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A technology assessment of on-farm renewable energy carbon mitigation strategies

Laura Kossey
James Madison University

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A Technology Assessment of On-Farm Renewable Energy Carbon Mitigation Strategies

Laura Kossey

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 Resources Management AND Integrated Science and Technology

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Abstract

This project explores whether the Shenandoah Valley can achieve its 25x’25 (25% from renewable energies by 2025) goals on farms in the agricultural sector. Solar photovoltaic electric power production was assessed to be the most feasible renewable energy technology for such farms. After a review of the barriers to the adoption of renewable energy by agricultural operations, estimations of the potential rates of adoption and energy output using US data from the US Census of Agriculture were calculated. Multiple scenarios were explored, including the “maximum theoretical” contribution of renewable energy to the agricultural sector as well as scenarios of farm behavior under different constraints. It was found that although it is technically feasible to get the Valley agriculture sector to 25x’25 with all farms implementing a 10 KW solar photovoltaic (PV) system, achieving the 25x’25 goal is unlikely in the current benefit cost environment of solar photovoltaics for farmers. In addition to issues about the affordability of the initial purchase and installation costs for the PV systems, the payback period for solar PV technology in the Shenandoah Valley typically exceeds 30 years, well beyond the agricultural sector’s preferred payback period for comparable investments of 3-5 years or less and well beyond the useful life of the equipment.
Chapter 1: Introduction

Introduction

This thesis focuses on assessing the feasibility of solar PV adoption on farms in the Shenandoah Valley, and how much that can contribute to the region’s goal of meeting 25% of its total energy needs with renewable energy by the year 2025. It uses formal technology assessment techniques to evaluate the opportunities and barriers to renewable energy, specifically solar in the agriculture sector. It takes an in-depth look into the technical, economic, social, and public policy opportunities and barriers in order to conduct a two-part analysis. This project explores whether the Shenandoah Valley can achieve its 25x’25 goals in facility-based farms in the agricultural sector. After a review of the barriers to the adoption of renewable energy by agricultural operations, the potential rates of adoption and energy output is estimated using data from the US Census of Agriculture and the Department of Energy. Multiple scenarios are explored, including the “maximum theoretical” contribution of renewable energy to the agricultural sector as well as scenarios of farm behavior under a variety of constraints.

At current rates of consumption and over the long term, fossil fuel-based energy is not a sustainable energy solution. Energy, economic development, national security, and environmental quality are inseparably connected. Renewable energies are less subject to price volatility and help protect and cushion the US’s national energy system from natural catastrophe, terrorist attack, and dependence on supply from hostile and unstable regions of the world (Sovacool, 2009a). The future of the United States’ energy potential can be found in already-existing practices and establishments on its own lands (25x’25 Action Plan, 2007). Through farms, ranches and forests, the potential to generate new energy solutions exists for crop, livestock and grass and horticultural producers, as well as forest land owners, to become major producers of the nation’s energy (25x’25 Action Plan, 2007).
Thesis Structure

This thesis contains five chapters. The introduction is contained in Chapter one, which includes the significance of the thesis, a short introduction to the 25x’25 Initiative, and barriers and opportunities of renewable energy in the Valley. Chapter two takes an in-depth look at the literature and background of agriculture in the Shenandoah Valley. Chapter three describes the methodology and concept of maximum theoretical yield for solar photovoltaics while calculating the maximum theoretical output as a percent of total farm electricity use and total energy use options for attaining 25x’25 in the Valley agricultural sector. Chapter three also introduces a cost benefit analysis and discussion on affordability and Chapter four explores carbon dioxide mitigation. Chapter five contains conclusions, realistic rates of adoption, limitations of the thesis, and opportunities for further study.

Significance

With the threat of climate change caused by anthropogenic greenhouse gas (GHG) emissions, humankind is responsible for making a plan to slow, stop, and reverse the harmful effects its actions have caused. The potential impacts of climate change include changes in: seasonal weather patterns; the amount and type of precipitation; storms and sea level; regular climate fluctuations; ocean acidity; ecosystems and biodiversity; agriculture, forestry, and fishing; water supply and other infrastructure; and human health (Shackleton, 2009). The United States has 4.5% of the world's population and the largest economy in the world. Because it meets 83% of its energy needs by burning fossil fuels, it is responsible for about 19% of global carbon dioxide emissions from burning fossil fuels in 2008, and 18% in 2009 (EIA, 2010). With the largest economy in the world, the US also has the potential to become the largest producer of locally produced sustainable energy. Renewable energy such as solar, geothermal, wind, biomass, and hydropower already makes up roughly 8% of US energy consumption but 8% is not enough to
achieve US goals for energy security, economic productivity and development, national security, and environmental quality (EIA, 2010).

The United States imports more petroleum and natural gas than any other country. About 95% of the US’s net imports were imported energy in the form of petroleum and in the past twenty years, natural gas imports have also expanded rapidly (EIA, 2010). In 2010, the United States consumed 98 quadrillion British thermal units (BTU) of energy, 22% of which was imported (roughly 33 quadrillion BTUs) while 8 quadrillion BTU was exported (EIA, 2010). Coal, crude oil-based petroleum and nuclear energy make up the remainder of bulk of energy consumed, with renewable energy coming in at only 8% of US energy consumption (EIA, 2010). The dependency of foreign energy imports threatens the United States’ energy security and economic productivity, while the heavy use of fossil fuels has, and will continue to have, a negative environmental impact (Arvizu, 2007). Using renewable energy produced in the United States provides:

- **Energy security** Secure supply and reliability. With a projected level of oil imports to reach an estimated 70% by 2025, the US is dependent on the Middle East, from where two-thirds of the world’s oil comes (25x’25, n.d.a). The US’s agriculture and forestry sectors have the ability to produce enough biofuels (such as ethanol and biodiesel) to meet at least 25% of current US gasoline consumption (25x’25, n.d.a). Not only does the security of the US gain from renewable energy but domestic renewable energy sources are insulated from international market uncertainty and by virtue of shorter supply chains and avoiding unstable producing nations, domestic renewable energy sources are more secure (25x’25, n.d.a).

- **Economic productivity** Growth in demand and price volatility. As domestic supplies of fossil fuels have run low, renewable energy has become more competitive in price. It can save consumers money by competing with gasoline and allowing natural gas to be used in homes as opposed to power plants (25x’25, n.d.b). Developing renewable energy has the
ability to bring new technologies to market and create jobs in America in addition to diversifying local economies and increasing local tax bases. By 2020, wind energy alone could create 80,000 new jobs and $1.2 billion in new income in the US (25x’25, n.d.b).

- **Environmental impact** Land and water use, carbon emissions. Fossil fuel and nuclear power plants are the nation’s second largest users of water, produce millions of tons of solid waste, emit mercury, particulate matter, and other noxious pollutants into the atmosphere, and cause social inequity by exacerbating poverty (Sovacool, 2009a).

**The 25x’25 Initiative**

The 25x’25 Initiative is a private sector, non-profit renewable energy program with a national goal of having America’s farms, ranches and forests provide 25% of the nation’s total energy consumed by the year 2025, while continuing to provide food, feed, and fiber that is safe and affordable (25x’25 Action Plan, 2007). Started by a group of volunteer farmers, 25x’25 has evolved into an alliance that includes leaders from business, labor, conservation and religious groups, and is supported financially by the Energy Future Coalition, a non-partisan public policy initiative funded by foundations (25x’25 Action Plan, 2007). By increasing US renewable energy production and use, new technology will be available to save consumers money, dependency on fossil fuels will be reduced, new jobs will be created in rural America, and air quality will improve with the reduction of greenhouse gas emissions and urban smog (25x’25 Action Plan, 2007).

The 25x’25 Initiative started in the Western States out of the agriculture and forestry sectors. The Initiative helped coordinate issues on a federal policy level and the San Joaquin Valley in California started looking into what agriculture specifically could do to get the US to 25x’25 (25x’25, n.d.c). In 2005, the San Joaquin Valley was the first regional demonstration project to take the National goal to a community level goal (25x’25, n.d.c). The 25x’25 Initiative and the San Joaquin Valley Clean Energy Organization (SJVCEO) lead a regional effort to
develop, plan and implement energy efficiencies and clean energy in the San Joaquin Valley (25x’25, n.d.c). Recognized as one of the fastest growing agriculture regions in the nation, the San Joaquin Valley (composed of eight counties) aims to promote energy use efficiencies and the adoption of clean, renewable energy technologies to ensure a reliable energy supply, grow the economy and improve air quality (25x’25, n.d.c). The 23-member SJVCEO board includes representatives from other partnership work groups, educational institutions, community-based organizations, and agriculture and business leaders.

In 2008, Shenandoah Valley 25x’25 advocates sought funding from the 2010 Federal Budget and received a 4-year, $750,000 grant to establish a South East footprint demonstration project, the second demonstration project in the country, to achieve 25x’25 using the Shenandoah Valley (K. Newbold, personal communication, September 8, 2011). Learning from the San Joaquin Valley’s blueprints and lessons learned, while creating their own, the Shenandoah Valley’s 25x’25 Initiative has many of the same goals as the first demonstration project (K. Newbold, personal communication, September 8, 2011). Through academic outreach programs, agritourism, and lobbying efforts, the Valley 25x’25 Initiative has a goal to get the Valley to 25% renewable energy by the year 2025, a target that is 14 years away (K. Newbold, personal communication, September 8, 2011).

With energy demand in the United States projected to increase 24% by 2025, the 25x’25 Action Plan serves as a guide to provide safety, security, and profitability of meeting the increased energy demand through five areas (25x’25 Action Plan, 2007). These areas include:

- Increasing production of renewable energy
- Delivering renewable energy to markets
- Expanding renewable energy markets
- Improving energy efficiency and productivity
- Strengthening conservation of natural resources (p. 5)
The 25x’25 initiative in the Shenandoah Valley is important to provide the guidance and focus needed for a specific goal. Energy conservation and renewable energy are key elements to attaining the 25x’25 goal. With these guidelines, the Shenandoah Valley has the potential to work toward energy independence from fossil fuels and become more sustainable, while also meeting current demands and projected increases.

An important element to attaining the 25x’25 goal is to first reduce the amount of energy used or wasted by implementing energy efficiency and conservation measures. Energy efficiency and conservation allows farmers to implement techniques that are more cost effective for their operations than implementing a new technology, which may require more money, investment, or infrastructure than they are willing or able to afford. Conservation measures can include weather- and season-specific updates, such as adding temporary insulation. Making a building more energy efficient can include lighting upgrades, reevaluating irrigation techniques, and updating equipment to more energy-efficient models.

The potential of Valley farms to conserve energy will help decrease the total cost and energy used on the establishments. In order to follow the 25x’25 guidelines of improving the efficiency and productivity of renewable energy and the renewable markets, the use of solar power on farms will be needed. In exploring what makes the use of renewables possible, including opportunities and barriers alike, the feasibility of achieving the 25x’25 goal will be made possible.

**Agriculture in the Shenandoah Valley**

Virginia is home to 95 counties, 11 of which are in the Shenandoah Valley under the 25x’25 scope. The 25x’25 Valley Initiative includes Allegheny, Augusta, Bath, Clarke, Frederick, Highland, Page, Rockbridge, Rockingham, Shenandoah, and Warren Counties (Figure 1). Most of the farm data used in this thesis to analyze Valley farms are from the 2007 US Department of Agriculture (USDA) Census of Agriculture. The USDA conducts a Census of Agriculture every
five years, collecting data on “the number of farms, land use, production expenses, value of land, buildings, and farm products, farm size, characteristics of farm operators, market value of agricultural production sold, acreage of major crops, inventory of livestock and poultry, and farm irrigation practices” (USDA, 2007).

