing their current cost of heating water to the cost of a installing a solar thermal system would not likely be inclined to give up the low monthly cost of water heating to install solar thermal equipment for almost $6,200. However, the cost of a solar thermal hot water system is very similar to a 1 KW solar PV system, yet the payback period is much shorter. This alludes to the fact that if a homeowner is willing to install solar technology and aware of all the current options and costs, the first choice would likely be a solar thermal system because it has a shorter payback period (regardless if using electricity or natural gas). The solar thermal system would meet 100% of a homeowners hot water needs for a slight increase in upfront costs.

Discounting

Taking into account the time value of money is essential to get a realistic picture of the length of time for payback required for a solar system. The value of money in the future is less than the value of money in present value which means that the monetary savings of each size system will decrease and the length of time required to pay off the system will increase. Two discounting formulas were used to determine the discounted life cycle costs of PV and thermal systems. To find the discounted solar PV life cycle cost, the replacement costs (inverters) were discounted using a single present worth formula as follows:

$$P = F \times \frac{1}{(1+i)^N}$$

where P is the present value, F is the future sum of money, ‘i’ is an interest or discount rate, and n is the number of years or discounting periods. This equation is used because the replacement costs are incremental costs as opposed to a uniform series of payments. Shown below in Table 9 is a comparison of the simple and discounted life cycle costs and payback periods.

Table 9. Comparison of Life Cycle Costs and Payback Periods for Simple and Discounted Computation Methods of Solar PV Technology

	Life Cycle Costs for Solar PV				
	0.5 KW	**1 KW**	**3 KW**	**5 KW**	**Payback (Years)**
Simple Payback	$3,720	$7,440	$22,320	$37,200	40
Discounted Payback	$3,471	$6,942	$20,827	$34,712	57

Source: Author's calculations. See text.

The present value of an inverter is $0.71 per watt, which is used in the above equation (SMA America LLC., 2011). The discount rate used is 3%, which is used by the Virginia Federal Credit Union for a home equity line of credit. This figure is used because homeowners in the Valley that can afford a system will likely combine it with house payments or a mortgage (if they have one) rather than paying out of pocket or applying for a personal loan. A home equity line of credit loan payback period is generally 15 years, but it will be assumed that the length of loan will not be shorter than the life of the technology. For this reason, it will be assumed that the loan for the solar technology will be paid off in 30 years.

The rate of 3% is also a common estimate used for the rate of inflation over time. It is assumed that the replacement inverters will have the same price point in the future as they do today. This scenario is favorable, but not the most favorable and not the most conservative estimate for the price of an inverter replacement. From Table 9 above, it can be seen that the discounted life cycle costs are lower for each size system, but not by significant amounts. The 1 KW system has a difference of about $500 when the time value of money is accounted for. The payback period, however, lengthens because the purchasing power of money is less in the future. Also taken into account in the above table is the changing cost of energy. The equation below was used to determine the present value for the cost of energy in the future.

$$P = A \times \frac{(1+i)^N - 1}{i\,(1+i)^N}$$

The cost of energy is accounted for in the discount rate in this equation because the discount rate is the same as the inflation rate. This is true because of the assumption that the inflation rate is 3% and the increasing cost of energy also occurs at a rate of 3%. They are moving in opposite directions, basically cancelling each other out.

Greenhouse Gas Mitigation

Greenhouse Gases

Greenhouse gases such as carbon dioxide (CO_2), methane, nitrous oxide, chlorofluorocarbons (CFC's) and many others are found naturally in the atmosphere. However, anthropogenic activities have increased GHGs substantially since the Industrial Revolution and the result will be global warming and climate change. Since the Industrial Revolution, a 30% increase has been reported in atmospheric carbon dioxide concentrations. Not all GHGs are created equal though. One CFC molecule, such as Freon, has the same ability to heat the Earth's atmosphere (global warming potential) as 10,000 carbon dioxide molecules. Carbon dioxide occurs in much higher atmospheric concentrations, but it is by no means the most potent. Greenhouse gases are sometimes grouped together for ease of explanation in what is referred to as CO_2 equivalent (CO_2e) because CO_2 is more widely understood in its effects on global warming. For the purpose of this carbon dioxide mitigation analysis, CO_2 will be examined for mitigation potential, but CO_2e will also be reported (Hinrichs & Kleinbach, 2006).

The combustion of fossil fuels for energy is a primary contributor to GHG emissions. In the residential sector, it is used mostly for electricity. The energy to power homes comes from utility companies which burn either coal or natural gas, or use combined heat and power cycles. Combined heat and power (CHP) utilizes the heat (often in the form of steam) as well as the typical mechanical energy generated from the combustion of fossil fuels which is then converted into electricity. Combined heat and power is a more efficient use of energy and often cleaner, but less common than conventional fossil fuel sources. The map below shows the Shenandoah Valley utility companies which provide electricity to the region.

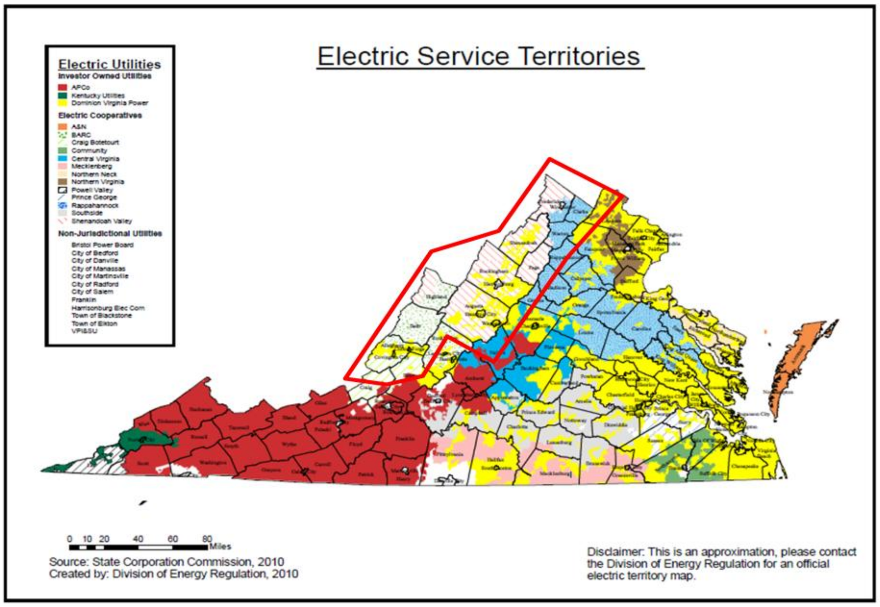

Figure 19. Virginia Electric Service Territories
Source: Division of Energy Regulation, 2010.

The Shenandoah Valley is supplied with electricity from four main utility companies, which include Dominion Virginia Power, Shenandoah Valley Electric Cooperative, Rappahannock Electric Cooperative, and BARC Electric Cooperative. Dominion Power and the Shenandoah Valley Electric Cooperative are the main suppliers of energy for the region. Normally, the fuel ratio for each utility company would need to be determined in order to evaluate the amount of carbon dioxide emissions; however, there is a tool available from the Greenhouse Gas Protocol which will calculate GHG emissions. The calculation tool has the option of selecting a geographic region which automatically assigns a fuel mix ratio which is characteristic of that region to determine the correct amount of emissions (WRI, 2011).

The Greenhouse Gas Protocol tool is designed to calculate the GHG emissions resulting from the generation of electricity for a given area. Information which is required to use the tool includes the amount of electricity being consumed and the country and region where electricity is being consumed. The fuel mix ratio can be manually chosen, but generally, the preselected fuel mix for each region is a good indicator of the fossil fuels being used for electricity generation. The predetermined region of SERC Virginia/Carolina was used, which uses the fuel mix specific for Virginia and North and South Carolina. The percentage of electricity that is being consumed by a building must also be specified, and since the GHGs are being calculated for the residential sector, it is assumed they are using 100 percent of the purchased electricity, whereas a single apartment in an apartment complex would only use a portion of the purchased electricity (WRI, 2011).

The Greenhouse Gas Protocol uses the Emissions & Generation Resource Integrated Database (eGRID) which is published by the U.S. EPA. The database reports data on environmental characteristics for much of the electric power generated in the U.S., including information for carbon dioxide, nitrogen oxides, sulfur dioxide, methane, and nitrous oxide. It gives details on emissions rates, net generation, resource mixes, among others (EPA, 2011a). The eGrid explains the differences in calculations for various GHGs as well.

> While CO_2 can be reasonably estimated by applying appropriate emission factors to the fuel quantity consumed, estimating CH_4 and N_2O depends not only upon fuel characteristics, but also on technology type and combustion characteristics, usage of pollution control equipment, and ambient environmental conditions (WRI, 2011).

The Greenhouse Gas Protocol Initiative tool was selected to determine potential carbon dioxide mitigation for the Shenandoah Valley because it is a reliable and credible source of information. The GHG Protocol Initiative is a long-standing partnership between the World Resources Institute and the World Business Council for Sustainable Development. The Protocol is held to high reporting standards, and each tool is accompanied by a guidance document which includes instructions on how to properly use the tool as well as explanations for equations or processes.

Solar PV Mitigation

For the maximum potential carbon dioxide mitigation in the Shenandoah Valley, electricity generated from each sized solar PV system (and varying numbers of OOHU) was used in calculations. The following table shows the electricity generated/consumed for each size solar PV system assuming the maximum theoretical potential, and the associated carbon dioxide offsets.

