8-2008

Estimating the Economic Feasibility of Heating Tennessee Broiler Houses with Solar Energy- A Two County Analysis

Matthew Austin Brown
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To the Graduate Council:

I am submitting herewith a thesis written by Matthew Austin Brown entitled "Estimating the Economic Feasibility of Heating Tennessee Broiler Houses with Solar Energy- A Two County Analysis." I have examined the final electronic copy of this thesis for form and content and recommend that it be accepted in partial fulfillment of the requirements for the degree of Master of Science, with a major in Agricultural Economics.

Ernest Bazen, Major Professor

We have read this thesis and recommend its acceptance:

Burton English, Dan McLemore, Michael Wilcox

Accepted for the Council:
Carolyn R. Hodges

Vice Provost and Dean of the Graduate School

(Original signatures are on file with official student records.)

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ESTIMATING THE ECONOMIC FEASIBILITY OF HEATING TENNESSEE BROILER HOUSES WITH SOLAR ENERGY
-A TWO-COUNTY ANALYSIS-

A THESIS
PRESENTED FOR THE
MASTER OF SCIENCE
DEGREE
THE UNIVERSITY OF TENNESSEE, KNOXVILLE

MATTHEW AUSTIN BROWN
AUGUST 2008

DEDICATION

I would like to dedicate this thesis to my family: Mom, Dad, my brother Nick, and my late grandmother, Julia Adams. Without their support and inspiration, I could not have possibly completed this research. I am forever grateful for all of your support and understanding.

ACKNOWLEDGMENTS

First and foremost, I would like to thank my Major Professor, Dr. Ernest Bazen. Without his guidance and supervision, it would have been extremely difficult to complete this research project. The invaluable life lessons provided by Dr. Bazen have proven to benefit me in my pursuit of life and early career success.

I would like to send a huge thanks to my committee members Dr. Burt English, Dr. Dan McLemore, and Dr. Michael Wilcox. My committee gave me all of the tools I needed to make this project successful and I appreciate their guidance and patience. I would also like to thank Dr. Morgan Gray, Jamey Menard, Dr. Chris Clark, and the rest of the Department of Agricultural Economics faculty and administrative support team for their insight and support.

Other folks that deserve special thanks include Tennessee Valley Authority's Richard Carson and Ed Colston, Larry Bradford, and several members of the Tennessee Poultry and Egg Association for their contributions to this research.

I would like to thank my fellow graduate students for their friendship and support. Finally, I would like to thank my family and friends. Their support along with my family upbringing has proven to be key to my academic success over the years.

ABSTRACT

Due to rising energy costs, renewable energy sources have become an increasingly important national issue. The rising cost of fuel coupled with the increased environmental awareness of carbon emissions has led to renewed research in renewable energy sources. The agricultural sector, especially broiler production, is an energy intensive industry. Poultry production (broilers and layers) is also the largest confined animal enterprise in Tennessee (Warren 2002). Furthermore, the increasing cost of heating fuel and electricity has put a financial strain on Tennessee broiler producers (Brown 2007; Railey 2007). Finding alternative sources of energy is important to the future financial performance of broiler producers in Tennessee and elsewhere. Solar energy has been suggested as one of the most promising frontiers in energy conversion (Bradford 2007).

The feasibility for solar heating applications in agriculture has been evaluated in the past. However, the majority of the studies were performed during the energy crisis of the 1970s and 1980s. Since then, capital costs for solar technologies have decreased and substantial gains in technical efficiencies have occurred. Additionally, there are financial incentives for adopting solar energy applications which were not available in the past. This research project compares the solar heating feasibility for broiler houses in two locations in Tennessee where broiler production is prevalent and differences in solar radiation exist.

The overall objective of this research is to estimate the economic feasibility of Tennessee broiler producers' adopting a solar thermal heating system to heat broiler houses. Climatic data were collected from the Southeast Regional Climate Center

(2007). Also, telephone interviews with production specialists from each region provided target bird growth specifications and production characteristics. This study utilizes a simulation model approach that integrates several parameters used in the literature along with new parameters addressing current economic conditions and financial incentives.

Results indicate that small solar heating systems that provide a portion of broiler producers' heating needs are more financially feasible than large systems. Also, production and management characteristics such as house size and broiler weight are a significant determinant on whether solar heating is a good investment. Adoption of small solar heating systems is recommended for Bradley County producers.

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CHAPTER I

INTRODUCTION

Problem Statement

Record high energy prices have raised concerns about the future cost and availability of conventional or petroleum-based energy sources. Increased environmental awareness coupled with the impacts of fossil fuel power generation on global warming has been the catalyst for newly devoted research regarding renewable energy sources. Energy use in the agricultural sector is also under analysis in order to maintain the economic viability of energy-intensive production activities. The poultry industry serves as an important piece of Tennessee's agricultural economy.

Broiler production ranked second only behind cattle in 2006 in cash receipts among the Tennessee's leading agricultural products (USDA NASS 2007). There has also been significant growth in production over the last decade. In 2000, there were 151.3 million broilers produced in the state with a value of $229.7 million. Production of broilers grew to 213.5 million in 2006 with a value over $413.7 million (USDA 1986-2006). All figures and tables in this study are located in the appendix at the end of the references section. Figure 1.1 illustrates the growth in the last 20 years in Tennessee broiler cash receipts in nominal dollar values.

Production of broilers requires substantial amounts of heat, traditionally supplied by propane, to maintain optimal temperatures for broiler growth and health. Since energy and fuel prices have escalated in recent years, this research evaluates a renewable "green" heating alternative, solar heat, and analyzes the economic viability of broiler producers

adopting solar heating systems. Research in alternative heating sources is important in order to maintain broiler production in the state (Hudson 2007).