Figure 1. Counties in the Shenandoah Valley Included in 25x’25 Scope

A considerable proportion of farms in Virginia are located within the Shenandoah Valley (Table 1). Of the 47,383 farms in Virginia, 8,204 are in the Valley; 17% of the farms in Virginia are thus located in 12% of its counties.
Table 1. Number of Farms in the Shenandoah Valley, Compared to Number of Farms in Virginia

<table>
<thead>
<tr>
<th>County</th>
<th>Less than $2,499</th>
<th>$2,500 to $4,999</th>
<th>$5,000 to $9,999</th>
<th>$10,000 to $24,999</th>
<th>$25,000 to $49,999</th>
<th>$50,000 to $99,999</th>
<th>$100,000 or more</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Virginia</td>
<td>20,191</td>
<td>5,391</td>
<td>6,191</td>
<td>6,597</td>
<td>3,399</td>
<td>1,886</td>
<td>3,728</td>
<td>47,383</td>
</tr>
<tr>
<td>Allegheny</td>
<td>107</td>
<td>38</td>
<td>28</td>
<td>27</td>
<td>7</td>
<td>1</td>
<td>1</td>
<td>209</td>
</tr>
<tr>
<td>Augusta</td>
<td>531</td>
<td>204</td>
<td>229</td>
<td>298</td>
<td>126</td>
<td>92</td>
<td>249</td>
<td>1,729</td>
</tr>
<tr>
<td>Bath</td>
<td>43</td>
<td>12</td>
<td>20</td>
<td>16</td>
<td>13</td>
<td>9</td>
<td>7</td>
<td>120</td>
</tr>
<tr>
<td>Clarke</td>
<td>258</td>
<td>46</td>
<td>54</td>
<td>57</td>
<td>22</td>
<td>24</td>
<td>35</td>
<td>496</td>
</tr>
<tr>
<td>Frederick</td>
<td>326</td>
<td>89</td>
<td>91</td>
<td>81</td>
<td>40</td>
<td>15</td>
<td>34</td>
<td>676</td>
</tr>
<tr>
<td>Highland</td>
<td>67</td>
<td>17</td>
<td>22</td>
<td>44</td>
<td>43</td>
<td>25</td>
<td>21</td>
<td>239</td>
</tr>
<tr>
<td>Page</td>
<td>182</td>
<td>35</td>
<td>65</td>
<td>61</td>
<td>33</td>
<td>18</td>
<td>136</td>
<td>530</td>
</tr>
<tr>
<td>Rockbridge</td>
<td>299</td>
<td>89</td>
<td>124</td>
<td>162</td>
<td>71</td>
<td>31</td>
<td>29</td>
<td>805</td>
</tr>
<tr>
<td>Rockingham</td>
<td>531</td>
<td>167</td>
<td>195</td>
<td>240</td>
<td>146</td>
<td>68</td>
<td>623</td>
<td>1,970</td>
</tr>
<tr>
<td>Shenandoah</td>
<td>366</td>
<td>130</td>
<td>166</td>
<td>140</td>
<td>73</td>
<td>53</td>
<td>115</td>
<td>1,043</td>
</tr>
<tr>
<td>Warren</td>
<td>196</td>
<td>48</td>
<td>48</td>
<td>48</td>
<td>29</td>
<td>10</td>
<td>8</td>
<td>387</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>2,906</strong></td>
<td><strong>875</strong></td>
<td><strong>1,042</strong></td>
<td><strong>1,174</strong></td>
<td><strong>603</strong></td>
<td><strong>346</strong></td>
<td><strong>1,258</strong></td>
<td><strong>8,204</strong></td>
</tr>
</tbody>
</table>


The Valley has diverse farms, ranging from crop farming to livestock production to aquaculture. The most numerous farm types are beef cattle ranching, crop farming, and aquaculture (Figure 2) (USDA, 2011a). The most energy-intensive, facility-based farm operations include poultry farms, dairy milk production, and greenhouses and nurseries. Rockingham County has the largest number of farms in the Valley. Allegheny, Bath, Clarke, Frederick, Page, and Warren Counties have larger numbers of farms (over 100) in beef, cropland, aquaculture, hogs, poultry, sheep, or goats (USDA, 2011a).
In terms of the distribution of farms by size and value of sales, Figure 3 shows that about half of the farms have a value of total sales of less than $5,000 and about 78% of the farms are less than 180 acres in size (USDA, 2007). These statistics could be potentially misleading, however, as some farms in the Valley with a value of sales under $5,000 could be “hobby farms,” for which the owners do not actively manage agricultural operations as a primary source of income (or only for recreational purposes, for example). The owners of such small farms may be able to afford the type of solar PV systems discussed in this thesis despite their farms’ recorded value of sales; this will be addressed later in the thesis. Given the structure of the USDA Census data, there is no way to separate the data to evaluate which farms in the Valley are hobby farms and which are used as a means of primary income.

Source: USDA, 2011a.
In a 2009 article on the quickly disappearing Virginia farmland, the Richmond Times-Dispatch cited a USDA Census of Agriculture report finding a 521,000-acre loss of farmland from 2002 to 2007, the largest decline in the past 20 years (Santos, 2009). The main reason identified for the loss of farmland was housing and commercial development, with some acres having gone to conservation programs or simply falling fallow (Santos, 2009). Among farmers reporting in the Census, there was a 3% rise (54% to 57%) listing their primary occupation as “off farm” from 2002 to 2007 (Santos, 2009). There is also evidence of a trend in which the average age of the principle farm operator is growing older. The average age of a principal farm operator in 2007 was 58 years old, about 2.5 years older than 2002 farm operators (USDA, 2007). There has also been a state-wide increase in small farms generating $1,000 or less a year (Santos, 2009). Despite the loss of acreage, aging farmers, and a growing number of smaller farms, better technology and equipment on Virginia’s farms enabled productivity to reach near record levels in 2007 and 2008 (Santos, 2009). While these are trends from the state of Virginia, the trends seem to hold true for the Shenandoah Valley as demonstrated in Table 2 below.

The USDA Census data from 2002 and 2007 was compared to calculate the average farm loss or gain per county by value of sales. The average loss of farms in the Valley is about three farms per county while the farms by value of sales less than $2,500 gained on average 17 farms per county, holding true to the Virginia trend of farms in that category increasing (derived from
The largest loss category of farms is in the $2,500 to $4,999 range at about 15 farms lost per county with the $100,000 and over farms by value of sales coming in close behind with a 14-farm average loss per county (derived from USDA, 2007). Rockingham County experienced the most loss from 2002 to 2007 with 73 farms from that county alone while Augusta County gained the most overall with 38 farms (derived from USDA, 2007). One limitation to the data evaluated here is that it isn’t possible to tell where the farms went. It’s possible that some of the losses or gains recorded were merely farms that had jumped up or down in the value of sale category, but as the trends in Virginia have applied to the farms in the Valley, it is easily assumed that the problems of age, commercial development and recession also apply to the Valley.

Table 2. Average Loss or Gain of Farms by Value of Sales per County

<table>
<thead>
<tr>
<th>Farms by value of sales</th>
<th>Average Loss or Gain per County</th>
</tr>
</thead>
<tbody>
<tr>
<td>Less than $2,500</td>
<td>+17</td>
</tr>
<tr>
<td>$2,500 to $4,999</td>
<td>-15</td>
</tr>
<tr>
<td>$5,000 to $9,999</td>
<td>-9</td>
</tr>
<tr>
<td>$10,000 to $24,999</td>
<td>+8</td>
</tr>
<tr>
<td>$25,000 to $49,999</td>
<td>+8</td>
</tr>
<tr>
<td>$50,000 to $99,999</td>
<td>+2</td>
</tr>
<tr>
<td>$100,000 or more</td>
<td>-14</td>
</tr>
</tbody>
</table>

Source: USDA, 2007 and author’s calculations. See text.

What do the above trends mean for the 25x’25 goal? It’s possible that the aging population of farmers in Virginia could find a new outlook on energy challenging. The cleaner renewable energy technologies could, without appropriate education programs, be more than farmers are willing to invest in, especially without a high rate of return. Without a relatively fast payback period or incentives that defray costs of expensive solar and wind technologies, the reality of farmers being able or willing to afford renewable energies may hinder their willingness to learn more about the technologies, how they work, and why they should implement them.
Barriers and Opportunities

There are a number of barriers and opportunities that are affecting the implementation of renewable energy in agricultural sector of the United States, including the Shenandoah Valley. They include cost, awareness, technical barriers, and policy. These topics can be seen as both barriers and opportunities.

One of the most debilitating barriers to renewable energy is cost. In an article for the journal *Energy Policy* in which utility executives, state and federal regulators, manufacturers, energy analysts, economists, and users were interviewed about renewable energy, more than 90% stated cost as the single largest obstruction to renewables. (Sovacool, 2009a). When those large up front costs and long payback periods are translated directly to the consumer, there doesn’t seem to be any economic incentives that outweigh conventional electricity choices. When farm owners are faced with financial decisions and budgeting in an unfavorable economy, especially taking into account the current trends of shrinking farmland and ageing primary farm operators, there is little incentive to invest in a costly renewable energy system with a long term payback period.

Renewable energy technologies experience a systemic cost barrier compared to conventional fossil fuel electricity rates, because the cost structures of electricity pricing fail to account for all of the social costs and benefits of an energy choice, such as environmental pollution and health impacts. As Margolis and Zuboy state, this is a “failure to internalize all costs of conventional energy (e.g., effects of air pollution, risk of supply disruption) and failure to internalize all benefits of energy efficiency/renewable energy (e.g., cleaner air, energy security)” (Margolis & Zuboy, 2006).

Along with cost, awareness is a substantial social barrier - while at the same time, a potential opportunity. It can be a twofold barrier and opportunity with one part being the psychological aspect and the other part being a purely technical education. The social aspect of
humans’ psychological resistance to change comes into play with education. Current implementation of renewable energy requires consumers to be knowledge and patient (Dymond, 2002). While the concept of renewable energy has ebbed and flowed since the 1970s with the fluctuation of oil prices, it isn’t a mainstream “normal” source of energy in the national portfolio, much less the consumer’s mind. Part of the reason consumers are uninformed of renewable energy systems is due to the fact that they aren’t given accurate price signals about electricity consumption because of market distortions (such as subsidies and split incentives) (Sovacool, 2009a). There is an overall lack of information dissemination and consumer awareness about energy, energy efficiency, and renewable energy, though not necessarily through any fault of the consumer (Margolis & Zuboy, 2006). Because of this lack of awareness and understanding, the natural human impulse to resist change is exacerbated by the lack of an educational stream about energy (Sovacool, 2009b). In order to break the cycle of being comfortable with where their electricity comes from, consumers can be encouraged to use renewable energy by small commitments to energy-saving actions, which gives it the potential to be an opportunity instead of a barrier (Sovacool, 2009b).