Table 10. GHG Emissions Mitigation for Solar PV Electricity Generation

			Emissions			
Number of OOHU	**Size of PV System (KW)**	**Electricity Generated (MWh)**	**CO_2 (tonnes)**	**CH_4 (kg)**	**N_2O (kg)**	**CO_2e (tonnes)**
139,990	0.5	122,631	63,127	1,322	1,100	6,349
139,990	1	245,262	126,254	2,644	2,201	126,992
139,990	3	735,787	378,763	7,933	6,604	380,977
139,990	5	1,226,312	631,271	13,221	11,007	634,961

Source: World Resource Institute, 2011 and author's calculations. See text.

From the above table, it can be seen that the carbon dioxide emissions for the maximum number of OOHU (assuming the likely 1 KW system) is about 126,000 metric tons. For reference, this amount would be equal to the offset in emissions from 22,458 passenger vehicles (EPA, 2011b). This is a noteworthy reduction in the emissions for the residential sector in the Shenandoah Valley. The emissions of carbon dioxide for every occupied housing unit in the Valley equal over one million metric tons. The offset of emissions if all owner occupied housing units (maximum theoretical potential) installed a 3 KW system would be about 37% of the total emissions from occupied homes; if every homeowner installed a 1 KW system it would offset 12.5% of total emissions from occupied homes in the Valley.

Solar Thermal Mitigation

In order to determine the amount of carbon dioxide that would be mitigated in the Valley by homeowners who choose to install solar thermal hot water systems, a weighted average of natural gas and electricity as fuel sources was used. This weighted average was determined using the U.S. Census American Community Survey data on primary home heating fuel. It is assumed that if a homeowner heats their home with one fuel, the same fuel will also likely be used to heat their water. From the Census data, it was found that 43% of the total occupied housing units used electricity as a heating source, and 31% used natural gas. When added together, they account for 74% of the total. Because other sources (wood, biogas, etc.) are not commonly used for hot water heating, the percent of electricity and natural gas were divided by 74% to give a new ratio that would equal 100%. This calculation resulted in 58% of the homes using electricity and 42% using natural gas for home hot water heating.

Because CO_2 emissions are different for electricity and natural gas, each hot water heating source was calculated individually and then added together for each scenario to get the total amount of carbon dioxide emissions that would be mitigated. The same calculation tool from the GHG Protocol that was used to calculate PV emissions mitigation was used for solar thermal hot water users who heat with electricity (WRI, 2011). This tool was utilized again due to the fuel mix which is exploited in this region to generate electricity, and therefore takes into account the varying amounts of GHG emissions from each primary energy source. However, because this tool calculates only emissions for electricity, another calculation tool was needed for natural gas. Because natural gas is a primary energy source and not region-specific with respect to GHG emissions, the EPA greenhouse gas emissions calculator tool was used (EPA, 2011b). The amount of energy which a household uses for hot water was converted from BTU into kWh for electricity and therms for natural gas, to be compatible with each tool used.

Because it is a ratio of the number of owner occupied housing units which use each fuel, 58% and 42% were multiplied by the number of owner occupied housing units in each scenario to determine the number that were using electricity and natural gas to heat their water, respectively. Then, the amount of hot water used in BTU was converted to kWh or therms for each fuel, and then input into their respective calculation tools. Table 11 shows the GHG emissions for the maximum theoretical scenario of solar thermal adoption in the Valley.

Table 11. Maximum Theoretical GHG Emissions Mitigation for Solar Thermal Hot Water Systems

Maximum theoretical: 139,990 housing units	**Electricity: 58%**	**Natural Gas: 42%**
# Owner-Occupied Housing Units	81,194	58,796
kWh offset (metric tons of CO_2e)*	369,494,244	*N/A*
Therms offset (metric tons of CO_2e)*	*N/A*	9,129,311
Metric Tons CO_2e	191,317	45,647
Total Emissions Mitigated (metric tons of CO_2e)	236,964	

***Note: The average household in the Shenandoah Valley uses 15,527,148 BTU of energy for hot water heating annually. This number was converted into kWh (4,451) and therms (15,060). Each of these numbers was input into a GHG calculator specific for electricity and natural gas, respectively.**
Source: World Resource Institute, 2011; EPA 2011b, and author's calculations. See text.

As can be seen above, the total GHG emissions mitigated from solar thermal hot water systems is equal to almost 237,000 metric tons of carbon dioxide equivalent (CO_2e). This would equate to offsetting the emissions of 46,464 passenger vehicles (EPA, 2011b). The carbon dioxide equivalent was used for emissions mitigation potential for solar thermal because the calculation tool for natural gas only reported CO_2e, and not CO_2. Carbon dioxide equivalent differs from carbon dioxide in that it includes methane, nitrous oxide, and other non-CO_2 gases. It is still an accurate picture though, of the mitigation potential for the maximum theoretical adoption scenario in the Valley.

Conclusions

This chapter outlines the methodology used to determine the affordability of solar technology for the average homeowner, which is influenced by the solar resource available to the Shenandoah Valley. The Valley receives 4.8 kWh/m^2/day of solar radiation which is average for the United States, considering the Southwest can receive up to 7 kWh/m^2/day and the Northwest may only receive 2 kWh/m^2/day. The maximum theoretical output for a PV system in the Valley would include a 5 KW system on 139,990 owner occupied housing units, which would produce enough electricity to meet 24.6% of the entire Valley's energy needs. Using the U.S. Census data of selected monthly owner costs as a percentage of income, the average disposable income for a Shenandoah Valley homeowner was determined and this information was then used with various assumptions to find the real likelihood of adoption for each size solar PV system. It was found that the most likely size solar PV system to be adopted would be 1 KW system, which would cost $7,217 over the 30-year life of a system, which would take 39 years to pay off. A salvage value of $0 after 30 years is the most likely scenario for both solar PV and solar thermal systems. The average homeowner would not be able to afford a 5 KW system, and installation of a 3KW is unlikely due to the amount of disposable income remaining after housing costs are considered. A solar thermal hot water system life cycle cost is $6,157 with a 12.8 year payback period if the solar thermal system offsets electricity, and 21.3 years if the system offsets natural gas use for hot water heating. The solar thermal system is more likely to be attractive to a homeowner in the Valley when compared to a 1 KW PV system, because it will meet 100% of the hot water needs for a home, with a shorter payback period and a faster return on investment, as well less expensive upfront costs.

Chapter 4: Estimates of the Rates of Adoption of Solar Technology in the Shenandoah Valley

The estimates of rates of adoption the in Shenandoah Valley are a core component to determine the feasibility of achieving the Valley 25x'25 goals. These estimates were generated using U.S. Census data with the assumptions that the Shenandoah Valley households are a fairly accurate representation of the whole population. The scenarios below present options and alternatives for the rates of adoption in the Shenandoah Valley with various demographic restrictions. These scenarios could help policy officials to see the real situation in the Valley and therefore plan and develop policies (such as those dealing with financial incentives) to increase the adoption and diffusion of solar technology while aiding the Valley in working toward the goal of 25% renewable energy by 2025.

Data Resources

The data which was used for this research was acquired from the U.S. Census Bureau American Community Survey (ACS). The ACS was conducted as part of the 2010 Decennial Census Program and its primary goal was to survey the American population each year to keep current with demographic, socio-economic, and housing trends. The Decennial Census data can quickly become outdated when used for research and statistical purposes and therefore would not be recent enough on which to base solid conclusions or decisions. The ACS aims to keep population information up to date so that governments and organizations continually have current data to make decisions, especially when it comes to financing public works such as schools, hospitals, and roads (U.S. ACS, 2011b). This survey supplies the most recent information to "help determine how more than $400 billion in federal and state funds are distributed each year"

(U.S. ACS, 2011a). As with the Decennial Censuses, it is required by law that United States residents respond to the ACS.

The American Community Survey (ACS) is conducted every year in order to keep current data available. Therefore, the ACS has 3 sets of data available to the public which are the 1-year, 3-year, and 5-year estimates, of which the latter two are compiled from multiple years of data. The ACS 5-year estimate was used for the research conducted because it provided data for small locales- counties and independent cities. The Decennial Censuses, 3-year estimates, and 1-year estimates do not release information with that level of detail. The 5-year estimates include the largest sample size and most months of collected data and information for areas with populations smaller than 20,000. The 2005-2009 5-year estimate data was available for more than 600,000 geographic areas. Compared to the Decennial 2000 Census, the ACS is less reliable due to the design of the form and also the ACS does not follow up with all non-respondents like the 2000 Census does. However, because the response form is shorter than the Decennial Census forms, response levels have been consistently high as well as data completeness on the forms. Responses from the ACS also indicate that the target populations are being reached with the survey. When compared with the 1-year and 3-year estimates however, the 5-year estimates survey is more reliable because it averages more data over time but for the same reason it is also the least current.

The 5-year estimates were used for this research by searching the ACS database for the Shenandoah Valley counties and independent cities. The Census Bureau separates the independent cities from counties for Virginia because of legal jurisdictions. The data supplied information on social, economic, housing and demographic statistics for these areas. The ACS data is credible because the U.S. Census Bureau is held to high reporting standards and the equitable dispersal of government money depends on the Census Bureau being reliable and accurate.