Donald, Eckman, and Simpson (2001) estimated that heating costs can account for as much as 40 percent of a grower's out-of-pocket expenses. It is estimated that at least 75 percent of all broiler and turkey production houses in the United States (U.S.) use propane (Foundation for Organic Resources Management, Inc. 2002). Because the poultry industry is heavily dependent on gas and petroleum, it is sensitive to short- and long-run shortages, and vulnerable to increased prices (Rogers, Benson, and Van Dyne 1976). Thus volatile propane prices in recent years have reduced poultry producers' net farm incomes and financial security (Simpson and Donald 2005). Propane prices generally follow the price of crude oil, and as oil prices continue to reach record highs, propane prices are expected to increase as well (Donald, Eckman, and Simpson 2004). Some poultry integrators in Tennessee are distributing Supplemental Energy or Fuel Bonus payments to producers due to strains on cash flows during cold winter months (Brown 2007; Railey 2007). Investment in renewable heating sources for the future that do not follow crude oil prices could possibly alleviate the need for integrators to make these payments.

Solar energy is one alternative heating source to be considered. Solar energy is abundant, renewable, and non-polluting (Van Dyne 1976). According to the U.S. Department of Energy (DOE), America could supply its entire energy needs by covering 1.6 percent of its land area with solar cells (The Economist 2007). Solar thermal or heat collectors transfer the sun's heat to a storage material, typically water tanks, and can provide a portion of a broiler houses' heating needs. Solar thermal is usually less

expensive per delivered energy unit than solar photovoltaic (PV) technologies (i.e., electricity), and solar thermal systems require about one-fifth of the area required by PV (Gallagher 2007). Due to the advances in solar technologies over the last thirty years, the rising cost of propane, and changes in the production of broilers, this research is intended to assist Tennessee's broiler producers in making capital investment decisions regarding solar thermal heating systems for on-farm energy usage.

Broiler production in Tennessee is generally located in five clusters across the state as shown in Figure 1.2. In order to analyze potential geographical advantages for solar adoption across the state, two counties (i.e., Bradley and Weakley) located at opposite ends of the state are compared in this study. Both of these counties ranked in the top 12 Tennessee counties in 2001 in terms of number of broilers produced (Warren 2002). Also, it is evident that differences in solar energy resources exist due in part to their geographical positions in the state (Figures 1.3 and 1.4).

Objectives of the Research

The primary objective of this research study is to evaluate the technical and economic feasibility of heating Tennessee broiler houses with solar energy. In achieving the primary objective, the following sub-objectives were identified and completed:

1) Simulate weather conditions (temperature and solar radiation) for Bradley and Weakley counties;
2) Simulate the daily heating needs for two Tennessee broiler houses (one in each county), and determine the percentage that may be supplied by solar energy;

3) Determine whether geographical and production differences between the two counties significantly affect the feasibility for solar heating; and

4) Estimate the optimal size solar system that is the most cost-competitive with propane over the life of the system.

The findings from this research may provide several benefits to the agricultural community. Results could assist broiler producers, not only in Tennessee but nationwide, in assessing the economic feasibility of renewable energy sources as an alternative option to propane for heating broiler houses. Findings will also provide broiler producers with a decision support model to analyze capital investment decisions regarding solar heating alternatives in order to reduce the impact of the volatile propane market on annual costs of production.

Overview of the Following Chapters

The following chapters include the information obtained from achieving the stated objectives. Chapter II contains a broad literature review on solar energy technologies and simulation programs, previous studies on solar energy applications, energy usage in broiler production, broiler house heating needs simulation, and the current state and federal incentives for solar energy technology adoption. The review also summarizes findings from past research involving solar energy uses in agriculture.

Chapter III summarizes the data and methodologies utilized in the economic analysis model for solar thermal heating systems. Current state and federal policy and financial incentives are also reported for solar energy technologies. This chapter includes details on the simulations performed to estimate daily climate and daily heating needs of each broiler house.

Chapter IV summarizes the results of the sensitivity analyses performed for solar heating systems and the impacts of several parameters on economic feasibility. Finally, Chapter V provides conclusions from this research study along with a discussion of possible future policy decisions regarding solar energy technologies. Chapter V concludes with suggestions for future research efforts.

CHAPTER II

REVIEW OF LITERATURE

This chapter provides an overview of the research on solar energy technologies along with energy use in broiler production. It is organized around the following topics: (1) an overview of solar energy technologies and their applications, (2) energy usage in broiler production, (3) broiler house heating simulation, and (4) current policy and incentives regarding solar and other renewable technologies.

Solar Energy Technology

Capturing solar energy and using it for heat is not a new idea. The energy crisis of the 1970's spurred research in solar technology. Once again, there is widespread perception that global warming is occurring at an increasing rate, and traditional energy supplies are being depleted faster than ever. The current mix of rising energy prices and increased awareness of global warming is setting the stage for increased interest in renewable sources of energy, including solar energy technologies.

Solar energy can be captured and utilized in several diverse end-uses. Some en-use technologies include solar photovoltaic (PV) systems for electricity production, irrigation, and water pumping. Additional technologies include solar thermal energy systems for heating and cooling applications (i.e., space heating, water heating, and grain drying). Another category of heating systems includes "passive" solar heating systems, which are typically constructed during the new construction of a building or structure to take advantage of the south orientation of the sun to heat buildings. Because this study analyzes existing broiler houses that can only be retrofitted for solar heating, an "active" water-to-water solar thermal heating system was chosen (Van Dyne 1976). Solar thermal

collectors and a water-to-water heating storage system is the technology analyzed in this study.