Sovacool’s argument in technology adoption is strengthened by the approach Everett Rogers takes in his technology adoption model. Rogers states that the decision making process is a number of stages that a potential user of the technology (in this case, the farmer) must go through to adopt a new technology (Rogers, 2003). In Rogers’ model, the decision-making process begins when a farmer becomes aware of an innovation (knowledge) and weighs the costs and benefits of the technology (persuasion) (Rogers, 2003). The farmer will then make a decision based on three factors: advantages, complexity, and “triability” (Rogers, 2003). The first factor involves the farmer deciding whether or not the new technology is economically or socially advantageous. The second factor, “complexity,” is the farmer’s understanding and awareness of the how the technology works (Rogers, 2003). The third factor is “triability,” or the farmer’s ability to try out a technology before they are obligated to commit to it (Rogers, 2003). Once
these three factors in the decision-making process are complete, the farmer can make the decision on whether or not to use the new technology and confirms their decision by either using it, not using it, or reserving the right to change their mind (Rogers, 2003). It should also be noted that information and experience from a trusted source (another farmer, for example) can have a tremendous effect on local attitudes toward and perceptions of renewable energy.

The second aspect of education is the technical side. Part of farmer hesitation to change is a fear of the unknown. Consumers have to be knowledgeable and patient but also need to be able to trust the workforce skills (including scientific, technical, and manufacturing) and training in the workforce (Margolis & Zuboy, 2006). A lack of “reliable installation, maintenance, and inspection services and failure of the educational system to provide adequate training in new technologies” can severely hinder the trust of education given to consumers (Margolis & Zuboy, 2006).

The actual technical challenges facing the adoption of solar PV in the Valley includes net metering and integration with farm electric systems. Net metering is a regulatory policy that allows farmers to use their energy generation to offset their electricity consumption by sending excess electricity generated on their farm back to the grid for credit (Vick & Xiarchos, 2011). Powering buildings is an important application for solar energy on the farm, especially when grid connection and net metering are available (Vick & Xiarchos, 2011). As described by Vick and Xiarchos (2011) in *Solar Energy Use in US Agriculture*,

Under a net metering arrangement a single, bi-directional meter is used to record both electricity drawn from the grid (the meter spins forward) and the excess electricity fed back into the grid (the meter spins backwards). During this period customers receive retail prices for the excess electricity they generate. The higher the retail electricity price, the greater the benefit of net metering to the farmer. At the end of the period, the remaining credit is transferred to the utility, paid at the retail rate or paid at the avoided cost (the price the utility pays for electricity produced from fossil fuels). (p. 46)
Some electricity providers require more than one meter, however. In dual metering, one meter measures the flow of electricity from the grid and another to measure the flow into the grid and farmers are generally not paid for the electricity generated in excess of what they use themselves over a set time period (Vick & Xiarchos, 2011). Herein lies the technological challenge on farms, especially large farms. Not only is it possible to have differing meters but it’s also possible they often have multiple meters and as a result accounting for the electricity can be difficult.

Cost, awareness, and technology barriers and opportunities are important factors in the adoption of solar technology; however, policy plays a large part in that adoption evolution. Supporting policies and cost reductions in the solar industry are important factors in solar development. A combination of Federal tax incentives, State policies, and increased energy costs have quadrupled the annual capacity installed each year from 2005 to 2009 (Vick & Xiarchos, 2011). In agriculture specifically, 63% of solar panels were installed from 2005 to 2009 while 26% were installed from 2000-2004, partly due to a fivefold increase of solar energy projects funded under USDA’s Rural Energy for America Program (REAP) between 2007 and 2009 (Vick & Xiarchos, 2011). Widely adopted net metering policies alone can have an effect on mitigating externality costs and supplying public goods if kept in place until after efficient energy pricing policies are implemented, (Duke, Williams & Payne, 2005).

While cost, education, and policy are identified in this thesis as barriers, they have the potential to be the driving opportunities for renewable energy in the Valley. With the financial incentives (including a 25% cost-share and REAP grant and a 30% Federal tax credit) available to farm owners, as well as stakeholder and community participation in renewable energy and energy choices, there is a potential for a positive snowball effect. With the help of energy efficiency measures implemented on farms, a strong educational base, and the use of subsidized solar, the 25x’25 goal could be reached.
Chapter 2: Solar Photovoltaic (PV) and Agriculture

Introduction

There are many forms of renewable energy that can be implemented in agriculture. From anaerobic digesters to composters to solar to wind, depending on the resources and needs of the farm, the possibilities are numerous. Narrowing the scope of renewables to solely solar, this thesis acknowledges the technologies of solar hot water, and solar space heating, but will be focusing specifically on solar photovoltaics due to their competitive market reputation. Solar radiation varies across the United States, dictating which forms of renewable energies are the most practical and efficient to install. In this chapter, the solar radiation map shows that the Shenandoah Valley has enough solar radiation for solar PV to be an effective source of electricity for the Valley.

Solar PV

Solar cells, also called photovoltaic (PV) cells, are the main solar technology discussed and evaluated in this thesis. PV technology converts sunlight into electricity and gets its name from the process of converting light (photons) to electricity (voltage), also called the PV effect (NREL, 2009). Traditional solar cells are made from silicon, are usually flat-plate, generally are the most efficient, and produce about 1 to 2 watts of power per cell of sizes of 1 to 2 square feet. The cell responds to direct or diffuse sunlight and while direct sun is preferred, diffuse light accounts for 10-20% of total solar radiation on a horizontal surface (EERE, 2011b). On partly sunny days, up to 50% of that radiation is diffuse, and on cloudy days, 100% of the radiation is diffuse (EERE, 2011b).

In order to get a useable amount of power from PV, individual cells are connected to form modules, which can be connected together to form arrays, which can also be connected with
other arrays to produce more power to meet any small or large electric power demand (EERE, 2011b).

![Cell Module Array](image)

**Figure 4. Solar PV Power Arrangements**

Notes: Cells can be connected together to form modules. Modules can be connected to form arrays. Arrays can be connected to other arrays to meet larger electricity needs. Source: EERE, 2011b.

A solar panel used to power homes and businesses are usually configured in modules made up of about 40 solar cells and it usually takes between 10 to 20 solar modules to power a home (NREL, 2009). In a solar PV system, the PV cell (or module, array, or arrays) is the component that converts the photon to electricity but in order to be useable in most home, business, or agriculture functions, that electricity must be converted from the direct current outputted by a solar PV cell into an alternating current that can be utilized by an end source (the electricity grid or appliance) (EERE, 2011b). The current is then either stored in the battery (off-grid system), used, or sent to the electric distribution grid (grid-tied system). A grid-tied PV system is a semi-autonomous electrical generation system linked to the local electrical grid (Vick & Xiarchos, 2011). When a PV system is grid-tied, the PV system feeds excess or unused electricity generated back into the grid and when the demand for electricity is more than the PV system is producing, electricity is drawn from the grid (Vick & Xiarchos, 2011). In a complete PV system there are several photovoltaic solar cells and other components, often called balance of systems (BOS) components, that can include a tracking structure that point the cells toward the sun for optimal sunlight exposure, batteries, a charge controller, and an inverter (EERE, 2011b).

While systems that have mobile instead of fixed bases are advantageous, only fixed PV grid-tied
systems will be addressed in this thesis due to the low maintenance aspect of no moving parts or extra equipment.

![Solar PV System](source)

**Figure 5. Solar PV System**  

An entire PV system usually contains everything needed to meet a particular energy demand, such as powering electricity for a building, and depending on the size, potentially for an entire farm. In the agriculture sector, solar energy in the past has mainly been off-grid but because of interconnection, net metering policies, and green and carbon neutral initiatives, grid-tied systems that offset energy needs have gained popularity (Vick & Xiarchos, 2011).

Newer but currently less efficient solar technology are second and third generation solar cells. Second-generation solar cells, made from amorphous silicon or nonsilicon materials such as cadmium telluride, are called thin-film solar cells (NREL, 2009). These solar cells use layers of semiconductor materials only a few micrometers thick and can double as materials like rooftop shingles and tiles, building facades, or glazing for skylights due to their flexibility (NREL, 2009). Third-generation solar cells are being made from new materials other than silicon, including solar inks (NREL, 2009). While this new PV material is more expensive, little is needed to be effective which lends to these systems becoming more cost effective for use by utilities and industry, although they can only be used in extremely sunny conditions due to their small collector lenses (NREL, 2009).
Solar availability varies across the United States, dictating which forms of renewable energy is the most practical and efficient to install. In the figure below, the solar radiation resource map is shown with Virginia highlighted. With an annual solar radiation of 4.8 kWh/m²/day, the Shenandoah Valley has enough solar radiation for solar PV to be an effective source of electricity.

**Figure 6. PV Solar Resource of the United States**

Notes: The Shenandoah Valley has an annual solar radiation value of 4.8 kWh/m²/day. Annual average solar resource data is shown for tilt = latitude collector. The data for Hawaii and the 48 contiguous states is a 10 km, satellite modeled dataset (SUNY/NREL, 2007) representing data from 1988-2005. Source: NREL.

The basic components of the typical PV system include the PV panel and usually a small housing unit that holds and monitors the AC/DC inverter, meters, and feedbox. The amount of space required for the typical PV system is about 160 square feet per KW-DC rating of the system (SRP, 2011). For example, a 1 KW system would require about 160 square feet, a 5 KW system 800 square feet, and a 10 KW system about 1,600 square feet. A 5 KW system would
take up roughly a 20×40 square feet section of land, excluding the small housing unit. To put into perspective the powering ability of a solar PV system, it takes roughly 1200 to 1875 watts (or 1.2 to roughly 2 KWs) to run a standard hair dryer and between 4500 and 5500 watts (4.5 to 5.5 KWs) to run a 40 gallon water heater (EERE, 2011a).

**Current Status of Agriculture PV in the US and Virginia**

Data are available on farms that reported the installation of PV panels in 2009, on-farm energy production using solar panels (both PV and solar thermal) was reported in all 50 states with numbers ranging from four farms in Delaware to 1,906 farms in California (USDA, 2009). There were reportedly a total of 7,968 US farms using solar panels (92% using PV and 23% using thermal solar) to generate energy (USDA, 2009). These farms recorded an average generating capacity of PV panels at 4,449 watts with an average installation cost of $31,947 per farm for all panel types (USDA, 2009). In 2009, Virginia had 70 farms that reported PV solar panels at an average PV rated generating capacity of 869 watts per farm¹ (USDA, 2011b).

Given the ranking of States with farms that reported the installation of PV panels in 2009, it is possible to geographically contextualize how Virginia compares to other states. Figure 7. Total State Installed PV Capacity in Watts shows the total installed PV capacity in watts for Virginia and for the top five highest ranking States in the US. While California is the national leader by far, there are other States (Wisconsin, New Jersey, and New York) with higher levels of installation compared to Virginia, but with a weaker solar radiation resource (Virginia ranks 32nd in installed PV capacity). The fact that states with less solar radiation than Virginia have higher installed PV capacity suggests that the amount of solar radiation is not the principal limiting factor in terms of solar successful PV installed power.

¹ The data only include positive reported data. Operations that reported zero or failed to report are not included. (USDA, 2011b)
Figure 7. Total State Installed PV Capacity in Watts


Scope of Energy Use on Farms

The amount and type of energy used on farms is dependent on the type, size, and location of the farm. For example, a farm in the Southwest uses more energy in irrigation needs than a farm in the Northeast. But across the US, a dairy farm consistently uses more energy in every day operations than a poultry farm, while a dairy cow uses 10 times more electricity than a beef cow because of specialized equipment for harvesting, processing, and cooling milk (Bailey, Gordon, Burton, & Yiridoe, 2008). Hog and poultry farmers have livestock in barns that require their own electricity for housing, including ventilation, lighting and heating; greenhouse farmers may need cold storage, irrigation or specialized harvesters (Bailey et al., 2008). Dairy, poultry, greenhouses, and aquaculture, are all highly energy intensive operations. Energy use can also fluctuate over time depending on factors such as weather, changes in energy prices, and changes in total annual crop and livestock production (USDA, 2008).
This thesis will explore direct energy on farms, which is the energy used for various operations including lighting, transportation, and the operation of machinery and equipment. Indirect energy is not explored, as it represents embodied energy and resources, such as the energy used to produce commercial fertilizers (USDA, 2008). In addition, this research pays particular attention to electricity rather than natural gas, oil, or biomass, because solar PV displaces electricity, not these other forms of energy.