Demographic Scenarios

The specific social, economic, housing and demographic characteristics for the Shenandoah Valley are extremely influential in determining the possible solar technology adoption. Without this information, the realistic potential for the Valley could not be determined. The maximum theoretical potential for the number of households in the Shenandoah Valley for solar technology adoption is 139,990 homes because this is the number of owner occupied housing units (OOHU). However, since this number is the absolute maximum and does not take into account any barriers to implementing a solar PV or thermal system, other scenarios will also be addressed based on the barriers and opportunities to adoption found for the Shenandoah Valley. Each scenario will be assessed with each size solar PV system of 0.5, 1, 3, and 5 kilowatts, and a 'typical' solar thermal hot water system. For all calculations, installed PV systems are assumed to be current, flat-plate, off-the-shelf technology, facing south with a fixed tilt, receiving the maximum amount of sunlight. The solar thermal system is assumed to be a drainback system which meets 100% of a home's hot water needs. Income, education, and age will be applied to each size of system and a realistic adoption scenario for the Valley will be identified.

In 2009, the average U.S. household electricity consumption was 908 kWh per month. For Virginia, the average was 1,170 kWh per month or roughly 14,040 kWh annually (EIA, 2011c). Given the current electricity prices of around 10.61 cents per kWh for Virginia (EIA, 2011c), the average monthly utility bill for a Virginia resident would be about $124.06 (EIA, 2011c). For reference, Table 12 shows the cost for each size of a system, given the average installation cost for Virginia of $8.60 per watt (NREL, 2011). A 3KW system is a typical size for residential PV.

Table 12. Installed Costs of a Solar PV System

Size of Solar PV System	Installed Cost
0.5 KW	$4,300
1 KW	$8,600
3 KW	$25,800
5 KW	$43,000

Source: NREL and author's calculations

Scenarios

Scenario 1. Income Barriers

Because the high capital cost of solar technology is a very significant obstacle, the income barrier is the first applied to the total OOHU. In order to determine the number of homeowners which could afford a system based on income, the 'selected monthly owner costs as a percentage of household income' (SMOCAPI) data was used from the ACS. By using this information as opposed to the raw income data, this gives a better picture of affordability and amount of disposable income. A homeowner may make $75,000 annually, but if housing costs require half of that, they will likely not be able to afford solar technology. The figure used for determining the number of households which could afford solar PV or solar thermal technology based on income is 104,654 homes. This was determined by adding together the number of households (mortgaged and owned free and clear) which have SMOCAPI less than 30% of total household income. This percentage was used because conventionally a loan will not be given to any applicant whose monthly costs are more than 30% of total income because it presents a financial liability to the lender for repayment. Table 13 shows the amount of electricity which can be generated from households restricted by income, for solar PV. Table 14 shows the households restricted by income for a solar thermal hot water system.

Table 13. Solar PV Electricity Generation in the Shenandoah Valley, with Adoption Levels Restricted by Income

Number of Housing Units	kWh Generated Annually	Size of PV system (KW)	Percent of Total SV OOHU Electricity Need Met by PV	Percent of Total SV Household Energy Need Met by PV
104,654	91,676,904	0.5	5%	2%
104,654	183,353,808	1	9%	4%
104,654	550,061,424	3	28%	11%
104,654	916,769,040	5	47%	18%

Source: U.S. Census Bureau, ACS 2005- 2009 and author's calculations. See text.

Table 14. Solar Thermal Electricity Generation in the Shenandoah Valley, with Adoption Levels Restricted by Income

Number of Housing Units	kWh Generated for a Single Solar Hot Water Heater	Total kWh Generated Annually	Percent of Total SV Household Energy Need Met by Solar Thermal
104,654	4,550	476,175,700	10%

Source: U.S. Census Bureau, ACS 2005- 2009 and author's calculations. See text.

Table 13 clearly shows that even if every household that could possibly afford PV installed the largest system (5 KW), less than half of the total Shenandoah Valley OOHU electricity needs would be met. Notably, if a single household has lower electricity needs, it might meet a larger percentage of the individual total. The table also shows that if every person who could afford solar PV installed a system, the percent of total household energy use in the Valley would equate to about 18%. Table 14 shows that if all homeowners who were restricted by income installed a solar thermal hot water system, 10% of all energy consumed in occupied housing units in the Valley would be met.

Scenario 2. Education Barriers

Another barrier which needs to be applied to the PV adoption scenarios is the attainment of education. It is inferred that the amount of education a person receives will directly influence the likelihood of knowledge and awareness of renewable technologies. Therefore, for this scenario only residents which achieved higher education of some kind (at least some college education) were included in the calculations. Because the Census data was not *directly* correlated, some assumptions were made. In order to find the number of households which would be able (or restricted) to install solar technology based on education, the total number of residents age 25 or older who achieved at least some college education for each county in the SV was added together. Then, the "educated" residents were divided by the total population age 25 or older to determine the percentage of the population that was educated. This percentage (44.15%) was then multiplied by the total number of OOHU in the Valley. The assumption is that the number of OOHU is a representative portion of the population, so that the same percentage could be applied to both (i.e. homeowners are not necessarily more or less educated than those who rent). This resulted in 61,806 households which may be able to install solar technology based on their educational attainment. Tables 15 and 16 show the calculations for annual electricity generation for these households.

Table 15. Solar PV Electricity Generation in the Shenandoah Valley, with Adoption Levels Restricted by Education

Number of Housing Units	kWh Generated Annually	Size of PV system (KW)	Percent of Total SV OOHU Electricity Need Met by PV	Percent of Total SV Household Energy Need Met by PV
61,806	54,141,692	0.5	3%	1%
61,806	108,283,385	1	6%	2%
61,806	324,850,155	3	17%	7%
61,806	541,416,925	5	28%	11%

Source: U.S. Census Bureau, ACS 2005- 2009 and author's calculations. See text.

Table 16. Solar Thermal Electricity Generation in the Shenandoah Valley, with Adoption Levels Restricted by Education

Number of Housing Units	kWh Generated for a Single Solar Hot Water Heater	Total kWh Generated Annually	Percent of Total SV Household Energy Need Met by Solar Thermal
61,806	4,550	281,215,412	6%

Source: U.S. Census Bureau, ACS 2005- 2009 and author's calculations. See text.

Because this scenario took into account the barrier of education, it can be seen that there are even fewer households than those restricted by income which might be willing to install a solar PV system. A 3 KW system is thought to be a typical size for residential solar PV. If every household which had achieved at least some college education installed a 3 KW solar PV system, the electricity generated would meet 17% of the total electricity needs and 7% of total energy needs for the homeowners in the Shenandoah Valley. Table 16 shows that if all homeowners who were restricted by education installed a solar thermal hot water system, 6% of all energy consumed in occupied housing units in the Valley would be met.

Scenario 3. Age Barriers

Another significant barrier to adoption rates for the Shenandoah Valley is homeowner age. Zahran, et al. (2008) stated that the consumption of expensive durable goods often peak during midlife, usually between the ages 40-49. It was also stated that this generally occurs regardless of other social factors such as family structure, education, and occupation. Because solar PV systems are expensive durable goods, age of homeowner was included as a major barrier (or opportunity) for residential solar technology adoption. For this scenario, two age groups from the ACS were used in the calculations; one group age 35 to 44 and the other group ages 45 to 54. These age groups were used because they included Zahran et al.'s target age population, and because residents younger than 35 are less likely to have a static living situation or the financial means to install solar technology. People over age 55, even if educated and aware of renewable technologies will probably not be eager to take the financial risk as they are closer to retirement age. The total number of residents in these age ranges was added together and then divided by the total population. Again, the assumption was made that the OOHU includes residents who are representative of the total population. This assumption is carried out throughout the remaining scenarios as well. Therefore, the percentage of the total population age 35 to 54 was found to be 28.36%. This value was then multiplied by the total number of OOHU (139,990) to find the number of OOHU whose owners were in the target age range. Tables 17 and 18 shows the likely electricity generated from homes which have been restricted by age.

Table 17. Solar PV Electricity Generation in the Shenandoah Valley, with Adoption Levels Restricted by Age

Number of Housing Units	kWh Generated Annually	Size of PV system (KW)	Percent of Total SV OOHU Electricity Need Met by PV	Percent of Total SV Household Energy Need Met by PV
39,701	34,778,220	0.5	2%	< 1%
39,701	69,556,439	1	4%	1%
39,701	208,669,318	3	11%	4%
39,701	347,782,197	5	18%	7%

Source: U.S. Census Bureau, ACS 2005- 2009 and author's calculations. See text.

Table 18. Solar Thermal Electricity Generation in the Shenandoah Valley, with Adoption Levels Restricted by Age

Number of Housing Units	kWh Generated for a Single Solar Hot Water Heater	Total kWh Generated Annually	Percent of Total SV Household Energy Need Met by Solar Thermal
39,701	4,550	180,640,296	4%

Source: U.S. Census Bureau, ACS 2005- 2009 and author's calculations. See text.

As can be seen by the number of housing units, age is far more limiting than income or education for homeowners. If all the homeowners between the age of 35 and 54 installed a 3 KW solar system, it would generate about 11% of the total electricity needs, and 4% total energy needs of the homeowners in the Shenandoah Valley. Table 18 shows that if all homeowners who were restricted by age installed a solar thermal hot water system, 4% of all energy consumed in occupied housing units in the Valley would be met.

Scenario 4. Combined Barriers

Even though just one of these barriers applied to the total number of Shenandoah Valley homeowners seems very restrictive, it is probably not realistic. A number of homeowners may be restricted by more than one factor, such as income and education, or age and income, or age and education. Income and education are the two barriers which are most closely correlated. The methodology to determine the number of housing units and generated electricity for each one is very similar. Because the high capital cost of a system and therefore the amount of household disposable income is the most common barrier, it was used as the baseline to apply the education and age percentages. For example, to find the number of housing units restricted by income and education, the percentage of the population which has achieved higher educational attainment (44.15%) was multiplied by the number of housing units already restricted by income (104,654). This resulted in a new value which is restricted by both factors. The same methodology was used to find adoption levels restricted by income and age, and age and education. When determining which percentage to apply to which factor, the most significant factor was used as the baseline. For instance, income is more influential than age or education so for all barriers which include income, the percentage of either education or age is multiplied by the number of households already restricted by income. It was determined that education is the least influential of the three because it is the most easily changed. Knowledge and awareness of solar technology can be gained through classes or social networking regardless of income and age, whereas it is significantly more difficult to change one's income. Age is a significant adoption component but it is considered a static factor for this research. Tables 19 through 24 below show the number of OOHU and possible electricity generation for solar PV and solar thermal hot water systems taking into account the combined barriers.