The major component of any solar system is the solar collector which absorbs the solar radiation and converts it into heat which is transferred to a liquid (Kalogirou 2004). Hottel and Woertz (1942) provided the first comprehensive research on the performance of solar flat-plate heat collectors. Stationary flat-plate solar collectors are the most used type of collector (Kalogirou 2004) and are typically faced south at an optimum tilt angle equal to the latitude of the location with variations of 10 to 15 degrees (Kalogirou 2003). Heat collection and transfer to storage occurs within a closed system, and is activated by a thermostat when the solar collector becomes warmer than the storage tank (Van Dyne 1976). The water is circulated by a pump and moved to storage where a heat exchanger is submerged in the storage tank. Heated water is pumped through the heating system pipes to the conventional propane brooders in the brooding area. The system is controlled by thermostats for each conventional propane brooder (Van Dyne 1976).

Modeling and Simulation of Solar Systems

There have been numerous approaches to estimating the performance of solar thermal heating systems. One solar simulation program, TRNSYS, or Transient Systems Simulation program, was developed by the University of Wisconsin and the Solar Energy Laboratory (Solar Energy Laboratory 1996). The TRNSYS program consists of many costly dynamic mathematical models (Klein et al. 1975) and subroutines with several input parameters to calculate performance. Output results, when compared with actual systems, have resulted in a mean error of about 10 percent (Kreider and Kreith 1981). However, the program is considered complex and not user-friendly (Kalogirou 2004).

Another simulation program, WATSUN, was developed by the Watsun Simulation Laboratory of the University of Waterloo in Canada (Watsun Simulation Laboratory 1992). The program requires input of several climatic parameters, but offers an economic analysis option as an output of the simulation. For locations without hourly climatic data, another simulation generator, WATGEN, must be used to produce synthetic hourly data (Kalogirou 2004).

Another simulation option is the f-chart method. Beckman et al. (1977) developed the f-chart method which provides the solar heating fraction of total heat demand (Gunter and Smathers 1984). This method also requires input ranges of several parameters including system specifications, heating requirements, and climatic data. The required calculations of the f-chart method are considered cumbersome and time consuming. Computer program F-Chart (Klein and Beckman 1981) was constructed by the same originators of the TRNSYS program and is considered easier to use (Kalogirou 2004). However, Kalogirou (2004) also states that the model does not provide the flexibility of detailed simulation parameters and performance measures.

PVWATTS Solar Energy Calculator, developed by the National Renewable Energy Laboratory's Renewable Resource Data Center (NREL 2007), is a simulation map tool that allows the user to pinpoint the area of study specific to 40 km by 40 km cells, about the size of an average Tennessee county (RREDC 2007). The interactive maps were developed from the Climatological Solar Radiation (CSR) Model (RREDC 2007). The model uses long-term average weather data (e.g., cloud cover, atmospheric water vapor, and aerosols) to estimate the solar energy available (RREDC 2007). Marion and Wilcox (1994) describe the conversion of modeled total solar insolation into the

insolation received by a flat plate collector at certain tilts (NREL 2007). The PVWATTS tool is flexible in that parameters can be altered for specific analysis. One adjustable parameter is the derate factor, which is essentially a compilation of technical efficiency measures. Solar energy results use a 0.77 derate factor, which is representative of typical shading and technology efficiencies (RREDC 2007). The collector tilt for the flat plate collector can also be adjusted for comparative analysis. Output of the PVWATTS simulation includes monthly averages of usable solar energy.

Solar Energy Applications and Feasibility

As mentioned previously, solar energy can be captured and utilized for several different applications. Kalogirou (2003) investigated the technical and economic potential of solar industrial process heat applications using the TRNSYS program. The economic analysis consisted of a present value investment analysis with life cycle savings (LCS) estimates. Kalogirou (2003) concludes that economic feasibility is dependent on future conventional fuel prices, but appears favorable when coupled with environmental benefits of solar adoption.

The economic feasibility of solar energy used for residential heating has been examined by Tybout and Lof (1970). Their work emphasized designing a system to achieve the minimum total annual heating cost possible under a particular climate. The solar collector tilt providing maximum wintertime collection was 15 degrees above latitude. The analysis includes analyzing solar heating potential for eight cities across the U.S. Results indicated that suitable areas for solar residential heating included climates with medium-to-high heating requirements, abundant solar radiation, and heating needs throughout the year. Several studies have investigated the technical and economic

feasibility of domestic solar water heating (Kaldellis et al. 2005; Chandrasekar and Kandpal 2004; Diakoulaki et al. 2001; Colle et al. 2001). Results are mixed based on the location studied, however, the benefit cost analysis, life cycle cost analysis, and investment feasibility approaches are all commonly used adoption measures or criteria.

The feasibility for solar technology adoption in agricultural activities has been considered as well. One application includes using solar energy for crop irrigation through solar photovoltaic systems. Katzman and Matlin (1978) investigated the economic feasibility of adopting solar systems for this purpose using benefit cost and present value of investment analysis. The authors concluded that solar PV crop irrigation systems were projected to become profitable in the late 1980s (Katzman and Matlin 1978).