Of total direct energy used in the United States, agriculture accounts for 1.1% with the non-agriculture, transportation, residential, and commercial sectors using roughly 20% or more per sector (see Figure 8) (Schneef, 2004). Taking into account the differences between direct energy and indirect energy, direct energy consumes twice as many BTUs as indirect energy, but it accounts for 5-7% of farm expenditures while indirect energy accounts for 9-10% of farm expenditures (Miranowski, 2004).

Figure 8. 2002 Total US Direct Energy Use
Notes: Agriculture accounted for 1% of the total US direct energy use. Total US direct energy consumption in 2002 was 98 Quadrillion BTU. Each user category includes primary energy plus electricity. Electric generation used 38.2 billion Btu of primary energy (Schneef, 2004). Source: Department of Energy, Energy Information Agency.
When calculating national agricultural energy use, transportation and field equipment that use petroleum fuel account for over half (54.5%) of total direct energy use. In the 25x’25 scope, the only energy use taken into consideration is building, not transportation or farm equipment and machinery. The total direct farm energy consumed excluding transportation and farm equipment and machinery is calculated in the below chart, which shows that electricity accounts for 70% of total direct energy consumed on farms in 2002, excluding transportation, machinery, or farm equipment (see Figure 10) (Miranowski, 2004).

**Figure 9. Total Farm Energy Use (Direct and Indirect)**
Notes: Total direct and indirect energy consumed on US farms in 2002 was 1.7 quadrillion BTUs. Source: Derived from Miranowski, 2004.

**Figure 10. Total Direct Farm Energy Consumed on US Farms in 2002 (Excluding Transportation, Field Machinery, and Equipment)**
Estimating Farm Agriculture Use in the Shenandoah Valley

This thesis only evaluates electricity as an energy source, though it is important to note that other forms of energy are frequently used such as diesel, gasoline, LP gas, and natural gas, even in farm operations that are facilities-based and not field-based (greenhouses versus crop production, for example).

Based on the total energy consumed on US farms in 2002, it is possible to estimate the total energy used on farms in the Shenandoah Valley. Taking the 1.1% of total direct US agriculture energy use (derived from Miranowski, 2004) and multiplying it by Virginia’s total energy use of 1,499 trillion BTU, total Virginia agriculture energy use is estimated as 16.5 trillion BTUs. Because Shenandoah Valley farms make up 17% of total farms in Virginia, Valley agriculture energy is estimated as 2.8 trillion BTU. In order to figure out the amount of electricity consumption on farms from energy use, the amount of electricity, LP gas, and natural gas is calculated from total energy consumed on US farms in 2002 (derived from Miranowski, 2004).

Diesel and gasoline are calculated out of the total direct energy consumed on farms as they were assessed to be used for farm machinery and transportation related activities as opposed to electricity using activities on farms. The direct, non-transport as a share of total direct energy is calculated at 45.5%, which includes natural gas, LP gas, and electricity, the sources of energy that are most likely to go to electricity and not transportation related activities (derived from Miranowski, 2004). The results show that the total direct energy use (excluding transportation, field machinery and equipment) on farms in the Valley is 1.28 trillion BTUs (See Table 3).

---

2 In this total BTU usage on farms in Virginia, it is assumed that the National trends also represent the trends for the Shenandoah Valley and that the distribution of farms in Virginia are representative of the energy and electricity BTU usage on farms in the Shenandoah Valley.
Table 3. Progression of Total Energy and Electricity Consumption on Virginia and Valley Farms

<table>
<thead>
<tr>
<th></th>
<th>Trillion BTU</th>
</tr>
</thead>
<tbody>
<tr>
<td>Virginia Total Energy</td>
<td>1,499</td>
</tr>
<tr>
<td>Virginia Total Direct Agriculture Energy Use (1.1% of total)</td>
<td>16.5</td>
</tr>
<tr>
<td>Shenandoah Valley Direct Agriculture Energy Use (17% of Virginia Agriculture Direct Energy)</td>
<td>2.8</td>
</tr>
<tr>
<td>Shenandoah Valley Direct Energy Use, Excluding Transportation and Field Machinery and Equipment (45.5% of Direct Energy Use)</td>
<td>1.28</td>
</tr>
<tr>
<td>Electricity</td>
<td>0.9</td>
</tr>
<tr>
<td>Natural and LP Gas</td>
<td>0.38</td>
</tr>
</tbody>
</table>

Source: derived from Miranowski, 2004 and author’s calculations, note that 1 kWh = 3412 BTU. See text.

Barriers and Opportunities

Throughout the history of energy in the United States, there have been significant and pointed events that have empowered pushes for renewable energy. These events opened the door to the possibility of renewable energy as a viable and competitive future of energy production. In 1977, the director of the Solar Energy Research Institute (predecessor to the National Renewable Energy Laboratory) predicted that by the year 2000 renewable energy sources would provide 40% of the nation’s energy supply (Sovacool, 2009a). The energy crisis of 1979 found President Jimmy Carter expecting renewable power technologies such as wind turbines and solar panels to make up a minimum of 10% of national electricity capacity in the United States by 1985 (Sovacool, 2009a). Similarly, the National Research Council declared that solar energy alone would account for roughly 38% of American electricity supply by the year 2010 (Sovacool, 2009a). None of these predictions came close to reality; in 2009, renewable energy only provided around 8% of the United States’ national electricity generation, which also included large-scale hydroelectric power production (EIA, 2010).

So what are the barriers and opportunities that are both hindering and enabling the current adoption and diffusion of solar technology in the Shenandoah Valley today? There is a mixture of contributing factors, including cost, consumer awareness and education, and policy. Benjamin Sovacool, in his Energy Policy journal article entitled “Rejecting renewables: The socio-technical
impediments to renewable electricity in the United States,” states that in the context of trying to understand the reason renewable energy accounts for so little in national electricity generation despite potential benefits, is the idea that separating impediments into distinct social, economic, political, and technical categories is almost impossible. He presents the term “socio-technical,” a term that encapsulates the technological, social, political, regulatory, and cultural aspects of electricity supply and use (Sovacool, 2009a). If one wants to come to a full understanding of the reasons behind the hesitation in adopting renewable energy, Sovacool states that the following definitions are encompassed in the term “socio-technical:”

“Economic” barriers include financial impediments, market barriers, and market failures.

“Political” barriers reflect regulatory challenges including weak and inconsistent political incentives, varying standards, competition among utilities, and underfunding of research and development. “Behavioral” barriers encompass the cultural and social dimensions of power technologies, and include public apathy and misunderstanding, psychological resistance, and the interpretive flexibility surrounding what consumers believe electricity should be. (p. 4502)

Within the context of this “socio-technical” idea, the cost of renewable energies remains economically inefficient because of cost. Cost as an opportunity has powerful potential. If the cost of renewables were to become more affordable than current electricity, it would open the possibility of locations that may not necessarily have the most cost effective amounts of the renewable power (solar or wind) but could contribute to lessening the overall use of fossil fuel usage in the US. In other words, it would lower the threshold at which renewables are considered to be uneconomical.

Part of educating a farmer in the technology they are being encouraged to use or buy is making sure they know all of the details, not just in the technology itself but in how much it costs and how they can have assistance in buying it. Policy incentives that help defer the cost of
renewable energies are the most promising opportunities. With federal, state, and local incentives, farmers can afford renewable energy systems they previously had to discount as outside of their budget. The Rural Energy for America Program, or REAP (formerly known as the "Section 9006" program) was enacted by the 2008 Farm Bill and offers grants, loans, and guarantees for small businesses, farmers, and ranchers to purchase and install renewable energy systems, as well as for energy efficiency improvements (USDA, 2011a). REAP grants and guarantees are only awarded to projects located in rural areas but can be used individually or combined on projects (USDA, 2011a). The REAP monies together can finance up to 75% of a project's cost, while grants specifically can finance up to 25% of project cost if the project doesn’t exceed $500,000 for renewables or $250,000 for energy efficiency (USDA, 2011a). In addition to financing the project itself, there are REAP grants available that can help pay for technical assistance on energy projects, energy audits, and feasibility studies (USDA, 2011a).

The 11 counties that make up the Shenandoah Valley’s 25x25 Initiative are all serviced by a combination of four electric service territories: Dominion Virginia Power, Shenandoah Valley Electric Cooperative, Rappahannock Electric Cooperative, and the BARC Electric Cooperative. These providers also offer various incentives at the local level. In the US, “net metering” is required by federal law for all electric power utilities, with the exception of 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. Virginia law limits the size of generators used in net metering applications to 10 KW or smaller for residential members and 500 KW or less for commercial members (REC, 2011). The Shenandoah Valley Electric Cooperative and Rappahannock Electric Cooperative both offer a non-residential net metering program for customers (REC, 2011; SVEC, 2011). At the state level, various incentives are also offered. In Warren County specifically, the Property Tax Exemption for Solar allows residential, commercial, or industrial properties to
exempt or partially exempt solar energy equipment or recycling equipment from local property taxes (DSIRE, 2011).

The integration of all aspects of social, technological, political, and economic considerations is paramount to creating a comprehensive look at the barriers and opportunities that solar faces in the Valley. A combination of cost, education, and policy can either help or hinder the Valley in attaining 25% renewable energies by the year 2025, especially when combined with energy efficiency measures that will help cut the amount of energy being used in the first place.
Chapter 3: Potential for Solar PV Electric Power in Shenandoah Valley Agriculture

Introduction

This chapter explores the feasibility of solar PV in the agricultural sector in the Shenandoah Valley. It establishes the “maximum theoretical” electricity output assuming every farm (regardless of farm size or value of sale) installs a PV system (the system sizes analyzed here are 1 KW, 5 KW, and 10 KW). This theoretical maximum estimates the largest technically possible PV electric power generation by the agricultural sector of the Shenandoah Valley for the most realistic PV system sizes. After the maximum theoretical output is estimated, a formal benefit cost analysis is conducted to explore the economic feasibility of PV on farm in the Valley. This analysis shows that the payback period for solar PV systems is over 51 years, well beyond the 3-to 5-year time horizon desired by Valley farmers and well beyond the useful life of the equipment. Using strict economic criteria of payback and affordability, it is unlikely that any farm operation in the Valley would adopt solar PV because of its high financial opportunity cost.

However, there are other reasons and motivations for adopting solar PV, such as a desire to “tinker” with the technology, environmental values, a willingness to accept a longer payback period, and an interest in “branding” farm products as more sustainably produced. Regrettably, there is no research literature that would allow for informed estimates of rates of adoption for these different motivations. As a consequence, this chapter also explores the impacts of PV at different rates of adoption by the farm sector.