Table 19. Solar PV Electricity Generation in the Shenandoah Valley, with Adoption Levels Restricted by Income and Education

Number of Housing Units	kWh Generated Annually	Size of PV system (KW)	Percent of Total SV OOHU Electricity Need Met by PV	Percent of Total SV Household Energy Need Met by PV
46,205	40,475,353	0.5	2%	< 1%
46,205	80,950,706	1	4%	2%
46,205	242,852,119	3	12%	5%
46,205	404,753,531	5	21%	8%

Source: U.S. Census Bureau, ACS 2005- 2009 and author's calculations. See text.

Table 20. Solar Thermal Electricity Generation in the Shenandoah Valley, with Adoption Levels Restricted by Income and Education

Number of Housing Units	kWh Generated for a Single Solar Hot Water Heater	Total kWh Generated Annually	Percent of Total SV Household Energy Need Met by Solar Thermal
46,205	4,550	210,231,572	4%

Source: U.S. Census Bureau, ACS 2005- 2009 and author's calculations. See text.

Table 21. Solar PV Electricity Generation in the Shenandoah Valley, with Adoption Levels Restricted by Income and Age

Number of Housing Units	kWh Generated Annually	Size of PV system (KW)	Percent of Total SV OOHU Electricity Need Met by PV	Percent of Total SV Household Energy Need Met by PV
29,575	25,907,893	0.5	1%	< 1%
29,575	51,815,786	1	3%	1%
29,575	155,447,358	3	8%	3%
29,575	259,078,931	5	13%	5%

Source: U.S. Census Bureau, ACS 2005- 2009 and author's calculations. See text.

Table 22. Solar Thermal Electricity Generation in the Shenandoah Valley, with Adoption Levels Income and Age

Number of Housing Units	kWh Generated for a Single Solar Hot Water Heater	Total kWh Generated Annually	Percent of Total SV Household Energy Need Met by Solar Thermal
29,575	4,550	134,567,253	3%

Source: U.S. Census Bureau, ACS 2005- 2009 and author's calculations. See text.

Table 23. Solar PV Electricity Generation in the Shenandoah Valley, with Adoption Levels Restricted by Age and Education

Number of Housing Units	kWh Generated Annually	Size of PV system (KW)	Percent of Total SV OOHU Electricity Need Met by PV	Percent of Total SV Household Energy Need Met by PV
17,528	15,354,584	0.5	< 1%	< 1%
17,528	30,709,168	1	2%	< 1%
17,528	92,127,504	3	5%	2%
17,528	153,545,840	5	8%	3%

Source: U.S. Census Bureau, ACS 2005- 2009 and author's calculations. See text.

Table 24. Solar Thermal Electricity Generation in the Shenandoah Valley, with Adoption Levels Restricted by Age and Education

Number of Housing Units	kWh Generated for a Single Solar Hot Water Heater	Total kWh Generated Annually	Percent of Total SV Household Energy Need Met by Solar Thermal
17,528	4,550	79,752,691	2%

Source: U.S. Census Bureau, ACS 2005- 2009 and author's calculations. See text.

Using the above tables, it can be assessed that those scenarios restricted by age have the least adoption potential. The age factor is significant because it implies that there is only a 20-year span when a homeowner would want to install a solar PV system, which may or may not be accurate. Without that restriction, all ages of the population of homeowners are included in the pool for solar technology adoption which increases the odds greatly. Given the above information, it is logical to expect that since two barriers were more restrictive than one, three barriers applied to the OOHU would create the lowest adoption rates and generation of electricity. Table 25 shows the electricity generated from PV and adoption levels if the barriers of income, education and age are all applied to the residential sector. Table 26 shows the same constraints and adoption levels for solar thermal hot water systems in the Valley.

Table 25. Solar PV Electricity Generation in the Shenandoah Valley, with Adoption Levels Restricted by Income, Age, and Education

Number of Housing Units	kWh Generated Annually	Size of PV system (KW)	Percent of Total SV OOHU Electricity Need Met by PV	Percent of Total SV Household Energy Need Met by PV
13,057	11,438,335	0.5	< 1%	< 1%
13,057	22,876,670	1	1%	< 1%
13,057	68,630,009	3	3%	1%
13,057	114,383,348	5	6%	2%

Source: U.S. Census Bureau, ACS 2005- 2009 and author's calculations. See text.

Table 26. Solar Thermal Electricity Generation in the Shenandoah Valley, with Adoption Levels Restricted by Age and Education

Number of Housing Units	kWh Generated for a Single Solar Hot Water Heater	Total kWh Generated Annually	Percent of Total SV Household Energy Need Met by Solar Thermal
13,057	4,550	59,411,442	1%

Source: U.S. Census Bureau, ACS 2005- 2009 and author's calculations. See text.

This information was determined in the same way that two-barrier scenarios were calculated, except the order of factors was important to consider. Because education is more variable than income or age, the percentage of the population (and assuming the number of OOHU) was multiplied by the scenario which was already restricted by income and age (Table 13). In order of factors subtracted from the maximum possible adoption level, income was restricted from the total number of OOHU based on affordability using the SMOCAPI of less than 30%. Then, the age barrier was accounted for by multiplying the result by 0.2836 (28.36%) to find those restricted by income and age. The final condition was placed on the OOHU by multiplying the percentage of the population with some college education (44.15%). The resulting number of housing units which might apply residential solar technology is 13,057. Assuming the 3 KW PV system size which is average for residential homes, 68 million kWh of electricity would be generated, or about 3% of the total electricity needs for owner occupied housing units in the Shenandoah Valley. A 3 KW system would also generate about 1% of the total energy for the occupied housing units in the residential sector. Table 24 shows that if all homeowners who were restricted by income installed a solar thermal hot water system, only 1% of all energy consumed in occupied housing units in the Valley would be met.

A three-barrier situation is very realistic, however for this paper, it cannot be confidently stated whether or not a majority of the population would be affected by all three barriers. A majority of the people would likely be affected by two barriers to solar PV installation, however. For that reason, the moderate scenario will be restricted by income and education. To generalize about the population that would or would not adopt solar PV technology, income and education are better gauges together than any of the other combinations, mostly because they are easily correlated together and the age range barrier between 35 and 54 is the most restrictive.

Scenario 5. Most Likely Scenario

In conclusion, the maximum theoretical adoption potential for the Shenandoah Valley is 139,990 homes and assuming the installation of an "average" sized PV system of 3 KW, it would generate 735,787,440 kWh of electricity annually, or 37% of the total electricity needs, and 14.8% of the total Shenandoah Valley household energy needs. The maximum theoretical output for solar thermal hot water systems in the Valley is equal to 13% of the total energy used in occupied Valley homes. A moderate scenario and probably the most realistic is the two-barrier scenario restricted by income and education. A 3 KW system in this case would generate 242,852,119 kWh or about 242 gigawatts of electricity annually from 46,205 housing units, or 12.4% of the total electricity consumption needs of the homeowners in the Valley, and 5% of the total household energy in the Valley. Solar thermal water heating systems would produce enough to meet 4% of the Valley's total energy consumption needs, assuming the same restrictions as solar PV. Another scenario considered all three barriers to adoption in a conservative scenario which resulted in 13,057 households generating 68,630,009 kWh of electricity annually. This much electricity generated from PV panels would meet only about 3% of the total electricity needs for the homeowners in the Valley, and 1% of the total energy needs for Valley homeowners. The solar thermal offset of electricity generation in this scenario would meet only 1% of the Valley's total energy needs. The most likely scenario, however, as shown in Tables 27 and 28, occur when homeowners in the Valley are restricted by income, education, and the affordability of solar technology.

Table 27. Solar PV Electricity Generation in the Shenandoah Valley, with Adoption Levels Restricted by Income, Education, and Affordability

Number of Housing Units	kWh Generated Annually	Size of PV system (KW)	Percent of Total SV OOHU Electricity Need Met by PV	Percent of Total SV Household Energy Need Met by PV
29,530	25,868,280	0.5	1%	< 1%
29,530	51,736,560	1	3%	1%
29,530	155,209,680	3	8%	3%
29,530	258,682,800	5	13%	5%

Source: U.S. Census Bureau, ACS 2005- 2009 and author's calculations. See text.

Table 28. Solar Thermal Electricity Generation in the Shenandoah Valley, with Adoption Levels Restricted by Income, Education and Affordability

Number of Housing Units	kWh Generated for a Single Solar Hot Water Heater	Total kWh Generated Annually	Percent of Total SV Household Energy Need Met by Solar Thermal
29,530	4,550	134,361,500	3%

Source: U.S. Census Bureau, ACS 2005- 2009 and author's calculations. See text.