In livestock operations, solar applications in the dairy industry have been examined. Hayden and Thompson (1977) found that solar thermal technology can significantly reduce heat demand, but did not perform an extensive economic analysis. Solar heating technologies have been evaluated for other sectors of the livestock industry including swine production. Williams et al. (1983) estimated the economic feasibility of solar heating systems (or “solar walls”) for swine housing in Kansas. The economic analysis used a capital budgeting simulation approach taking into account such variables as technical performance, solar radiation, operating and maintenance costs, and tax credits. Results illustrated that four separately designed solar heating systems displayed payback periods from 5 to 12 years, and could supply up to 58 percent of heat demand (Williams et al. 1983).

Other research has taken a broader analysis approach and analyzed multi-purpose on-farm solar energy systems (Van Zweden et al. 1985; Gunter and Smathers 1984). Their research analyzed a multipurpose on-farm solar energy intensifier system by examining three separate combinations of solar energy use scenarios that included grain-drying, ventilation, air heating, and water heating. Results indicated that solar energy intensifier systems may be economical under some farm conditions, but low rates of return and long payback periods hindered widespread adoption. Results demonstrated that if higher real rates of energy inflation should continue, on-farm solar systems would become more attractive. With respect to grain drying, Kwon (1980) concluded that solar technologies are economically feasible. Brantley (1978) investigated the technical feasibility of on-farm solar collectors in the 1970's and results displayed that systems could pay back in eight to ten years depending on the portion of on-farm demand that can be met by the solar system.

In a study by Walpole and Roane (1974), solar heating feasibility was investigated specifically for poultry (broiler) production. Specifically, they studied the use of solar energy for heating farm buildings and focused their research on a broiler house in the Delmarva Peninsula using a solar collector that covered the south-facing roof and assumed collection of 35 percent of available solar radiation. Results displayed that the solar heating system could provide 50 and 70 percent of broiler house heating needs in the first and second week of flock placement, respectively. Assumptions included placing the flock in January with a solar heating system sufficient in supplying all of the heating needs for the remainder of the flock grow-out period.

Brewer and Dunn (1975) analyzed the potential for the use of solar energy in poultry production for three production areas. Results displayed that improved solar performance occurred during the winter months when collector efficiencies were higher. Additional outcomes of the analysis showed that the most cost effective solar heating system supplied significantly less than 100 percent of total broiler house heating needs. The authors also estimated that a national shift to solar heating for broiler houses would decrease fuel use by 50 percent in 1975 (Brewer and Dunn 1975).

Van Dyne (1976) utilized a simulation model approach to determine the economic feasibility of solar heating for broiler houses in Maryland. This research consisted of simulating annual climate data for one location, Salisbury, Maryland, and then estimating the heat demand for broiler producers assuming a 40 ft by 306 ft house that housed 15,000 birds. This study analyzed the potential of 150 combinations of different size and quality solar collectors along with several storage tanks to supply heat to the broiler house. The least cost system provided about 42 percent of total required building heat and projected thirteen years before becoming less expensive than propane. Van Dyne (1976) suggested that further research target additional geographic regions under future economic conditions and fuel prices. More research was conducted on solar heating of poultry housing in the late 1970's during the energy crisis. Results from the studies (Reece 1977; Flood et al. 1979; Rokeby et al. 1979; Brown and Forbes 1976) are consistent with previous research and reiterate that solar heating of poultry houses appears economical when delivering a portion of total heat needs while economic feasibility of adoption depends primarily on the volatility and future of propane and other conventional fuel prices.

Hardy, Clark, and White (1983) took a different approach to evaluating solar heating for poultry production. The authors constructed a linear programming model for solar thermal collectors and storage tanks to supply a poultry house with 60, 40, and 20 percent of its annual heating needs. Results displayed that the smallest solar heating system, which provided 20 percent of heating needs, was still more expensive than the conventional propane system.

However, there has been limited research in the last twenty years on solar energy heating applications in the poultry industry. This is likely due to relatively inexpensive fuel prices over the last two decades. Thornbloom et al. (2006) analyzed the potential for solar thermal applications for poultry integrator processing plants in the Delmarva poultry industry. The potential for solar space heating for individual growers was not analyzed in the study however. Although Van Dyne (1976) conducted a related research study for Maryland, trends in poultry production have changed over the last thirty years. Today, broiler houses are larger and bird weight is generally heavier at grow-out (Goan 2007; Simpson 2007; Fairchild 2005) and solar energy technologies have become more efficient as well (Bradford 2006).

Energy Usage in Broiler Production

The need for heat energy in broiler houses is vital for bird growth and health. Broiler production requires large amounts of electricity for lighting, ventilation, and motors to distribute feed. Simpson and Donald (2005) projected that poultry producers require 200-700 million Btu's per year per house for heating needs depending on specific location, bird size, and insulation of housing. Costello's (2006) estimates of 450 million Btu's of heat demand per broiler house are consistent with these findings.

Rapid increases in the cost of fuel have had a large impact on producers' profitability. Cunningham (2003) estimated that Georgia poultry producers' net income during the 1992-2002 period increased at a slightly lower rate (2.06 percent) than cash costs (2.38 percent) due primarily to the increased cost for fuel and electricity in the late 1990s and early 2000s. Out-of-pocket fuel operating costs can be substantial. This is evident as one Tennessee producer with four broiler houses spent $21,700 in propane in 2005 (Newman 2006).

Electricity costs also represent a significant cost to producers, although not as sizeable as heating expenses. This is largely due to the relatively cheap cost of electricity provided to the region by the Tennessee Valley Authority, the nation's largest public utility provider. Simpson, Donald, and Campbell (2007) analyzed cost trends in poultry production and conclude that electricity costs are the second largest cost item (behind heating costs) in dollar amounts to producers.