The Maximum Theoretical Output of Solar PV in the Agricultural Sector

The maximum theoretical output concept is an estimate of total energy output assuming 100% adoption of the technology on all farms in the Valley, given the available solar resource in
Virginia. To calculate the maximum theoretical output, some assumptions were made. First, the type of technology referred to in this thesis is the current, off-the-shelf flat-plate, fixed tilt, solar PV equipment available today. All of the calculations for the theoretical maximum electricity output a solar PV system can generate use solar radiation data from the Roanoke meteorological station. The number used is 4.8 kWh/m²/day, the average at latitude 37.32° N for flat-plate collectors facing south at a fixed tilt, with an uncertainty of +/- 9% (Figure 11).

Figure 11 (WBAN Identification Numbers, 1990). This leads directly into the third assumption that all installed solar PV equipment is be positioned in a manner that leads to the optimum solar collection (tilt, sun angle, etc.).

![Global Solar Radiation at Latitude Tilt - Annual for Virginia](source: NREL)

Given the available solar resource in the Shenandoah Valley’s longitude and latitude, a maximum theoretical value was established by assuming that every farm in each county would install a 1 KW system, a 5 KW system and a 10 KW solar PV system. At a total of 8,204 farms in the Valley, the results show that the amount of electricity that is possible to generate exceeds 14,300
mWh for a 1 KW system, 71,800 mWh for a 5 KW system, and over 143,700 mWh for a 10 KW system adoption (Table 4). When calculated as a share of the total direct, non-transport agricultural energy in the Valley, the table results show what percentage of the Valley agricultural sector will reach 25% renewable energy by the year 2025. As Table 4 demonstrates, if every farm in the valley were to install a 1 KW system, the Valley agricultural sector would only attain 4% renewable energy by 2025. With a 5 KW system, 19% renewable energy would be reached by 2025. If a 10 KW system were adopted, however, solar PV would get the Valley agricultural sector to 38% renewable energy and would supply 55% of the Valley agricultural sector’s electricity use.

Table 4. Theoretical Maximum Electricity Output from Solar PV in the Agricultural Sector of the Shenandoah Valley

<table>
<thead>
<tr>
<th>Size of System</th>
<th>Total number of farms = 8,204</th>
<th>Total Output (kWh)</th>
<th>Total Output (BTU)</th>
<th>Total Output (trillion BTU)</th>
<th>Output As A Share of Total Direct, Non-Transport Agricultural Energy in the Valley</th>
<th>Output As A Share of Total Direct, Non-Transport Agricultural Electricity in the Valley</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 KW</td>
<td>14,373,408</td>
<td>49,042,068,096</td>
<td>0.0490421</td>
<td>4%</td>
<td>5%</td>
<td></td>
</tr>
<tr>
<td>5 KW</td>
<td>71,867,040</td>
<td>245,210,340,480</td>
<td>0.2452103</td>
<td>19%</td>
<td>27%</td>
<td></td>
</tr>
<tr>
<td>10 KW</td>
<td>143,734,080</td>
<td>490,420,680,960</td>
<td>0.4904207</td>
<td>38%</td>
<td>55%</td>
<td></td>
</tr>
</tbody>
</table>

Notes: Theoretical maximum electricity output results of all farms in the Valley adopting solar PV systems. Source: Derived from Miranowski, 2004; USDA, 2007; and author’s calculations. See Text.

For reasons detailed below in the sections on benefit-cost analysis and system affordability, the 38% adoption rate for the Valley agricultural sector, while promising at the outset, is not a realistic expectation due to the cost of the system and amount of time it will take for it to pay back. Despite the cost, however, it is realistic to assume that some level of adoption will occur by those farmers not driven solely by the cost of the system. These motivations will be considered in more detail in the Rates of PV Adoption Under Different Assumptions section below.
Benefit-Cost Analysis

In the business world, the primary motivator for investments in energy efficiency, conservation, and renewable energy is an expectation of economic advantage through cost savings, investment payback, or other measures of financial return on investment (Marshall & Ruegg, 1980). Through formal economic benefit cost analysis, the economic attractiveness of an investment can be measured by the costs and benefits associated with it (Marshall & Ruegg, 1980). The preferred investment is one with an end goal of an investment with the lowest total lifecycle cost that still meets the investor’s objective and constraints (Marshall & Ruegg, 1980). A related investor objective (or constraint) may be the payback period, the length of time an investor is willing to accept for the cost of an investment to “break even” and then begin generating net revenues.

This section, therefore, explores the 30-year lifecycle costs (LCC) for 1 KW, 5 KW, and 10 KW solar PV systems, including current cost offsets of tax credits and installation incentives. It estimates how much money these systems will cost out of pocket, the LCC, and the payback periods. The first LCC analysis is not discounted (in other words, it does not take into account the time value of money), and is considered a simple payback period. The second LCC analysis includes both the REAP grant and Federal Tax incentives available to farmers, as well as the time value of money and is a more realistic payback period.

According to the US Department of Commerce’s Simplified Energy Design Economics, the equation for Lifecycle Costs (LCC) is the following (Marshall & Ruegg, 1980):

\[
\text{Lifecycle Costs} = \text{Purchase and Installation Costs} - \text{Salvage Value} + \text{Maintenance and Repair Costs} + \text{Replacement Costs} + \text{Energy Costs}
\]

**Purchase and Installation Costs.** In order to calculate the LCC for each of the 1 KW, 5 KW, and 10 KW systems, the purchase and installation costs are assumed to be combined to represent the price per watt of electricity in Virginia today of $8.6/watt (NREL, n.d.). With this
assumption, the following table from Chapter 3 represents the purchase and installation costs for each system:

**Table 5. Cost of 1 KW, 5 KW, and 10 KW Solar PV System in Dollars**

<table>
<thead>
<tr>
<th>System</th>
<th>$/System</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 KW system</td>
<td>8,600</td>
</tr>
<tr>
<td>5 KW system</td>
<td>34,000</td>
</tr>
<tr>
<td>10 KW system</td>
<td>86,000</td>
</tr>
</tbody>
</table>

Source: Author’s calculations. See text.

**Salvage Value.** The salvage value is the amount of money the system is projected to be worth at the end of its lifecycle. Still-functioning PV systems will have a revenue value based on their life and performance expectations and are projected to have a strong resale value for years to come (McCabe, n.d.). Because of the small size of the systems addressed for installation on the farms in the Valley, the salvage value depends heavily on which company the farmer decides to sell the spent PV to. The Sacramento Municipal Utility District (SMUD) has been reselling salvaged PV equipment since 2005 at a resale salvage value of $0.04 to $1.26 per watt (McCabe, n.d.). The LCC calculation in this analysis is conducted for two different salvage values. First, no salvage value is assumed (worst case scenario). Second, a best-case scenario of $1.26 per watt is assumed.

**Maintenance and Repair.** Maintenance and repair costs are those costs of maintaining the system. This includes oiling moving parts, cleaning the glass, etc. For the systems projected to be installed on the farms, the maintenance and repair is assumed to be minimal enough to be reasonably carried out by the farm owner. For that reason, the cost of maintenance and repair for all systems will be zero.

**Replacement Costs.** Replacement costs, on the other hand, are those costs which require a replacement of a physical part or element of the system. The solar PV inverters, the only part most likely to expire and affect the overall performance of the electricity production of a PV system, are generally guaranteed for 10 years. Since the solar panels themselves are usually guaranteed for 30 years, it will be assumed for the purposes of these calculations that an inverter
will have to be purchased two times during the lifetime of the system. While this assumption is
on the specific guaranteed 10-year life of an inverter, consumers have a variety of options. They
could buy an additional 10-year warranty for around $1,700, in which case, it is possible that an
inverter will only need to be replaced once in the lifetime of a solar PV system. This option
generally is only economically viable when the PV system is over 10 KW because of the price of
the inverter versus the price of the extended warranty (SMA America, LLC, 2011). The consumer
could also choose to buy multiple smaller inverters instead of one large one. While this option has
attractive perks such as not needing to replace an entire inverter should it fail but instead only
replace a smaller inverter and still be able to produce electricity. For the purposes of this analysis,
it will be assumed that the farmer will buy an inverter with the exact size of the system and that
other than the inverter, nothing will happen to the system that warrants replacement (i.e., the
actual solar panels will not need replacement).

The price of the inverter is calculated based on a highly-rated inverter company, SMA
America, LLC. An American subsidiary of SMA Solar Technology AG, based in Germany,
SMA America, LLC is a leader in solar technology (SMA America, LLC, 2011). The prices of a
700 W, 3 KW, 4 KW, 5 KW, and 8 KW inverters are calculated and averaged to equal an
estimated $0.70 per watt. Taking that $0.70 and multiplying it by a 1 KW, 5 KW, and 10 KW
systems, it is established that the inverters for those PV systems would cost $700, $3,500, and
$7,000, respectively. Each inverter comes with a 10-year warranty.

**Energy Costs.** Energy costs are how much electricity costs over the lifetime of the
system. For solar PV, the energy cost is $0 because energy from the sun is free. Grid electricity,
on the other hand, is calculated by the following equation:

\[
\text{Yearly energy costs} = \text{Annual electricity output of the solar PV system} \times 30 \text{ years} \times \text{cost per kilowatt hour of electricity}
\]

Table 6 below demonstrates the cost of buying grid electricity in amounts comparable to
the solar PV systems. Over the 30-year life of a 1 KW system, using $0.1061/kWh, the energy
costs is $0 while over that same time period with the same amount of electricity, grid purchases are over $5,500.

**Table 6. Energy Costs for Each PV System (Excluding 0.75 of De-Rating Factor*) for Purchasing Grid Electricity Over a 30 Year Period**

<table>
<thead>
<tr>
<th>Size of PV (kWh)</th>
<th>Energy Costs for Purchasing PV Electricity</th>
<th>Energy Costs for Purchasing Grid Electricity</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>$0</td>
<td>$5,577</td>
</tr>
<tr>
<td>5</td>
<td>$0</td>
<td>$27,883</td>
</tr>
<tr>
<td>10</td>
<td>$0</td>
<td>$55,766</td>
</tr>
</tbody>
</table>

Notes: *De-rating factor is based on buyer’s choice of PV modules and inverter and is typically about 0.84 (Randolph, 2008). In actual field conditions, however (including dirt, mismatch, and other factors), a more likely de-rating factor to predict actual performance is about 0.75. 100% PV efficiency was assumed available to end-use in this thesis and the de-rating factor wasn’t taken into consideration. Source: Author’s calculations.