This scenario clearly shows that a 1 KW system would meet 2.6% of the total OOHU electricity needs and about 1% of the total Shenandoah Valley household need. The most likely scenario for solar thermal indicates that it would offset 134,361 megawatts of electricity and meet 3% of the total Shenandoah Valley energy needs. It should be noted that the scenarios restricted by income do not take into account financing options or federal, state, or local incentives, but affordability calculations do include the tax breaks for homeowners. The cost effectiveness and affordability issues are addressed in Chapter 3, which would make the results a more reasonable and practical assessment of the true adoption potential for the Shenandoah Valley.

Likelihood of Adopting Both Solar PV& Solar Thermal

The most likely scenario for adoption in the Valley for each type of solar technology is restricted by income, education, and affordability. While this is the most likely scenario for each type of system individually, the likelihood of installing both a solar PV and a solar thermal hot water system in the same housing unit is far less likely. The compounded cost of purchase and installation for both systems would equate to $12,177 after rebates. This amount would be about a third of the average annual household disposable income (roughly $32,000).

To find the likelihood of both types of solar technology adoption, an estimate of adoption rate will be taken from the most likely scenario. The number of housing units in the most likely scenario is about 15% of the total occupied housing units (139,990) which might be willing and able to adopt solar technology. For this reason, an adoption rate of 15% will be assumed for the adoption of solar PV and solar thermal. It will be assumed that 15% of the homeowners who install solar thermal hot water will also be likely to install solar PV. The reason that the solar thermal hot water system is the baseline technology is because it is more likely to be attractive and therefore installed than a solar PV system. This is due to the shorter payback period and also the fact that the solar hot water system would meet 100% of a home's needs, or 18.2% of their total annual energy costs. If 15% of the homeowners who installed a solar thermal system also installed a1 KW solar PV system, the result is 4,430 households. If this number is divided by the total number of occupied housing units in the Valley, it is found that 3.2% of all homeowners in the Valley are likely to install both types of systems.

The estimate of 3.2% of homeowner adoption of both types of solar technology in the Valley is only a rough approximation, as the estimation technique assumes that if a homeowner is able then they are also willing to install both technologies, which may or may not be the case. Only a small portion of the homeowner population will actually fit optimal criteria for willingness to install *both* technologies. Some of the criteria would include wealthy homeowners that earn more than the average annual disposable income, household innovators who like to install new technologies, and homeowners with strong environmental values. The homeowners who are most likely to install both solar technologies are going to be those that are intrinsically motivated by a number of factors and probably will not adopt both systems because someone convinced them to.

The approximation of 3.2% of homeowners who would install both technologies would lead to 0.68% of total energy needs met by occupied housing units in the Valley. This was found by determining the percentage of Valley total energy need met by solar PV and solar thermal from the 15% adoption rate situation and adding them together. This is a small percentage, but it should be noted that this is only for homeowners who will install both technologies, or 15% of households from the most likely scenario for each technology. The likelihood of all solar technology adoption in the Valley is higher than this, because this situation does not account for homeowners which would install just one system.

GHG Mitigation

Table 29 shows the most realistic demographic scenario where the number of housing units is restricted by income and education. The amount of electricity generated for a 3 KW system is almost 243,000 megawatt hours compared to almost 81,000 megawatt hours for a 1 KW system. The carbon dioxide offset is around 125,000 metric tons for a 3 KW system and about 42,000 for a 1 KW system. Clearly, there is a considerable difference in carbon dioxide mitigation between the two systems. For the same scenario, solar thermal hot water could offset 78,212 metric tons of CO_2e which is between a 1 and 3 KW PV system for perspective of mitigation potential.

Table 29. GHG Emissions Mitigation for Solar PV Electricity Generation Constrained by Income and Education

			Emissions			
Number of OOHU	**Size of PV system (KW)**	**Electricity Generated (MWh)**	**CO_2 (tonnes)**	**CH_4 (kg)**	**N_2O (kg)**	**CO_2e (tonnes)**
46,205	1	80,950	41,671	872	726	41,914
46,205	3	242,852	125,013	2,618	2,179	125,744

Source: World Resource Institute, 2011 and author's calculations. See text.

Table 30. GHG Emissions Mitigation for Solar Thermal Hot Water Systems Constrained by Income and Education

46,205 housing units	Electricity: 58%	Natural Gas: 42%
# Owner-Occupied Housing Units	26,799	19,406
kWh offset (metric tons of CO_2e)	121,955,008	*N/A*
Therms offset (metric tons of CO_2e)	*N/A*	3,013,214
Metric Tons CO_2e	63,146	15,066
Total Emissions Mitigated (metric tons of CO_2e)	78,212	

Source: U.S. Census Bureau, ACS 2005- 2009 and author's calculations; EPA, 2011b; and author's calculations. See text.

Taking economics into consideration to develop the most likely adoption scenario, Table 31 shows the amount of GHG emissions which would be offset by the most likely number of houses to adopt solar PV based on affordability. The life cycle benefit cost analysis resulted in a new number of housing units which would likely adopt a smaller PV system based income, education, and the cost of a system (affordability).

Table 31. GHG Emissions Mitigation for Solar PV Electricity Generation Constrained by Income, Education, and Affordability

			Emissions			
Number of OOHU	Size of PV system (KW)	Electricity Generated (MWh)	CO_2 (tonnes)	CH_4 (kg)	N_2O (kg)	CO_2e (tonnes)
29,530	1	51,736	26,633	557	464	26,788

Source: World Resource Institute, 2011, and author's calculations. See text.

Table 32. GHG Emissions Mitigation for Solar Thermal Hot Water Systems Constrained by Income, Education, and Affordability

29,530 housing units	Electricity: 58%	Natural Gas: 42%
# Owner-Occupied Housing Units	17,127	12,403
kWh offset (metric tons of CO_2e)	77,942,460	*N/A*
Therms offset (metric tons of CO_2e)	*N/A*	1,925,770
Metric Tons CO_2e	40,357	9,629
Total Emissions Mitigated (metric tons of CO_2e)	49,986	

Source: U.S. Census Bureau, ACS 2005- 2009 and author's calculations; EPA, 2011b; and author's calculations. See text.

Tables 31 and 32 show the most likely scenario to occur for solar PV and solar thermal adoption in the Shenandoah Valley. The amount of GHG emissions which would be offset by the number of homeowners which can afford and are likely to adopt solar PV is equal to 26,633 metric tons of CO_2, and 3% of the total electricity consumption needs of the owner occupied houses. This scenario would generate about 1% of the total energy needed for occupied homes in the Shenandoah Valley. Solar thermal hot water systems would offset almost twice as much carbon dioxide equivalent as a 1 KW solar PV system. Mitigating 49,986 metric tons of CO_2e would equate to offsetting the emissions from 9,801 passenger vehicles.

Conclusions

In conclusion, greenhouse gases emitted from the residential sector are a large contributor to global emissions and account for 21% of the total emissions in the United States which impact local air quality, weather patterns, and the condition of the environment (Hinrichs & Kleinbach, 2006). Solar PV technology may be out of reach for many of the homeowners in the Valley due to various obstacles, but if those that could afford it installed a PV system, it could lead to a noteworthy reduction in the amount of carbon dioxide emissions from the residential sector in the Shenandoah Valley. A little over 12% change may not seem like much in terms of slowing global warming and climate change, but it is a necessary step in the right direction toward transitioning to renewable energies. Realistically, the affordability of solar PV is a significant obstacle and considering it, the Shenandoah Valley would only be able to meet roughly 3% of the residential electricity consumption needs and 1% of the total energy needs. Solar thermal would meet 13% in the maximum theoretical scenario and in the most realistic scenario, 3% of the total energy needs in the Valley. There is a long way to go for solar PV and solar thermal to be considered a realistic option to getting to 25% renewable energy by 2025 in the Valley residential sector.

Chapter 5: Conclusions

Results of analysis

The results of this research analysis conclude that the maximum theoretical potential for solar technology adoption in the Shenandoah Valley is an unrealistic goal in the next 14 years. The 25x'25 goal would require all owner occupied housing units to implement either a solar PV or solar thermal hot water system which is equal to 139,990 homes, and would meet 24.6% of the total Valley's energy consumption needs and offset 631,271.7 metric tons of carbon dioxide. This is equivalent to the emissions of 123,779 passenger vehicles. There are a number of barriers which prohibit the maximum potential from occurring in the Valley, including those which fall into the categories of technical issues, lack of knowledge and awareness, consumer economic decision making barriers, and overcoming established systems.

A life cycle benefit cost analysis was integral in determining if Valley homeowner would be able to afford each type of solar technology. The results indicated that a 1 KW PV system would be the most affordable and likely for an average homeowner. This type of system would have a life cycle cost of $7,217 over 30 years after the 30% personal tax credit. The payback period of this system would take 39 years given the current electricity costs of $0.1061 per kWh, which means that the system would never pay for itself since the expected life of a system is 30 years. This is an undiscounted, simple payback period calculation and does not reflect the time value of money. The solar thermal system was assumed to meet 100% of the homeowner's needs and cost $6,157 after the 30% federal rebate. It also had a life cycle of 30 years but would be paid off in 12.8 years if it replaced electricity as a heating fuel and in 21.3 years if it replaced natural gas. These calculations are also undiscounted and do not reflect the time value of money.

From the barriers to residential adoption, it was deduced that the technologies that had the best chances of adoption would be solar PV and solar thermal hot water because they are easily retrofitted into the existing housing stock. Regional geography is a key issue to adoption and diffusion of solar technology as well. Matching the local demand with a region-specific renewable energy portfolio is vital to the success of any renewable energy program or campaign (Feder, 2004). For the case of the Shenandoah Valley, the amount of solar radiation as a resource is good but will not get any better. Therefore, with the current technology available and associated costs, the amount of solar radiation received will not make it cost effective or attractive for homeowners to install a system. In order for the geographic influences not to matter, the cost of system would have to decrease drastically or the cost of conventional fuels would have to increase accordingly.