A number of university Extension publications have addressed rising energy costs in poultry production. Smith (2001) lists several farm management practices and maintenance suggestions such as insulating poultry houses and sealing curtains in order to reduce energy costs. Cunningham (2005) estimated that North Georgia broiler producers with four 40 ft. by 500 ft. houses incur $11,600 in electricity costs annually (not including fuel for heat). Simpson, Donald, and Campbell (2007) estimated 2006 electricity costs per house to be about $3,700, an increase of about $1,200 per house from the previous year, for poultry operations in North Alabama. There is no current data available for Tennessee poultry producers regarding energy usage.

Broiler House Heating Simulation

Estimating the amount of fuel required to heat broiler houses requires utilizing a number of parameters given the site location and grower management practice(s). Previous literature has attempted to model heating needs for broiler production. Collins and Walpole (1974) constructed a computer simulation model to estimate the weekly fuel requirements for broiler production under several housing parameters. Output from the simulation included the calculated heat loss from the different parts of the broiler house and the amount of supplemental heat required on a weekly basis. The model predicted propane usage and results were fairly consistent with actual propane usage for a given farm.

Golz et al. (1990) estimated the economic feasibility of producing broilers by modeling heating costs for growers in North Dakota. Their study used a computer model developed by Harvey Hirning in 1990 (Golz et al. 1990) to estimate the amount of propane required for heating broiler houses. Parameters used to estimate heating needs included bird density, ventilation rate, heat production of birds, and building dimensions. Estimation of insulation levels for housing based upon R-Value ratings was also utilized. The R-Value is a measure of thermal resistance used in heat transfer problems. Hirning had estimated insulation levels for broiler producers located in the Southeast (including Tennessee) and included an R-Value of 4 for the walls of the broiler house and 9 for the ceiling (Golz et al. 1990). Simpson and Donald (2005) recommend insulation R-Values of at least 8 for the side and end walls and 19 for the ceiling.

A sizeable portion of heat required for broiler production is due to heat lost through the building. There are two types of heat loss in a broiler house: 1) surface heat

loss; and 2) ventilation heat loss. Surface heat loss includes heat loss through the ceiling, sidewalls, and end walls. Ceilings have the largest potential for heat or energy loss in a broiler house (Simpson et al. 2007). Other major sources of heat loss are the side and end walls. There can be 6,000 to 8,000 ft^2 of side and end wall area in a typical broiler house (Simpson et al. 2007). Ventilation heat loss includes heat loss through the entire broiler house via the ventilation system. Simpson and Donald (2005) calculate surface heat loss and ventilation heat loss on an hourly basis, using equations (1) and (2), respectively:

(1) *Surface Heat Loss = (Surface Area ÷ R-Value) × Temperature Difference (Outside – Inside Temperature)*

(2) *Ventilation Heat Loss (in Btus/hour) = Square Footage × Temperature Difference × Ventilation CFM Coefficient*

Other methods of calculating heating needs have been used in past studies. Van Dyne (1976) estimated the daily heat needs for broiler houses given heat loss and heat production from birds. Equation (3) represents Van Dyne's (1976) simulation method for daily heating needs. The equation was calculated when outside (ambient) temperature was less than the desired indoor temperature. The equation is defined as:

$$(3)\ HN = QC_t + QV_t + QI_t - SH_t$$

where *HN* is the heat need (Btu/day), *QC* is heat loss from conduction (Btu/day), *QV* is heat loss from ventilation (Btu/day), *QI* is heat loss from infiltration (Btu/day), *SH* is sensible heat produced by the birds (Btu/day), and *t* is time in days.

Financial Incentives for Solar Energy

State and federal incentives for renewable energy systems are currently available and are analyzed with the costs of the solar heating systems. Effective September 2006,

the Tennessee Economic and Community Development Energy Division is offering a grant program, the Tennessee Clean Energy Technology Grant (TN-CET), for businesses to install renewable energy systems at their facilities (North Carolina Solar Center 2006). Eligible technologies include solar heating and PV systems, wind, solar hybrid lighting, and fuel cells using renewable fuels. The TN-CET grant can cover up to 40 percent of the installed cost for solar energy systems with a maximum grant of $75,000 and minimum of $5,000. Funds allocated to this program for the 2007 fiscal year were $3,750,000. Grants are awarded on a competitive basis.

The U.S. Department of Agriculture (USDA) created the Renewable Energy Systems and Energy Efficiency Improvements Program through Section 9006 of the 2002 Farm Bill (North Carolina Solar Center 2006). Funds were appropriated for fiscal year 2002 through 2007. The current incentives are being evaluated for possible extension beyond 2007. Eligible renewable technologies include solar heating and PV systems, wind, biomass, geothermal, anaerobic digestion, and renewable fuels. The maximum grant award is 25 percent of eligible project costs up to $500,000 for renewable energy projects. Guaranteed loans are also offered under the program. Under the guaranteed loan option, funds up to 50 percent of eligible project costs are available with a maximum project cost of $10 million. Currently, this program is due to expire at the end of the 2007 fiscal year but legislation to extend the program is underway within the 2007 Farm Bill. It should be noted that the 2007 Farm Bill has not yet been approved and is still undergoing proposals and political discussion. There were approximately $11.4 million available for competitive grants and $176.5 million for guaranteed loans for 2007.