Calculated below is the LCC with simple payback period in amount of kWhs that are being produced by the solar PV system. The table takes the cost of the electricity produced from the solar panel and compares it to the amount produced from the grid. The LCC in Table 7 does not discount for the time value of money, nor does it assume that energy prices will increase over the next 15-20 years, hence the nature of the simple payback. Additional LCCs conducted in Table 8 and Table 9 will take into account tax credits and grants available to Valley farms and both time value of money and increasing energy prices.
Table 7. Life Cycle Cost of Solar PV, Simple Payback Period

<table>
<thead>
<tr>
<th>Life Cycle Cost (LCC)</th>
<th>1 KW System</th>
<th>5 KW System</th>
<th>10 KW System</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>PV System</td>
<td>Grid-Purchased electricity</td>
<td>PV System</td>
</tr>
<tr>
<td>Purchase &amp; Installation</td>
<td>$6,600</td>
<td>$43,000</td>
<td>$86,000</td>
</tr>
<tr>
<td>Salvage value at $0</td>
<td>$0</td>
<td>$0</td>
<td>$0</td>
</tr>
<tr>
<td>Salvage value at $1.26/watt</td>
<td>$1,260</td>
<td>$6,300</td>
<td>$12,600</td>
</tr>
<tr>
<td>Maintenance &amp; Repair</td>
<td>$0</td>
<td>$0</td>
<td>$0</td>
</tr>
<tr>
<td>Replacement Costs</td>
<td>$2,100</td>
<td>$10,500</td>
<td>$21,000</td>
</tr>
<tr>
<td>Energy Costs*</td>
<td>$0</td>
<td>$5,577</td>
<td>$27,883</td>
</tr>
<tr>
<td>Total LCC (no salvage)</td>
<td>$10,700</td>
<td>$53,500</td>
<td>$107,000</td>
</tr>
<tr>
<td>Total LCC (with salvage)</td>
<td>$9,440</td>
<td>$47,200</td>
<td>$94,400</td>
</tr>
<tr>
<td>Annual Energy Savings</td>
<td>$186</td>
<td>$929</td>
<td>$1,859</td>
</tr>
<tr>
<td>Simple Payback Period, in years (no salvage)</td>
<td>58</td>
<td>58</td>
<td>58</td>
</tr>
<tr>
<td>Simple Payback Period, in years (with salvage)</td>
<td>51</td>
<td>51</td>
<td>51</td>
</tr>
</tbody>
</table>

*EC @ 4.8 kWh/day* *365 d/yr* *$0.1061/kWh* *30 years

Notes: This is a simple payback calculation and does not assume any cost of borrowing or that electricity prices will increase over time. If electricity prices increase, the payback prices will be slightly shorter. Source: Author’s calculations. See text.

The total life cycle cost does not reflect the economic benefits of solar PV, such as the annual energy savings from not purchasing the equivalent amount of electricity from the grid. To understand that benefit cost relationship, the payback period is a useful measure. It is clear from the LCC that the simple payback period of a 1 KW system is dependent on the salvage value at the end of the system’s life. With the worst case scenario of $0 salvage value, the simple payback period of 58 years far exceeds the 3-5 year payback period that Valley farmers consider an economically feasible investment as well as the 30 year life of the equipment. The annual energy savings alone looks promising, but when all life cycle costs are taken into account, the solar PV system becomes greatly less attractive than paying current grid electricity prices. The farmer would save $186 in electricity costs per year ($5,580 for 30 years) only to accrue a best case scenario 51 year payback period, in addition to the difficulty that a new system would present logistically.
Cost Offsets

There are two major federal subsidy programs for renewable energy in the agricultural sector. One is a 30% Federal tax credit, the other is a 25% cost-share opportunity from the Rural Energy for America Program (REAP) of the US Department of Agriculture (USDA, 2011a). The tax credit is simply taken by farmers on their tax return; the REAP cost-share involves a complex application and certification process (USDA, 2011a). As a consequence, while all farmers can receive the tax credit, not all will apply for or receive the REAP cost share. In the Shenandoah Valley, a large number of Mennonite farmers will not use government cost-share assistance on religious grounds (Mizel, Papadakis, Degner, Shepard, & Havinga, 2008).

Table 8. Life Cycle Cost of Solar PV, Simple Payback Period Including 30% Federal Tax Credit and 25% REAP Grant

<table>
<thead>
<tr>
<th>Life Cycle Cost (LCC)</th>
<th>1 KW System</th>
<th>5 KW System</th>
<th>10 KW System</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>PV System</td>
<td>Grid-Purchased electricity</td>
<td>PV System</td>
</tr>
<tr>
<td>Purchase &amp; Installation</td>
<td>$3,870</td>
<td>$0</td>
<td>$19,350</td>
</tr>
<tr>
<td>Salvage value at $0</td>
<td>$0</td>
<td>$0</td>
<td>$0</td>
</tr>
<tr>
<td>Salvage value at $1.26/watt</td>
<td>$1,260</td>
<td>$6,300</td>
<td>$12,600</td>
</tr>
<tr>
<td>Maintenance &amp; Repair</td>
<td>$0</td>
<td>$0</td>
<td>$0</td>
</tr>
<tr>
<td>Replacement Costs</td>
<td>$1,400</td>
<td>$0</td>
<td>$7,000</td>
</tr>
<tr>
<td>Energy Costs*</td>
<td>$0</td>
<td>$5,577</td>
<td>$0</td>
</tr>
<tr>
<td><strong>Total LCC (no salvage)</strong></td>
<td><strong>$5,270</strong></td>
<td><strong>$5,577</strong></td>
<td><strong>$26,350</strong></td>
</tr>
<tr>
<td><strong>Total LCC (with salvage)</strong></td>
<td><strong>$4,010</strong></td>
<td><strong>$5,577</strong></td>
<td><strong>$20,050</strong></td>
</tr>
<tr>
<td>Annual Energy Savings</td>
<td>$186</td>
<td>$929</td>
<td>$1,859</td>
</tr>
<tr>
<td>Simple Payback Period, in years (no salvage)</td>
<td>28</td>
<td>28</td>
<td>28</td>
</tr>
<tr>
<td>Simple Payback Period, in years (with salvage)</td>
<td>22</td>
<td>22</td>
<td>22</td>
</tr>
</tbody>
</table>

*EC @ 4.8 kWh/day* 365 d/yr* $0.1061/kWh* 30 years

Notes: Subsidies are cumulative and taken off of the initial purchase and installation cost.
Source: Author’s calculations. See text.

The LCC analysis including offsets suggests that, even with subsidies, the benefit-cost of solar PV for farmers is not favorable. It can be seen that the payback periods of the systems with the inclusion of the tax credit and REAP grant are cut in half from 51-58 years to 22-28 years, however, the cost and simple payback period of PV is still higher than a farmer is willing to
consider. In addition to the long payback period, the only incentive that is offered to all farmers in the Valley is the 30% tax credit.

To move beyond a simple payback calculation and take into account the time value of money over the 30-year time period of the system, a discounted payback period is calculated. Replacement costs and energy costs are discounted as the cost of grid electricity is, without fail, significantly lower than inverters and the cost of electricity are evaluated to be factors that would change over time. In this discounting, the cost of an inverter is assumed to have the same price point in 30 years as it does today because the inverter is not considered a mainstream consumer electronic and therefore doesn’t fit the patterns of electronics consumption. As a result, the most favorable scenario that assumes a constant price was used. A personal loan with a 6% interest rate was evaluated as being the most realistic borrowing avenue for Valley farmers and an inflation rate of 3% was set as the average US rate for the 30 year time period.

| Table 9. Comparison of Life Cycle Cost that Accounts for the Time Value of Money |
|-----------------|-----------------|-----------------|-----------------|
|                 | LCC             |                 | Payback Period  |
|                 | 1 KW            | 5 KW            | 10 KW           |
| Simple (without incentives or salvage) | $10,000 | $50,000 | $100,000 | 54 years |
| Simple (with incentives, without salvage) | $5,270 | $26,350 | $52,700 | 28 years |
| Discounted at 6% (without incentives or salvage) | $9,218 | $46,089 | $92,178 | 53 years |

Source: Author’s calculations. See text.

When presenting the overall costs of the advantages of installing a solar PV system, one would be hard pressed to appeal to the purely economic side of an argument between solar PV and grid electricity. With the 51-58 year incentive-free simple payback period, the outlook for solar PV providing 25% of the Valley agricultural sector’s electricity by 2025 is bleak. A home with a 30-year mortgage will be paid off before a solar PV system starts paying for itself. Additionally, the aging population of farmers in the Valley, the long term investment, and the up front cost are more than Valley farms are likely to accept. In sum, using strictly traditional
economic LCC and payback criteria, farmers in the Valley are not likely to adopt any PV technology on their farms.

**Affordability Concerns**

The estimate of maximum theoretical output demonstrates that it is possible to attain 38% renewable energy in Shenandoah Valley farms by 2025. However, this is a purely technical calculation, and does not address the feasibility of all 8,204 farms in the valley adopting an $86,000 10 KW PV system. It is necessary to explore, realistically, the feasibility of adoption by farmers. The previous life cycle cost and payback analysis suggests that, using financial investment criteria, farmers are unlikely to invest in solar PV. An additional and important economic consideration is the issue of affordability: solar PV systems have high initial costs; even if they had some reasonable expectation of payback, farmers may still be challenged to afford such systems up front (e.g., opportunity costs of farm savings and liquidity) or be unwilling to borrow money for a PV purchase (e.g., opportunity costs of borrowing). The Census of Agriculture provides data on farms by value of their gross sales, which allows an exploration of the ways in which Valley farmers may confront barriers to the adoption of PV with respect to affordability. A large limitation to using this data is the fact that the value of gross sales only takes into account total farm sales, not net profit or loss, which is a better reflection of the potential affordability of solar PV for a farm operation.

Taking that limitation into consideration, the estimation that farms with a value of sales over $10,000 could afford the 1 KW system that costs $8,600 could be overstepping what a farmer could consider a financially viable option. At the same time assuming that only those farms with value of sales over $10,000 can afford that same 1 KW PV system, immediately eliminates almost half of the farms (3,781 farms) from the equation as being able to afford any solar PV system explored in this thesis. Additionally, the data from the Census are put into categories that couldn’t be broken down further. For example, the sectioning of the farms by
value of sales ranged from $25,000 to $49,999 (USDA, 2007). In estimating whether or not a farm could afford the 5 KW system costing $34,000, it was assumed the farms in that category could. It is assumed that since the farms making toward the higher end of value of sales could afford the system, all of the farms in that category could afford the system. Using the same logic, it was assumed that farms with a value of sales over $10,000 could afford a 1 KW system, farms with a value of sales over $25,000 could afford the 5 KW system and farms with a value of sales over $50,000 could afford the 10 KW PV system.

Table 10 summarizes the potential levels of adoption of solar PV when affordability is taken into account. Using the criteria discussion in the previous paragraph regarding affordability of solar PV systems using farm gross sales as a criterion, it becomes apparent that the Valley agricultural sector only has the opportunity to reach 8% of the renewable energy goal at 100% rate of adoption of a 10 KW PV system for all farms with a value of sales of more than $50,000.

<table>
<thead>
<tr>
<th>Total number of farms</th>
<th>Total Output (kWh)</th>
<th>Total Output (BTU)</th>
<th>Total Output (trillion BTU)</th>
<th>Output As A Share of Total Direct, Non-Transport Agricultural Energy in the Valley</th>
<th>Output As A Share of Total Direct, Non-Transport Agricultural Electricity in the Valley</th>
</tr>
</thead>
<tbody>
<tr>
<td>Farms with more than $10,000 in sales</td>
<td>3,381</td>
<td>5,923,512</td>
<td>20,211,022,944</td>
<td>0.0202110</td>
<td>2%</td>
</tr>
<tr>
<td>1 KW</td>
<td>5,923,512</td>
<td>20,211,022,944</td>
<td>0.0202110</td>
<td>2%</td>
<td>2%</td>
</tr>
<tr>
<td>Farms with more than $25,000 in sales</td>
<td>2,207</td>
<td>19,333,320</td>
<td>65,965,287,840</td>
<td>0.0659653</td>
<td>5%</td>
</tr>
<tr>
<td>5 KW</td>
<td>19,333,320</td>
<td>65,965,287,840</td>
<td>0.0659653</td>
<td>5%</td>
<td>7%</td>
</tr>
<tr>
<td>Farms with more than $50,000 in sales</td>
<td>1,604</td>
<td>28,102,080</td>
<td>95,884,296,960</td>
<td>0.0958843</td>
<td>8%</td>
</tr>
<tr>
<td>10 KW</td>
<td>28,102,080</td>
<td>95,884,296,960</td>
<td>0.0958843</td>
<td>8%</td>
<td>11%</td>
</tr>
</tbody>
</table>

Source: Derived from Miranowski, 2004; USDA, 2007; and author’s calculations. See Text.
Rates of PV Adoption Under Different Assumptions

It is possible and likely that some farmers in the Shenandoah Valley would be willing to invest in solar PV for other than purely economic reasons. There are other motivations for adopting solar PV, such as a farmer’s desire to “tinker” with an interesting technology, environmental values, a willingness to accept a longer payback period, and an interest in “branding” farm products as more sustainably produced. Regretfully, there is no research literature that would allow us to develop informed estimates of rates of adoption for these different motivations. As a consequence, this section estimates the impacts of PV at different general rates of adoption by the farm sector.