Demographics also played a big role in the adoption rates in the Shenandoah Valley and the main factors which influenced adoption rates were household income, amount of education attained, and the age of homeowners. The affordability was combined with these factors to determine the real likelihood of adoption solar technology. The most likely scenario for adoption is 29,530 homes, or about 15% of the total number of homes in the Valley. Given this scenario, the technologies would generate about 1% of the Valley's total energy needs for solar PV and about 3% would be met assuming solar thermal hot water installation. The carbon dioxide mitigation which would occur from the most likely solar PV scenario is equal to 26,632.6 metric tons, or the equivalent of mitigating the emissions from 5,222 passenger vehicles.

One opportunity that solar technology has to be more successful in the Valley is through educational campaigns. It has been found from literature that the adoption rate of solar water heaters in the residential sector is most inhibited by educational barriers (Leidl & Lubitz, 2009). New water heating technology adoption rates are low compared to the momentum of conventional water heating sources, such as electricity and natural gas, because they are familiar to the homeowner (Leidl & Lubitz, 2009). Another author used a technology adoption model developed by Rogers (2005. Diffusion of Innovations. Free Press, New York.) in urban Mexico to determine social acceptance patterns of solar technology. The predominant factor influencing adoption was also education, followed closely by complexity and trial-ability of the technology

(Mallet, 2007). Hirschberg & Schoen (1974) also state that while consumers understand the growing energy problems and the need for energy alternatives, it is not seen as an issue for individuals until it affects them personally. While these cases span geography and time and are not easily compared to the Valley, they provide a guide for social acceptance patterns of solar energy technology. The Valley should focus first on educating the public and homeowners about the benefits of solar technology and then continue to progress with persuasion and incentives.

The role of financial incentives is essential to widespread diffusion of solar technology in the residential sector. Currently there are very few incentives, and only one which makes a small difference for the average homeowner. This one incentive is a federal tax credit of 30% of the purchase and installation costs of solar equipment. If solar technology were more affordable to a Shenandoah Valley homeowner with an average annual income of about $32,000, adoption and diffusion rates would likely increase. Sadly, this is the result of deficient policies which do not aid the adoption and diffusion of solar technology in the residential sector. Increasing the strength and quantity of policies and financial incentives which support and promote solar technologies is one way which would help the Valley achieve its 25x'25 goals.

Sensitivity of Solar Technology Adoption to Cost Estimates

The calculations completed throughout this research assume that electricity rates and the price of solar technology do not change. While this is probably accurate for the near future, it may not be true long-term. For this reason, the sensitivity of solar technology adoption to current cost estimates is explored. Two options for price changes in solar technology exist: an increase in electricity prices, or a decrease in the cost of PV technology (with or without incentives or subsidies). Fluctuations in these prices could influence the rate of adoption of solar PV by homeowners in the residential sector.

It should be noted that while prices of electricity and the purchase costs of solar technology may change, the current rate for labor (installation, maintenance, etc.) will not likely change much. For example, the 'average' solar thermal system for the Valley included almost $5,000 in materials costs, and $3,100 was attributed to the cost of labor. This means that even extreme reductions in the cost of solar technology has a limited potential for changing the overall costs due to the current cost of labor. Solar thermal sensitivities will not be explored in this section, but would be an excellent opportunity for further research.

In order to make solar PV more affordable, a simple assumption will be made that homeowners will not likely install a PV system unless the payback period is 10 years or less. Ten years is a reasonable length of time to pay off a system for a homeowner and still gain a return on investment. It is also assumed that homeowners are willing to install a 1 KW system because it is the most affordable while producing more electricity than a 0.5 KW system.

In order to find what the installed cost of a system would have to be with a 10-year payback period, the energy savings per year was multiplied by 10 years. The annual savings for a 1 KW system in Virginia is about $186, (assuming a constant electricity rate of about 10.6 cents per kilowatt hour). Thus, the net installed cost of a system would have to be $1,860 to achieve a payback period of 10 years. This cost would reflect a mix of installed cost and any available incentives or subsidies. This result does not seem very realistic, especially for the next several years.

Another option is to hold the cost of a PV system at current prices and determine what the electricity rates would have to be in order to effect a 10-year payback period. Without incentives, the cost of a 1 KW system is $8,600. The cost without subsidies divided by the annual energy savings would have to equal 10 years. This results in a projected annual energy savings of $860. If the annual energy savings is divided by the annual energy output of a 1 KW system (1,752 kWh), the result is $0.49 per kWh. This is what the cost of electricity would need to be in order to achieve a 10-year payback period assuming the cost of PV technology does not change. Obviously, $0.49 per kilowatt hour is an outrageous electricity rate and is highly unlikely to occur.

A third option is a more practical estimate, where the cost of electricity increases but to a more realistic price. For this scenario, $0.16 per kilowatt hour (a reasonable increase from $0.10 per kWh) will be multiplied by the annual output of a 1 KW PV system (1,752 kWh), which results in an annual energy savings of $280. If this savings is multiplied by 10 years, the net cost of a system would be $2,800 which could be achieved through incentives and/or subsidies. The cost of electricity could be either the regulatory price from the utility company, or it could reflect the net metering or feed-in tariff rate for the electricity produced.

Strengths and Weaknesses of Methodology

The data used for this research was essential for the type of investigation that was conducted. The U.S. Census American Community Survey 5-year estimates data is reliable, credible and specific at the county and independent city level , which was advantageous for calculations. If this data was not available, estimations would have been made from Virginia state data, which would be less detailed and reliable.

Alternatively, some calculations required use of state data to make generalizations about the Shenandoah Valley when specific information was not available. The estimations which required extrapolating from the national to state to regional level are only approximations and should not be taken as exact calculations. Another weakness which could be considered is that not all forms of solar technology were included in the feasibility assessment. Some were excluded based on design and ease of retrofit issues. Therefore, this feasibility assessment only exemplifies the change solar PV and solar thermal hot water systems could make in energy savings and greenhouse gas reductions.[3] However, solar PV and solar thermal hot water are well-known technologies which would increase the likelihood of quality workmanship by installation

[3] Preheating water and the associated economic benefits is one example of an exclusion which is not accounted for because it is not a common type of heating system in the Valley. The purpose of these estimates is to have useful generalizations which can be applied to large portions of the population rather than specific cases for individual homeowners.

technicians. These technologies are also familiar to homeowners which increases the likelihood of adoption. This assessment, which does exclude some types of solar technology, provides a very real picture of the possibilities of adoption and diffusion in the residential sector in the next 14 years.

Opportunities for Further Study

One option for further study would be the impact that new construction homes would have on the goal of getting to 25x'25. New construction homes have more opportunities to integrate passive design, energy efficiency measures, and building integrated technologies. New construction homes can also be designed more efficiently with tighter building envelopes which would increase energy savings and reduce GHG emissions. Duke, Williams, and Payne (2005) found that by scaling up thin-film PV production, the market for solar technology opened because the technology was more affordable and cost effective at about $1.50 per watt. At this price, they estimate that solar PV technology would be affordable to about 125,000 new construction homes annually (Duke, Williams, & Payne, 2005).

Closely related to this study, another option would be to continue the current research completed and determine the impact that lower renewable technology prices would have on adoption rates in the Valley. Solar technology may or may not improve or get better at a rate which would influence the decisions of homeowners on whether or not it would be beneficial and cost effective to install solar technology. If prices do fall to around $1-$2 per watt, it would be economically beneficial for homeowners to consider installation because a system would actually become an investment which would pay for itself before the end of life expectancy.

Another opportunity for further study would be to examine the impacts of population patterns and cultural influences on adoption rates. Population growth/decline and migrations in and out of the Shenandoah Valley counties could change existing housing stock occupancy which would affect the maximum potential adoption for the Valley. Owner occupied housing units are necessary for solar technology to be installed, because the benefit cost ratio would not be advantageous for a landlord or renter to consider. Another option would be the socio-cultural influence of political affiliation and perceptions of renewable technologies by homeowners. In a political climate where there is a majority of liberals, the likelihood for renewable technology adoption is greater compared to a more conservative climate.

Similar to the research already conducted, the Valley 25x'25 organization could delve further into the demographics at the county level to determine where campaign and educational efforts would be best focused. Instead of considering the Shenandoah Valley as one community which is striving to reach the 25x'25 goals, more specific conclusions could come from county level research with respect to the impact of introducing educational and awareness campaigns on solar technology adoption and diffusion rates.

Perhaps one of the most important opportunities for further study would be to investigate the possibilities for policy to increase the adoption rates of solar technology. Whether or not financial incentives definitively influence the rates of adoption of solar technology has been taken into consideration in one study, where ten western states were examined (Durham, Colby, & Longstreth, 1988). From this research, it was found that both the policies advocating solar thermal systems as well as the policies influencing the cost of conventional fuel sources will influence a homeowner's decision to install such technology (Durham, Colby, & Longstreth, 1988). Net metering is another example of one type of policy which can be used as a substitute for affordable PV system pricing. It incentivizes homeowners and internalizes the benefits of solar technology, such as reduced local air pollution and a more reliable electricity supply (Duke, Williams, & Payne, 2005).

Closing Remarks

It can be concluded from the research conducted that the Shenandoah Valley is not likely to reach the goals of the 25x'25 in the residential sector solely through solar technology. The expectations of homeowners to adopt solar technology are high, even with the barriers present which make the technology not cost effective or advantageous for the homeowner. The offset in greenhouse gas emissions however, would be beneficial, even though it is not tangible or easily quantified.