An additional incentive includes a federal business tax credit of 30 percent for installing solar heating systems. The federal Tax Relief and Health Care Act of 2006 extended the federal business energy tax credit for solar systems completed by December 31, 2008 (North Carolina Solar Center 2006). State rebates, buydowns, grants or other incentives decrease the amount eligible for the federal investment tax credit if the farmer or company is not required to pay federal income tax on the incentive (Chadbourne and Parke, LLP 2006). Also, businesses that install solar systems can recover their investments under the federal Modified Accelerated Cost Recovery System (MACRS) over a class life of five years (North Carolina Solar Center 2006). Therefore, under MACRS, the installation of solar energy systems qualifies as an investment eligible to be depreciated over five years.

Available incentives included in the solar heating analysis are: 1) the Tennessee Clean Energy Technology Grant which provides up to 40 percent of the initial cost of the solar energy system with a limit of $75,000; 2) the USDA Rural Development grant which provides up to 25 percent of the initial cost of the system; 3) the 30 percent federal business tax credit; and 4) the MACRS investment recovery option.

CHAPTER III

DATA, METHODS, AND PROCEDURES

Broiler production in Tennessee is generally located in five clusters across the state as shown in Figure 1.2 with the majority of production in Bedford and Bradley counties. Differences in solar resources were examined among the top broiler-producing counties using the PVWATTS online tool. Substantial differences in solar resources existed between the Bradley and Weakley county areas. Both counties also ranked in the top 12 in 2001 in terms of number of broilers produced (Warren 2002). In order to analyze potential geographical advantages for solar adoption across the state, Bradley and Weakley County, located at opposite ends of the state, are compared in this study.

Before conducting the model simulation and economic analysis, it was hypothesized that Weakley County producers would possess a competitive advantage in adopting solar heating systems due to two factors: (1) Weakley County heating simulation model would result in a lower heating demand due to the assumption of higher daily average temperatures due to geographical position, and (2) Weakley County has a slightly higher amount of solar resource compared to Bradley County (Figures 1.3 and 1.4). It was also hypothesized that under comparable size systems, the latitude plus 15 degrees collector tilt would be more economical than the alternative collector tilt of latitude because of advantages in wintertime collection stated in previous literature (Van Dyne 1976). It should also be noted that the solar heating systems are to complement or supplement an auxiliary propane heating system rather than be the sole heating source.

Heating Demand Simulation

A simulation model is used in this analysis. The model was constructed to include as many relevant variables as possible. Primary performance data were not available for this research study. Therefore, there is currently no on-farm demonstration solar heating system in Tennessee. The simulation model is an abstraction of reality, with mathematical equations used to estimate a realistic broiler house situation for growers in Tennessee. However, the model is not exclusive to Tennessee producers, and can be adapted for further research in other regions of the country. The heating needs simulation model is divided into five subsections: definition of parameters, outdoor temperature data, heat production from broilers, building heat loss, and estimation of daily heat needs.

Definition of Parameters

Estimating the amount of fuel required to heat broiler houses requires simulation of a number of parameters given the site location and grower management practice. Production and management differences exist between growers under production contracts with different integrators in various regions of the state (Goan 2007). Broiler production is generally integrated by Tyson Foods in Weakley County and Koch Foods in Bradley County. Telephone interviews were conducted with poultry specialists from both Tyson and Koch Foods, Inc. (Brown 2007; Railey 2007). Production and management differences among the two counties' integrators are displayed in Tables 3.1 and 3.2.. These variances in production management practices are a significant driver in determining the amount of broiler house annual heat demand. For example, the size of the broiler house as well as the size of the broiler grown directly impact the amount of

heat demand. Thus, larger broiler houses generally require more fuel heat, ceteris paribus, and farm operations that grow larger birds may require less fuel heat since larger birds produce more heat. The economic feasibility of heating broiler houses with solar energy depends on the amount of propane cost that can be displaced by the solar heating system. Further, the differences in production management practices can significantly affect the feasibility for solar heating system adoption.

This research study focuses on the daily heating needs of broiler houses, and expands on the number of parameters used to model heating needs given grower management practices in two locations in Tennessee. Daily heating needs for a broiler house are estimated by integrating these parameters into the model for both Bradley and Weakley County producers.

Parameters that affect heating requirements for broiler houses include the number of birds placed in house (B), mortality rates (MRT), average number of broilers lost per day (B_{LOSS}), broiler growth rates in pounds per day (BGR), the target weight for each broiler at the end of each flock (B_{SIZE}), grow-out length (number of days to grow birds to specified weight) ($GROW$), house clean-out length (number of days between flocks that cleaning is performed and no production occurs) (CLN), and total broiler flock weight each day (TBW). Each of these parameters and their mathematical equations or sources is displayed in Table 3.3.

The total number of birds placed in house at the beginning of each flock (B) differs between the two counties' producers. Weakley County producers aim to place 22,600 chicks while Bradley County producers place about 29,400 chicks at each flock. The mortality rate (MRT) of 4.5% was reported for both groups of producers. MRT is

used to estimate the average number of birds lost per day (B_{LOSS}). This estimation is defined as:

$$(4)\ B_{LOSS} = (B - (B * MRT)) / GROW$$

Daily growth rates for individual broilers (in pounds per day) (*BGR*) were reported by poultry specialists from the respective integrators in each county. Bradley County producers target a 0.1020 (lbs/day) growth rate and Weakley County producers aim for 0.1206 (lbs/day). Target individual broiler weight (B_{SIZE}) at the end of each flock was also provided by the poultry specialists. This parameter is defined as:

$$(5)\ B_{SIZE} = BGR * GROW$$

Broiler growth and therefore size are appropriate parameters because of the amount of sensible and usable heat given off by the birds varies by the size of birds. According to test results by Czarick (2001), 23,000 broilers placed in a house produced more Btu's per hour as they grow in the latter stages of the flock. A broiler produces approximately 5 Btu's of heat per pound of body weight per hour (Tabler 2001).