As with affordability concerns, certain assumptions were made in determining what proportion of farmers would be willing to install a PV system, as well as the assumption that a 5 KW system would be the most affordable and practical to Valley farmers. A 5 KW PV system would get the Valley agricultural sector to the 25x’25 goal faster than a 1 KW system and would cost less than a 10 KW system; therefore PV systems that are sized 5 KW or less are the most realistic sizes for the purposes of this analysis. Table 11 explores the estimated rates of adoption at 10%, 15%, 20%, and 25% of total farms in the Valley at with 5 KW PV system, as well as the amount of mWh generated per year at the estimated adoption rates.

<table>
<thead>
<tr>
<th>Total Farms</th>
<th>Number of Farms Adopting 5 KW System</th>
<th>mWh generated/year at Estimated Rates of Adoption</th>
</tr>
</thead>
<tbody>
<tr>
<td>8,204</td>
<td>10% 1,231 1,641 2,051</td>
<td>7,187 10,780 14,373 17,967</td>
</tr>
</tbody>
</table>

Source: USDA, 2007 and author’s calculations. See text.

The above table demonstrates that if a quarter of the farms in the Valley were to adopt a 5 KW PV system, there would be 2,051 farms in the Valley with 5 KW PV systems that would generate a total of almost 18 mWh per year. The 2,051 farms with the 25% adoption rate are
compared with the 2,207 farms with a value of sales over $25,000 in Table 10’s maximum theoretical electricity output. Table 12 below shows that Valley farms would provide no more than 5% of the Valley’s renewable energy by 2025. That means that the extra 156 farms in the theoretical maximum output farm scenario will not make a difference in the amount of output as a share of total direct, non-transportation agricultural energy in the Valley.

Table 12. Rates of Adoption Scenarios of Solar PV in the Shenandoah Valley

<table>
<thead>
<tr>
<th>5 KW PV System</th>
<th>Total Output (kWh)</th>
<th>Total Output (BTU)</th>
<th>Total Output (trillion BTU)</th>
<th>Output As A Share of Total Direct, Non-Transport Agricultural Energy in the Valley</th>
<th>Output As A Share of Total Direct, Non-Transport Agricultural Electricity in the Valley</th>
</tr>
</thead>
<tbody>
<tr>
<td>Adoption Rate</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>10%</td>
<td>7,186,704</td>
<td>24,521,034,048</td>
<td>0.0245210</td>
<td>2%</td>
<td>3%</td>
</tr>
<tr>
<td>15%</td>
<td>10,780,056</td>
<td>36,781,551,072</td>
<td>0.0367816</td>
<td>3%</td>
<td>4%</td>
</tr>
<tr>
<td>20%</td>
<td>14,373,408</td>
<td>49,042,068,096</td>
<td>0.0490421</td>
<td>4%</td>
<td>5%</td>
</tr>
<tr>
<td>25%</td>
<td>17,966,760</td>
<td>61,302,585,120</td>
<td>0.0613026</td>
<td>5%</td>
<td>7%</td>
</tr>
</tbody>
</table>


Despite the reduction of more than 100 farms from the maximum theoretical scenario to the most likely rate of adoption, the Valley agricultural sector will not reach over 5% of renewable energy by the year 2025 with 25% of Valley farms with a value of sales over $25,000 (2,051 farms) adopting a 5 KW PV system. While it is likely and possible that some farmers in the Valley will be interested in adopting various sizes of PV systems, it will not be because of economic benefits. The farmers that do adopt the system will do so for reasons of their own, whether it be a desire to “tinker” with an interesting technology, environmental values, a willingness to accept a longer payback period, or an interest in “branding” farm products as more sustainably produced.
Chapter 4: Carbon Dioxide (CO₂) Mitigation

Greenhouse Gases (GHGs) are gases that trap heat in the atmosphere. While most GHGs are naturally occurring, there are specifically man-made GHGs, like gases used for aerosols that have been introduced into the atmosphere (EIA, 2004). GHGs include gases such as carbon dioxide (CO₂), methane (CH₄), nitrous oxide (N₂O), and fluorinated gases such as hydrofluorocarbon (HFC) and chlorofluorocarbon (CFL) (EIA, 2004). While the level of GHGs prior to the Industrial Revolution (roughly 150 years ago) was balanced and stable, they provided the Earth with the correct amount of gases in the atmosphere to maintain relatively normal temperatures in the air, as well as temperatures in the oceans. Since the Industrial Revolution, however, anthropogenic activity has increased these GHG levels so suddenly in a short span in the Earth’s timeline that adverse effects are being seen (EIA, 2004). There have already been and will continue to be increased examples of climate change, including changing oceanic temperatures, a potentially devastating consequence as those temperatures play a very large role in the weather patterns of the Earth. Climate change brought on by rapidly increasing levels of GHGs in the atmosphere due to human behavior is changing the Earth.

Electricity is traditionally produced by burning fossil fuels in a stationary combustion unit, for example a coal burning power plant (WRI, 2011). As a direct result of this electricity production, a number of GHGs are emitted, typically carbon dioxide (CO₂), methane (CH₄), and nitrous oxide (N₂O). Because of the large US economy, the fact that about 85% of its energy comes from burning fossil fuels makes the US accountable for roughly 25% of the global carbon dioxide emissions from burning fossil fuels (EIA, 2004). Since the GHG emissions are the consequence of activities of a consumer that buys electricity from a stationary plant, the emissions are “considered to be ‘indirect’ emissions because they are the indirect consequence of the purchase and consumption of electricity […] although the emissions physically occur at sources owned or controlled by another company” (WRI, 2011, p. 2-3). In order to calculate the
amounts of GHGs that are not being emitted when using renewable energy over fossil fuels, a GHG Protocol tool was used.

The GHG Protocol is the most widely used international accounting tool to understand, quantify, and manage GHG emissions (GHG Protocol Initiative, 2011). In partnership with the World Resources Institute (WRI) and the World Business Council for Sustainable Development (WBCSD), the GHG Protocol works with businesses, governments, and environmental groups to create programs that address climate change (GHG Protocol Initiative, 2011). Of the multitude of tools offered by the GHG Protocol Initiative, the standard method GHG emissions from stationary combustion carbon mitigation tool was used to calculate the amount of carbon dioxide that is mitigated by using renewable energy (in this case, specifically solar PV). The amount of electricity theoretically generated, and consequently carbon dioxide mitigated, was inputted into the following equation:

\[
\text{CO}_2 \text{ Emissions} = \text{Activity data} \times \text{Emissions factor}
\]

This equation calculates the GHG emissions associated with the generation of purchased electricity. It uses activity data, or the quantity of purchased electricity, as well as emissions factors, which are default factors for regions defined by the US Environmental Protection Agency in Emissions & Generation Resource Integrated Database (eGRID) (WRI, 2011). The equation is an accurate gauge of CO\textsubscript{2} emissions when the fuel quantity, characteristics, technology type, combustion characteristics, usage of pollutant control equipment, and ambient environmental conditions are accounted for (WRI, 2011).

The electric service territories that provide power to the Shenandoah Valley are the following: Dominion Virginia Power, Shenandoah Valley Electric Cooperative, Rappahannock Electric Cooperative, and the BARC Electric Cooperative, also illustrated in the map below. These companies and their use of fossil fuels are incorporated in the US EPA’s eGRID North American Electricity Reliability Council Eastern region (WRI, 2011).
The maximum theoretical yield of the three scenarios explored in Chapter 3 calculated the electricity generated from the installation of a 1 KW, 5 KW, and 10 KW solar PV system for every farm in the Shenandoah Valley, not taking into consideration any sort of restrictions (including farm size or value of sales). For each of these scenarios, the mWhs of electricity generated by the solar PV systems was used to determine the amount of CO₂ that wouldn’t be expelled into the atmosphere. As show in Table 13 and Table 14, the higher the system and more mWh of electricity generated by each solar PV system, the more CO₂ would be mitigated. The amount of possible generation of electricity from solar PV per year is calculated to displace about 0.51 kg of CO₂ per kWh. For the 1 KW PV system adoption, there would be about 7,400 metric tons of CO₂ mitigated. For the 5 KW PV system, roughly 37,000 metric tons of CO₂ would be mitigated and with the 10 KW PV system, about 74,000 metric tons would be kept from being emitted.
Table 13. Amount of CO\textsubscript{2} in Metric Tons Mitigated by Each of the 1 KW, 5 KW, and 10 KW Maximum Theoretical Outputs

<table>
<thead>
<tr>
<th>Theoretical Max (all farms)</th>
<th>Shenandoah Valley Total (mWh)</th>
<th>CO\textsubscript{2} Mitigated (Metric Tons) Mitigated</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total Farms</td>
<td>8,204</td>
<td></td>
</tr>
<tr>
<td>kWh/year generated by:</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1 KW system</td>
<td>14,373</td>
<td>7,398</td>
</tr>
<tr>
<td>5 KW system</td>
<td>71,867</td>
<td>36,995</td>
</tr>
<tr>
<td>10 KW system</td>
<td>143,734</td>
<td>73,990</td>
</tr>
</tbody>
</table>

Notes: Theoretical maximum electricity output results of all farms in the Valley adopting solar PV systems. Source: GHG Protocol and author’s calculations. See Text.

The maximum, almost 74,000 metric tons of CO\textsubscript{2} is equivalent to the annual GHG emissions from 14,508 passenger vehicles or the CO\textsubscript{2} emissions from the combustion of 8,294,843 gallons of gasoline. In comparison, in 1999, the estimated emissions of CO\textsubscript{2} produced by coal-fired generation of electricity in the US was 1,788 million metric tons (DOE, 2000).

Using the same calculations as above, the amount of CO\textsubscript{2} mitigated by the different adoption scenarios were calculated below (EPA, 2011a).

Table 14. Amount of CO\textsubscript{2} in Metric Tons Mitigated by Various Rates of Adoption of a 5 KW PV System

<table>
<thead>
<tr>
<th>Adoption Rate with 5 KW system</th>
<th>Total Output (mWh)</th>
<th>CO\textsubscript{2} Mitigated (Metric Tons)</th>
</tr>
</thead>
<tbody>
<tr>
<td>10%</td>
<td>7,187</td>
<td>3,700</td>
</tr>
<tr>
<td>15%</td>
<td>10,780</td>
<td>5,549</td>
</tr>
<tr>
<td>20%</td>
<td>14,373</td>
<td>7,399</td>
</tr>
<tr>
<td>25%</td>
<td>17,967</td>
<td>9,249</td>
</tr>
</tbody>
</table>

Source: GHG Protocol and author’s calculations. See Text.