The year 2025 is only 14 years away, which is a short time period considering all that would have to happen to make the implementation of solar technology in the residential sector more feasible for the average homeowner. In order for adoption of solar technology to be more feasible, the costs of the technology would have to become more affordable including a shorter payback period. Policies promoting solar technology installation and use are needed. Financial incentives which make the up-front costs of a system affordable would also aid the adoption and diffusion in the residential sector. Educational and awareness campaigns for homeowners would make the technology more familiar and less complicated which would favorably impact adoption and diffusion rates throughout the residential sector.

Solar technology in the residential sector is not the only technology available to help the Valley achieve its goals, however. Various types of renewable technologies such as wind, hydropower, biomass, and geothermal would have to be implemented in a collaborative and aggressive effort to get to 25x'25. The Valley initiative is using all tools at its disposal to try to make 25% renewable energy happen by 2025. Changes in energy sources and efficiency measures will also need to occur in all sectors including agricultural, non-agricultural industrial, commercial, transportation, and not just residential energy.

Appendix A

Table 33. Discounted Life Cycle Costing for Solar PV

Life Cycle Costing with Discounting -Electricity	**0.5 KW**		**1 KW**		**3 KW**		**5 KW**	
	PV System	**Grid-tied electricity**	**PV System**	**Grid-tied electricity**	**PV System**	**Grid-tied electricity**	**PV System**	**Grid-tied electricity**
Purchase and Installation	$3,010	$0	$6,020	$0	$18,060	$0	$30,100	$0
Salvage	$0	$0	$0	$0	$0	$0	$0	$0
Maintenance and Repair	$0	$0	$0	$0	$0	$0	$0	$0
Replacement Costs								
Simple	$710	$0	$1,420	$0	$4,260	$0	$7,100	$0
Discounted at 3%	$461		$922		$2,767		$4,612	
Energy Costs*	$0	$2,788	$0	$5,577	$0	$16,730	$0	$27,883
Annual energy savings	$92.94	$0	$185.89	$0	$557.66	$0	$929.44	$0
*Discounted stream of annual savings over 30 years	N/A	$1,822	N/A	$3,643	N/A	$10,930	N/A	$18,217
Total Life Cycle Cost	**$3,471**	**$2,788**	**$6,942**	**$5,577**	**$20,827**	**$16,730**	**$34,712**	**$27,883**
Difference between Solar and Grid over 30 years	$683		$1,366		$4,097		$6,829	
Discounted Payback Period	57	N/A	57	N/A	57	N/A	57	N/A

Source: Author's calculation

Table 34. Discounted Life Cycle Cost Analysis for Solar Thermal Technology which Offsets Electricity

Solar Hot Water	One size meets 100% of hot water need	
Discounted Life Cycle Costing for Electricity	**Solar Thermal Hot Water System**	**Grid-tied Electricity**
Purchase and Installation	$8,795	$0
Cost after 30% Personal Tax Credit	$6,157	
Salvage	$0	$0
Maintenance and Repair	$0	$0
Replacement Costs	$0	$0
Energy Costs*	$0	$482.83
Annual energy savings	$482.83	N/A
**Discounted stream of annual savings over 30 years*	*$9,463.76*	N/A
Total Life Cycle Cost	$6,157	$482.83
Difference between Solar and Grid	$5,674	
Payback Period	**19.5**	

Source: Author's calculations.

Table 35. Discounted Life Cycle Cost Analysis for Solar Thermal Technology which Offsets Natural Gas

Solar Hot Water	One size meets 100% of hot water need	
Discounted Life Cycle Costing for Natural Gas	**Solar Thermal Hot Water System**	**Natural Gas**
Purchase and Installation	$8,795	$0
Cost after 30% Personal Tax Credit	$6,157	$0
Salvage	$0	$0
Maintenance and Repair	$0	$0
Replacement Costs	$0	$0
Energy Costs*	$0	$289.46
Annual energy savings	$289.46	N/A
**Discounted stream of annual savings over 30 years*	*$5,673.52*	N/A
Total Life Cycle Cost	$6,157	$289.46
Difference between Solar and Grid	$5,867	
Payback Period	**32.6**	

Source: Author's calculations

References

25x'25. (n.d.). *25x'25 and California Partnership Join Forces to Pursue Clean Energy.* Retrieved from http://www.25x25.org/index.php?option=com_content&task=view&id=327&Itemid=57

25x'25 Action Plan. (2007). *Charting America's Energy Future.* Retrieved from http://www.25x25.org/storage/25x25/documents/IP%20Documents/Action_Plan/actionplan_64pg_11-11-07.pdf

25x'25 National Steering Committee. (n.d.c.). What is 25x'25? Retrieved from http://www.25x25.org/index.php?option=com_content&task=view&id=12&Itemid=41

25x'25 National Steering Committee. (n.d.a). Why renewables. Retrieved from http://www.25x25.org/index.php?option=com_content&task=view&id=15&Itemid=44

25x'25 National Steering Committee. (n.d.b.). Why renewables: Solar power. Retrieved from http://www.25x25.org/index.php?option=com_content&task=view&id=17&Itemid=46

Adachi, C. (2010). *The adoption of residential solar photovoltaic systems in the presence of a financial incentive: A case study of consumer experiences with the renewable energy standard offer program in Ontario (Canada). Masters Abstracts International, 48*(3), 1671.

Alternate Energy Technologies, LLC. (n.d). AE-series collectors. Available from http://www.aetsolar.com/AEseries.html

Bureau of Labor Statistics (BLS). (2009). Unemployed persons by occupation and sex. Retrieved from ftp://ftp.bls.gov/pub/special.requests/lf/aa2009/aat25.txt

California Energy Commission. (2011). Passive solar design. Retrieved from http://www.consumerenergycenter.org/home/construction/solardesign/index.html

Charlotte Solar Power. (n.d.) Home [photo]. Retrieved from http://www.solarnc.net/

Database of State Incentives for Renewables & Efficiency (DSIRE). (2011). Virginia solar incentives. Retrieved from http://www.dsireusa.org/incentives/index.cfm?EE=1&RE=1&SPV=0&ST=0&sector=Residential&state=VA&technology=all_solar&sh=1

Department of Energy Efficiency and Renewable Energy (EERE). (2011a). Energy savers: Active Solar Heating. Retrieved from http://www.energysavers.gov/your_home/space_heating_cooling/index.cfm/mytopic=12490

Department of Energy Efficiency and Renewable Energy (EERE). (2011b). Energy savers: Conventional storage water heaters. Retrieved from http://www.energysavers.gov/your_home/water_heating/index.cfm/mytopic=12980

Department of Energy Efficiency and Renewable Energy (EERE). (2011c). Energy savers: Estimating appliance and home electronic energy use. Retrieved from http://www.energysavers.gov/your_home/appliances/index.cfm/mytopic=10040

Department of Energy Efficiency and Renewable Energy (EERE). (2011d). Energy savers: Five elements of passive solar home design. Retrieved from http://www.energysavers.gov/your_home/designing_remodeling/index.cfm/mytopic=10270

Department of Energy Efficiency and Renewable Energy (EERE). (2011e). Energy savers: Solar air heating. Retrieved from http://www.eere.energy.gov/basics/buildings/solar_air_heating.html

Department of Energy Efficiency and Renewable Energy (EERE). (2011f). Energy basics: Solar water heaters. Retrieved from http://www.eere.energy.gov/basics/buildings/water_heaters_solar.html

Department of Energy Efficiency and Renewable Energy (EERE). (2011g). Energy savers: Solar water heaters. Retrieved from http://www.energysavers.gov/your_home/water_heating/index.cfm/mytopic=12850

Department of Energy Efficiency and Renewable Energy (EERE). (2000). Passive solar design. Retrieved from http://apps1.eere.energy.gov/buildings/publications/pdfs/building_america/29236.pdf

Department of Mines, Minerals, and Energy (DMME). (2010). Virginia energy plan: Executive summary. Retrieved from http://www.dmme.virginia.gov/DE/VAEnergyPlan/2010-VEP/ExecSummary.pdf

Division of Energy Regulation (2010). Electric Service Territories. Retrieved from http://www.scc.virginia.gov/pue/elec/el_map.pdf

Dominion Virginia Power. (2011). Residential electric rates. Retrieved from http://www.dom.com/dominion-virginia-power/customer-service/rates-and-tariffs/pdf/vatc25ra.pdf

Duke, R., Williams, R., & Payne, A. (2005). Accelerating residential PV expansion: Demand analysis for competitive electricity markets. *Energy Policy, 33*(15), 1912-1929. doi:DOI: 10.1016/j.enpol.2004.03.005

Durability and Design. (2010). 'Solar shingle' gets UL safety ok as 2011 launch nears [photo]. Retrieved from http://www.durabilityanddesign.com/news/?fuseaction=view&id=4587

Energy Information Administration (EIA). (2011a). *Average monthly residential electricity consumption, prices, and bills by state*. [Data file]. Available from http://www.eia.gov/tools/faqs/faq.cfm?id=97&t=3

Energy Information Administration. (2009a). *Energy consumption by end use sector, ranked by state, 2009* . [Data file]. Retrieved from http://www.eia.gov/state/seds/hf.jsp?incfile=sep_sum/plain_html/rank_use.html

Energy Information Administration (EIA). (2009b). [Graph]. *Energy consumption by sector overview*. Retrieved from http://www.eia.gov/totalenergy/data/annual/pdf/sec2_4.pdf

Energy Information Administration (EIA). (2010a). Energy in Brief: How much of our electricity is generated from renewable sources? Retrieved from http://www.eia.gov/energy_in_brief/