The total amount of broiler weight in production (in pounds) (*TBW*) is estimated for each day during flock grow-out cycles. This calculation represents the total weight of live broilers in house on a given day, and is needed in order to estimate the total heat produced from broilers daily. Total amount of broiler weight in production is defined as:

$$(6)\ TBW = (B - (B_{LOSS} * n) * (BGR * n)$$

where n represents the number of days in each flock grow-out cycle, *GROW*.

Outdoor Temperature Data

Van Dyne (1976) simulated weather and climatic data using a Monte Carlo simulation routine on an hourly basis for one year. One objective of this study was to

modify the simulation by using daily average temperature data for each location. This was completed in order to adjust the simulation model and make it more suitable for individual broiler producers to estimate the economic feasibility of solar systems. Daily average temperature was obtained from the Southeast Regional Climate Center's (2007) 1971-2000 historical climate summaries. Daily average temperature data, defined by $T_{a,}$ are incorporated into the simulation model to estimate the daily heating needs for broiler houses in each county. Flock placement was assumed to be January 1 for year one of production, with continuous grow-out cycles over the twenty year evaluation period.

The purpose of the simulation is to estimate the daily heating needs for production. For purposes of this study, heating needs are not estimated when broilers are not present in the house during the cleanout period. Therefore, heating needs are only estimated when broilers are being housed and when the desired indoor temperature (T_i)is greater than the daily average temperature, T_a. Weekly estimates for T_i were reported by the poultry specialists from each integrator and are displayed in Table 3.2. When $T_i < T_a$, building heat loss and heat production from broilers were evaluated to determine whether additional heat was needed. When $T_i > T_a$, building heat loss and heat production from broilers were also evaluated in order to calculate the amount of heat needed to achieve the desired indoor temperature, T_i. The difference in T_i and T_a is defined in Equation 7 as:

(7) $T_i - T_a = \Delta T$

where ΔT is estimated and utilized to calculate the building heat loss and heat need during grow-out cycles.

Heat Production from Broilers

Sensible heat production from broilers (*HPB*) was estimated given that a single broiler produces approximately 5 Btu's of heat per pound of body weight per hour (Tabler 2001). Total heat production from broilers (in Btu) on a given day is defined in Equation 8 as:

(8) $HPB = TBW$ * 5 (Btu per pound of body weight) * 24 (hours/day)

Building Heat Loss

Building heat loss was estimated by altering Equations (1) and (2) stated in the literature review (Simpson and Donald 2005) given the parameters used in the analysis by taking into account the temperature difference, ΔT. Table 3.4 illustrates the calculation of both building heat loss and the derived heating demand equation. Heat loss is separated into surface heat loss (*SHL*) and ventilation heat loss (*VHL*). Surface heat loss and ventilation heat loss are estimated for broiler houses in each county given the growth/management specifications listed in Tables 3.1. and 3.2..

<u>*Surface Heat Loss*</u>

Surface heat loss (*SHL*) includes heat lost through the ceiling (*CL*), sidewalls (*SL*), and end walls (*EL*). R-values used for the surface heat loss calculations include 8 for side and end walls and 19 for the ceiling (Simpson and Donald 2005). Equations 9 through 12 define the calculation of each source of daily heat loss (in Btu) as:

(9) $CL = (SA_C / R_C) * \Delta T * 24$ (hours/day),

(10) $SL = (SA_S / R_S) * \Delta T * 24$ (hours/day),

(11) $EL = (SA_E / R_E) * \Delta T * 24$ (hours/day), and

(12) $SHL = CL + SL + EL$

where SA_X represents the total surface area in each respective section of the broiler house, and R_X represents the recommended R-value (insulation level) for each respective section of the broiler house.

Ventilation Heat Loss

Estimation of ventilation heat loss (*VHL*) requires a ventilation CFM (cubic feet per minute) coefficient. A conventional broiler house generally has a ventilation CFM coefficient of 0.30 (Simpson and Donald 2005). Ventilation CFM coefficients decrease as the level of insulation in the house is increased. Total floor square footage of the broiler house (SA_F) is applied for ventilation heat loss calculations. Ventilation heat loss (in Btu) on a given day is calculated in Equation 13 as:

(13) $VHL = SA_F * \Delta T * 0.3$ (Ventilation CFM coefficient) * 24 (hours/day)

Daily Heating Demand

Heat demand per day (in Btu) (*HN*) is estimated each day broilers are present in production over the 20 year evaluation period. The estimation of heat demand is summarized in Equation 14. If $T_i < T_a$, *HN* is calculated and evaluated to determine whether additional heat is needed. However, if $T_i > T_a$, then Equation 14 is utilized to determine the total heat needed in order to achieve T_i for the given day.

(14) $VHL + SHL - HPB = HN$.

Solar Heating Simulation

PVWATTS Solar Energy Output

Available solar radiation and energy data is difficult to find on a daily basis for specific locations. Therefore, for purposes of this study, PVWATTS Solar Energy Calculator, developed by the National Renewable Energy Laboratory's Renewable

Resource Data Center (RREDC 2007), is used to estimate average monthly solar energy collection for both Bradley and Weakley Counties. The PVWATTS interactive tool allows the user to pinpoint the area of study specific to 40 km by 40 km cells, about the size of an average Tennessee county. The model uses long-term average weather data (i.e., cloud cover, atmospheric water vapor, and aerosols) to estimate the usable solar energy given various technical parameters (RREDC 2007).