It can be seen that the amount of CO\textsubscript{2} mitigated is not as much as with the theoretical maximum, though with the 25% adoption rate of the 5 KW system in the Valley, over 9,000 metric tons would be kept from the atmosphere, the equivalent of annual GHG emissions from 1,814 passenger vehicles or the CO\textsubscript{2} emissions from 1,036,883 gallons of gasoline consumed (EPA, 2011a).
Greenhouse gases present a pressing and immediate concern regarding climate change. While the Earth is able to balance natural levels of GHGs, the sudden excess that has been introduced into the atmosphere anthropogenically in the last 150 years is happening at a faster rate than the Earth can sequester them and retain balance. In 2009, total US GHG emissions were 6,633 Tg (trillion grams) or million metric tons CO$_2$ Equivalent (Eq) (EPA, 2011b). The agriculture sector of the United States accounted for 419 million metric tons CO$_2$ Eq of GHG emissions in 2009 (EPA, 2011b). While those numbers have fluctuated over time, the importance of reducing the amount of GHG emissions is increasing.
Chapter 5: Conclusions

Implications for Energy Output and Realistic Rates of PV Adoption and 25x’25

Farms in the Shenandoah Valley have the theoretical potential to reach 25% renewable energy by the year 2025. When looking at adoption of PV in the Valley from a purely economic standpoint, it is unlikely that any farmer in the Valley would install any size PV system because of the high up front cost and 51-58 year payback period. The potential of reaching 25x’25 was shown to be possible from a technical standpoint supposing every farm were adopting a 10 KW PV system, which would get the Valley agricultural sector to 38% renewable energy and would supply 55% of the Valley agricultural sector’s electricity use. However, this expectation showed itself to be economically unrealistic.

Considering the possibility that farmers in the Valley could be motivated by reasons other than money, different rates of adopting a 5 KW PV system were explored. Supposing that motivating reasons could include a desire to “tinker” with new technology, environmental values, a willingness to accept a longer payback period, and an interest in “branding” farm products as more sustainably produced, rates of adoption in the range of 10%-25% were explored. The results showed that only 5% of the agricultural sector’s renewable energy would be met by the highest rate of adoption (25%) estimation by 2025. While it is likely and possible that some farmers in the Valley will be interested in adopting various sizes of PV systems, it will not be because of economic reasons or because the systems will get the Valley to 25x’25 solely with farm installation of solar PV.

Implications for CO₂ Mitigation

Greenhouse gases present a pressing and immediate concern regarding climate change. The maximum theoretical output of adopting PV in the Valley agricultural sector shows that there is
potential to mitigate almost 74,000 metric tons of CO₂ (equivalent to the annual GHG emissions from 14,508 passenger vehicles) with a 100% adoption rate of a 10 KW PV system by all farms in the Valley. While a maximum theoretical output adoption has shown to be economically unviable, at even a 5 KW solar PV system adoption by 25% of Valley farms (2,051 farms), there is potential to mitigate 9,249 metric tons of CO₂ (equivalent to the annual GHG emissions from 1,814 passenger vehicles). Even though the amount of CO₂ mitigated is a small number compared to the amount that is emitted on the greater US scale, the small start of programs like the 25x’25 Valley Initiative is the beginning of a big change.

**Implications and Limitation of Methodology**

For the various calculations conducted in this thesis, the data relied on most extensively were from the 2007 USDA Census. Numerous limitations from using this dataset were addressed and assumptions were made in order to move forward with calculations. The category itself, “farms by value of sales” only takes into account value of sales, not net profit or what amount of profit is a loss. Assumptions of what size PV systems farms could afford were based on this category alone and may not be entirely realistic as actual year-to-year expenses weren’t taken into consideration. Additionally, given the 2007 USDA Census data, there is no way to separate the data to evaluate which farms in the Valley are hobby farms and which are used as necessary income. Almost half of the farms were discounted from the start as being unable to afford any solar because they fell under the $5,000 range. The “under $5,000” category probably captures many types of farm operations, and it is likely that some (probably small) proportion of them could afford solar PV. There is no way to estimate how many farms there might be and whether or not they are hobby farms to independently wealthy owners who don’t necessarily rely on any of the income generated by the farms to sustain themselves or small farms that simply generate under $5,000 a year as a source of primary income for the farmers. The owners of such small farms could be the prime candidates of those who would not use any economic reasons to install
solar PV despite their farms’ recorded value of sales. Also assumed from the farms by value of sales categories were the extrapolations of the category that could not be broken down further. The category ranged from value of sales in increments that were too large in most cases and the data in this thesis would have been more accurate if it was known specifically how many farms were in the smaller farms by value of sales categories.

Certain trends in energy use and farm behavior were used to address trends of agriculture in the Valley. Trends in agricultural energy use from the US were assumed for Virginia and in turn, assumed to be trends in the Valley, including BTU usage trends on farms in the US. For example, total direct, non-transportation farm energy consumed on US farms in 2002 trends were applied to Virginia farms and also to Valley farms. In the absence of Valley farm data, national or state overall trends of compositions of farms were also applied to the Valley. One of the limitations to the Valley data includes the 2002 and 2007 USDA census data in which the gains or losses of farms in the Valley were reported. While it was assumed that trends in Virginia held true to trends in the Valley, there was no way to say with certainty that some of the losses or gains recorded were merely farms that had jumped up or down in the value of sales category. In addition to trend assumptions, the 25x’25 discussion is limited to only building and energy use, even though transportation and farm equipment and machinery (as petroleum-based energy) account for over half of the energy use in agriculture.

For more accurate and practical reasons in this thesis, certain assumptions were made on the PV equipment, technology, and installation. First, the solar PV technology was assumed to be standard, current, off-the-shelf flat-plate, fixed tilt, solar PV equipment available today. While it is recognized that Valley farmers have many and varied options of solar PV technology and equipment (including building and installing their own), it was necessary for standardization of comparisons to estimate a single type of technology. Second, the Roanoke meteorological station solar radiation average was used for theoretical maximum calculations, despite some parts of the Valley being slightly outside of this geographic range. Third, it was assumed that all solar PV
equipment installed will be positioned in a manner that leads to the optimum solar collection (tilt, sun angle, etc). All of these assumptions made calculations using different variables (including sized solar PV systems, location, and farms) more precise and manageable, yet they may not be accurate or truly realistic.

In addressing rates of adoption of PV systems that weren’t economically driven, a large limitation included no available research literature on possible farmer motivations that were driven by something other than economics. Consequently, a potentially representative range of rates of adoption were selected and evaluated.

**Opportunities for further study**

The Valley 25x’25 goal is an undertaking that can be explored with any renewable energy. Discussed in this thesis were only solar PV options of 1, 5, and 10 KW sizes. It was determined that these options will not feasibly get the agricultural sector of the Valley to its 25x’25 goal, a combination of solar and other renewable energies (such as wind or biofuels) could potentially meet that goal. Further research could include in-depth studies on farm types and what kind of renewable technology they could potentially provide (e.g., poultry farmers could explore biofuels or dairy farms could explore methane digesters) to offset their own energy use, as well as provide sources of energy for the Valley. Additionally, the “farms only” scope could be widened to include processing and canning plants. While this thesis is a useful study of solar PV use on farms in the Valley, it is by no means where the research should end.

There is potential opportunity for further study in the form of economic analyses. One such economic analysis could show what the configuration of solar PV life cycle costs and electricity rates would need to be to get a payback period of 10 years or less. Another option could include on-farm energy audits conducted for every farm in the Valley. These would be valuable starting points to assess where farms are consuming energy by farm type, location, and use. Additionally, the feasibility of increasing incentives of agriculture could be studied with
further study on specifically Valley farmer motivations other than economic. It would be interesting to discover what would influence farmers to adopt solar and renewable energy in general as it stands currently and what would it take for them to adopt solar and renewable energies on different levels.
Appendix A

Energy costs were evaluated to be a continuous stream of money (over the 30 years of changing energy costs) while the replacement costs were incremental (happening twice in the lifetime of the system because of the 10 year lifespan of the inverter). The length of the payback period of the loan farmers would take out was assumed to be 30 years instead of the more realistic 10 year payback of average personal loans. This was done because the calculations were not accounting for a loan period of less than the life of the technology, which was 30 years.

The following Single Present Worth Formula (SPW), taken from the Simplified Energy Design Economics handbook was used to calculate replacement costs:

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

Where \( P = \) a present sum of money

\( F = \) a future sum of money, equivalent to \( P \) at the end of \( N \) periods of time at an interest or discount rate of \( i \)

\( i = \) an interest or discount rate

\( N = \) number of interest or discounting periods (Marshall & Ruegg, 1980).

The following Uniform Present Worth Formula Modified (UPW) was used to find the changing cost of energy with an assumed inflation rate of 3%:

\[ P = A \times \frac{(1 + e)}{(i - e)} \times \left[ 1 - \left( \frac{1 + e}{1 + i} \right)^N \right] \]

Where \( P = \) a present sum of money

\( A = \) an end-of-period payment (or receipt) in a uniform series of payments (or receipts) over \( N \) periods at \( i \) interest or discount rate
e=rate of escalation of A in each of N periods

i=an interest or discount rate

N=number of interest or discounting periods (Marshall and Ruegg, 1980).

<table>
<thead>
<tr>
<th>Life Cycle Cost (LCC)</th>
<th>Size of PV (kWh)</th>
<th>Grid electricity</th>
<th>Size of PV (kWh)</th>
<th>Grid electricity</th>
<th>Size of PV (kWh)</th>
<th>Grid electricity</th>
</tr>
</thead>
<tbody>
<tr>
<td>Purchase and Installation</td>
<td>$8,600</td>
<td>$0</td>
<td>$43,000</td>
<td>$0</td>
<td>$86,000</td>
<td>$0</td>
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<tr>
<td>Salvage value at $0</td>
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<td>$0</td>
<td>$0</td>
<td>$0</td>
<td>$0</td>
<td>$0</td>
</tr>
<tr>
<td>Maintenance and Repair</td>
<td>$0</td>
<td>$0</td>
<td>$0</td>
<td>$0</td>
<td>$0</td>
<td>$0</td>
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<tr>
<td>Replacement Costs</td>
<td>$1,400</td>
<td>$0</td>
<td>$7,000</td>
<td>$0</td>
<td>$14,000</td>
<td>$0</td>
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<tr>
<td>Simple</td>
<td>$618</td>
<td>$3,089</td>
<td>$6,178</td>
<td>$0</td>
<td>$55,766</td>
<td></td>
</tr>
<tr>
<td>Discounted at 6%</td>
<td>$186</td>
<td>$929</td>
<td>$1,859</td>
<td>$0</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Energy Costs*</td>
<td>$0</td>
<td>$5,577</td>
<td>$0</td>
<td>$27,883</td>
<td>$0</td>
<td>$55,766</td>
</tr>
<tr>
<td>Annual Energy Savings</td>
<td>$175</td>
<td>$873</td>
<td>$1,746</td>
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<td></td>
<td></td>
</tr>
<tr>
<td>Total LCC (without salvage)</td>
<td>$10,000</td>
<td>$5,577</td>
<td>$50,000</td>
<td>$27,883</td>
<td>$100,000</td>
<td>$55,766</td>
</tr>
<tr>
<td>Discounted Total LCC (without salvage)</td>
<td>$9,218</td>
<td>$46,089</td>
<td>$92,178</td>
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<td></td>
<td></td>
</tr>
<tr>
<td>Payback Period (without salvage)</td>
<td>54</td>
<td>54</td>
<td>54</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Discounted Payback Period (without salvage)</td>
<td>53</td>
<td>53</td>
<td>53</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

*EC @ 4.8 kWh/day* 365 d/yr* $0.1061/kWh* 30 years
List of References