Energy Information Administration (EIA). (2011b). Energy in brief: What are greenhouse gases and how much are emitted by the United States? Retrieved from http://www.eia.gov/energy_in_brief/

Energy Information Administration (EIA). (2011c). How much electricity does an American home use? Retrieved from http://www.eia.gov/tools/faqs/faq.cfm?id=97&t=3

Energy Information Administration (EIA). (2007). Renewable and alternative fuels: Renewable energy consumption and electricity preliminary 2006 statistics. Retrieved from http://www.eia.gov/cneaf/solar.renewables/page/prelim_trends/rea_prereport.html

Energy Information Administration (EIA). (2009c). *Residential energy consumption estimates,2009.* [Data file]. Retrieved from http://www.eia.gov/state/seds/hf.jsp?incfile=sep_sum/plain_html/sum_btu_res.html

Energy Information Administration (EIA). (2011d). Residential energy consumption survey. Retrieved from http://www.eia.gov/consumption/residential/reports/2009overview.cfm

Energy Information Administration (EIA). (2009d). Virginia analysis. Retrieved from http://www.eia.gov/state/state-energy-profiles-analysis.cfm?sid=VA

Energy Information Administration (EIA). (2011f). Virginia data: Consumption. Retrieved from http://www.eia.gov/state/state-energy-profiles-data.cfm?sid=VA#Consumption

Energy Information Administration (EIA). (2011e). Virginia data: Prices. Retrieved from http://www.eia.gov/state/state-energy-profiles-data.cfm?sid=VA#Prices

Energy Information Administration. (2005a). *Total consumption for water heating by major fuels used, 2005.* [Data file]. Retrieved from http://www.eia.gov/emeu/recs/recs2005/c&e/waterheating/pdf/tablewh4.pdf

Energy Information Administration. (2005b). *Total energy consumption, expenditures, and intensities, 2005.* [Data file]. Retrieved from http://www.eia.gov/emeu/recs/recs2005/hc2005_tables/c&e/pdf/tableus1part1.pdf

Energy Information Administration (EIA). (2010b). Use of energy in the United States explained: Energy use in homes. Retrieved from http://205.254.135.24/energyexplained/index.cfm?page=us_energy_homes#tab1

Environmental Protection Agency (EPA). (2011a). EGrid clean energy. Retrieved from http://www.epa.gov/cleanenergy/energy-resources/egrid/index.html

Environmental Protection Agency (EPA). (2011b). Greenhouse gas equivalencies calculator. Retrieved from http://www.epa.gov/cleanenergy/energy-resources/calculator.html#results

Environmental Protection Agency (EPA). (2011c). Inventory of U.S. greenhouse gas emissions and sinks:1990-2009. Retrieved from http://epa.gov/climatechange/emissions/downloads11/US-GHG-Inventory-2011-Executive-Summary.pdf

Foreman, G. (2005). How much should I spend on housing? *Better Budgeting*. Retrieved from http://www.betterbudgeting.com/articles/budgeting/spendonhouse.htm

Gelman, R. (2010). *2009 Renewable energy data book.* Retrieved from http://www1.eere.energy.gov/maps_data/pdfs/eere_databook.pdf

Gelman, R., Hummon, M., McLaren, J., & Doris, E. (2010). *NREL's clean energy policy analyses project: 2009 U.S. state clean energy data book.* Retrieved from http://www.nrel.gov/docs/fy11osti/48212.pdf

Hinrichs, R.A. & Kleinbach, M. (2006). *Energy: It's use and the environment* (4th ed.). Toronto, Ontario: Thomson Brooks/Cole.

Kammen, D.M. (2004, Mar). Renewable energy options for the emerging economy: Advances, opportunities, and obstacles. Retrieved from http://www.physics.harvard.edu/~wilson/energypmp/Kammen.pew.pdf

Leidl, C., & David Lubitz, W. (2009). Comparing domestic water heating technologies. *Technology in Society*, *31*(3), 244-256. doi:DOI: 10.1016/j.techsoc.2009.06.005

Margolis, R. & Zuboy, J. (2006). Nontechnical barriers to solar energy use: Review of recent literature. Retrieved from http://www.nrel.gov/docs/fy07osti/40116.pdf

Marshall, H. and Ruegg, R. (1980). *Simplified Energy Design Economics: Principles of Economics Applied to Energy Conservation and Solar Energy Investments in Buildings*, Washington, DC: U.S. Department of Commerce.

Nair, G., Gustavsson, L., & Mahapatra, K. (2010). Factors influencing energy efficiency investments in existing swedish residential buildings. *Energy Policy*, *38*(6), 2956-2963. doi:10.1016/j.enpol.2010.01.033

National Renewable Energy Laboratory (NREL). (2009). Buildings research: Building integrated solar technologies. Retrieved from http://www.nrel.gov/buildings/building_solar.html

National Renewable Energy Laboratory (NREL). (2008). Photovoltaic Solar Resource of the United States. Retrieved from http://www.nrel.gov/gis/images/map_pv_national_lo-res.jpg

National Renewable Energy Laboratory (NREL). (2011). The Open PV Project: State rankings. Retrieved from http://openpv.nrel.gov/rankings

Patterson, J. (2011). Solar hot water basics. Retrieved from http://homepower.com/basics/hotwater/

Reddy, P. J. (2010). *Science technology of photovoltaics*. Hyderabad, IND: Global Media.

Shenandoah Valley Electric Cooperative. (2011). Residential net metering. Retrieved from http://www.svec.coop/v.php?pg=87

SMA America, LLC. (2011). Company profile. Retrieved from http://www.sma-america.com/en_US/company/about-sma.html

Solar Energy Industries Association (SEIA). (2011). Net metering and interconnection standards: Pathways to distributed generation. Retrieved from www.seia.org/galleries/FactSheets/Factsheet_netmetering_interconnection.pdf.

Summers, R. (2011). What is discretionary income? *Money and Business.* Retrieved from http://www.moneyandbusiness.com/personal-finance/taxes/filing/what-discretionary-income

Trisko, E. M. (2008). The rising burden of energy costs of Virginia families. Retrieved from http://www.deq.state.va.us/export/sites/default/info/documents/climate/Virginia_Energy_Analysis_091008.pdf

Uni-solar. (2003). Uni-solar shingle model SHR-17 data sheet. Retrieved from http://www.nooutage.com/pdf/Unisolar-SHR17specs.pdf

U.S. Census Bureau, 2005-2009 American Community Survey (ACS). (2011a). About the American community survey. Retrieved from http://www.census.gov/acs/www/about_the_survey/american_community_survey/

U.S. Census Bureau, 2005-2009 American Community Survey (ACS). (2009). *Virginia data profiles by county* [Data sets]. Available from http://factfinder.census.gov/servlet/DatasetMainPageServlet?_program=ACS&_submenuId=datasets_2&_lang=en

U.S. Census Bureau, 2005-2009 American Community Survey (ACS). (2011b). When to use 1-year, 3-year, or 5-year estimates. Retrieved from http://www.census.gov/acs/www/guidance_for_data_users/estimates/

U.S. Census Bureau. (1990). Building Permits. Retrieved from http://censtats.census.gov/bldg/bldgprmt.shtml

U.S. Census Bureau. (2011b). State and county quick facts: Virginia. Retrieved from http://quickfacts.census.gov/qfd/states/51000.html

U.S. Nuclear Regulatory Commissions (NRC). (2011). Operating nuclear power reactors. Retrieved from http://www.nrc.gov/info-finder/reactor/

U.S. Photovoltaic Industry Roadmap Steering Committee. (2001). Solar-electric power: the U.S. photovoltaic industry roadmap. Retrieved from http://photovoltaics.sandia.gov/docs/PDF/PV_Road_Map.pdf

Valley 25x'25. (2011a). About us. Retrieved from http://www.valley25x25.org/about

Valley 25x'25. (2011b). Renewables. Retrieved from http://www.valley25x25.org/renewables

Virginia Energy Sense. (2011). Incentives. Retrieved from http://www.virginiaenergysense.org/cue/home/incentives.html

Warkov, S., & Monnier, E. (1985). Social science research on residential solar technology in the United States and France. *International Journal of Comparative Sociology*, *26*(3-4), 240-245.

Weather Bureau Army Navy (WBAN) Identification Numbers. (1990). *30-Year Average of Monthly Solar Radiation, 1961-1990.* Retrieved from http://rredc.nrel.gov/solar/old_data/nsrdb/redbook/sum2/state.html

Wood, L. (2007). Solar shingles could power tomorrow's house. Retrieved from http://www.livescience.com/4501-solar-shingles-power-tomorrow-homes.html

World Resources Institute (WRI). (2011). GHG Protocol tool for stationary combustion. Version 4.2. Retrieved from http://www.ghgprotocol.org/calculation-tools/all-tools

Yang, C. (2010). Reconsidering solar grid parity. *Energy Policy*, *38*(7), 3270-3273. doi:DOI: 10.1016/j.enpol.2010.03.013

Zahran, S., Brody, S., Vedlitz, A., Lacy, M., & Schelly, C. (2008). Greening Local Energy: Explaining the geographic distribution of household solar energy use in the United States. Retrieved from http://www.scopus.com/inward/record.url?eid=2-s2.0-65449168793&partnerID=40&md5=d527adbeca1c12d6e82314639b4d4b87

Zaslow, S., & Cox, B. (1999). Passive solar retrofit for North Carolina homes. Retrieved from http://www.ncsc.ncsu.edu/include/_upload/media/pubs/01retrof.pdf