The PVWATTS tool was chosen because it is flexible in that parameters and location can be altered easily for specific analysis. One adjustable parameter is the derate factor, which is essentially a technical efficiency measure. The collector tilt for the flat plate collector can also be adjusted for comparative analysis. Solar energy production or output was estimated for each county with two different collector tilts: 1) latitude; and 2) latitude plus 15 degrees. These different collector tilts allowed comparisons of the long term performance and financial effects on adoption decisions. Previous studies (Van Dyne 1976) illustrate that the latitude plus 15 degree tilt maximized wintertime collection for heating purposes. However, the study did not compare the long term economic impacts of the alternative collector tilt scenario. Table 3.5. and Figure 3.1 display the PVWATTS results and solar energy available for the collector tilt scenarios in each county. Solar performance is degraded 1% annually over the twenty year evaluation period to take into account the degradation and reduced efficiency of the collector system over time (RREDC 2007).

Solar Heat Storage

Tybout and Lof (1970) indicated that solar is most economically competitive with conventional heating sources when maximum storage is one to three winter days' heat

delivery. In general, storage tanks require one to two gallons of water per square foot of collector area (U.S. Department of Energy 2005). The technical and engineering specifications of heat storage and transfer are beyond the scope of this study. For purposes of this study, all solar heat energy is assumed to be used during the given day of collection, or else it is considered overflow. Also, the costs of hot water storage tanks and installation are included in the total solar heating system costs.

Usable Solar Heat

Results from the PVWATTS calculator are delivered in terms of average kilowatt-hours (kWh) per square meter (m^2) of collector area per day ($kWh/m^2/day$) for each month of the year. This output (*SOL*) is converted to heat or thermal energy form ($Btu/ft^2/day$) by multiplying by a conversion factor of 317.1 (Apricus 2008). Daily available solar heat energy (SOL_{BTU}) is estimated for each combination of solar energy system size (ft^2 of collector) (*SOLFT*), and collector tilt (*TILT*). Daily usable solar heat (in Btu) is defined in Equation 15 as:

(15) $SOL_{BTU} = SOLFT * SOL$

Daily usable solar heat is estimated for every day given the system location, size of system, and collector tilt. SOL_{BTU} is compared with daily heating needs (*HN*) to estimate the total percentage of heating needs, in terms of total Btu, that can be delivered by the respective solar heating system. In terms of potential economic benefit, the amount of propane displaced (in gallons) ($PROP_{DISP}$) daily by each solar heating system is calculated.

Economic Model- Capital Investment Decision

A cost comparison of the various solar heating systems required estimation of all costs associated with each solar heating system over its expected twenty year lifetime. The economic feasibility for adopting solar heating systems is the primary focus of this study. Solar heating systems required estimation of equipment costs since they require a high initial investment for equipment purchase and installation, with low variable or operating costs relative to other heating alternatives and fuels.

Solar Heating System – Benefits and Costs

Costs for solar heating systems included the equipment and installation (capital) costs. Capital costs of the system are estimated by multiplying the size of collector system area in square feet (*FTSQ*), and cost per square foot of collector (*SOLFT*). Three different size collectors (1,000 ft^2, 2,000 ft^2, and 4,000 ft^2) are evaluated in this study. These sizes were chosen in an effort to select systems that would provide a broad range of total annual heating demand. A range of $30 - $50 cost per square foot of collector area is evaluated. These cost estimates are on the lower end of the $30 - $80 range estimated for commercial systems by the DOE's booklet titled *A Consumer's Guide to Energy Efficiency and Renewable Energy* (2005). The lower ranges of costs ($30 - $50 per square foot) are used due to assumed economies of size for the larger solar systems that are evaluated in this study.

Operating costs include annual maintenance costs (*MAINT*), annual insurance costs (*INS*), and property taxes (*PTAX*). Tennessee Farm Bureau Insurance Division was contacted for insurance rates on equipment purchases (Cashion 2007). An annual insurance rate of $7.50 per $1,000 (or 0.75% of system cost) of equipment value is used

as the base case amount for the study (Cashion 2007). Additionally, an annual maintenance cost of 0.6 percent of system cost was applied to the life of the system (Byrne et al. 2005). Property taxes are not included in the base case analysis, but a 4 percent annual property tax rate is added for evaluation in the sensitivity analysis. Four percent has been used as an upper limit for property tax rates in previous literature (Van Zweden et al. 1985). All operating costs are escalated at a 4 percent annual inflation rate, which represents the current rate of inflation as well as the annual average rate over the last twenty years (Capital Professional Services 2008).

Estimation of the benefits or "gross income" of each solar investment required a dollar value to be assigned to the amount of propane displaced ($PROP_{DISP}$). Propane prices ($PROP_P$) were forecasted and inflated over the twenty year period at various levels of real escalation with inflation ($PROP_{ESC}$). Annual gross income (GI) or benefit is calculated by multiplying $PROP_{DISP}$ and $PROP_P$ in any given year. Therefore, annual net income, NI, is estimated in Equation 16 as:

(16) $NI = GI - MAINT - INS - PTAX$,

where all operating costs are inflated at the general inflation rate of 4 percent annually and gross income is inflated at the appropriate escalation rate ($PROP_{ESC}$).

Financing Conditions

Terms for the financing of each solar heating system include a mortgage period of ten years with a ten percent down payment on the total amount financed. The mortgage interest rate (MIR) is applied to calculate the interest expense (INT) on the remaining principal amount after each year.

Taxable income (*TAXINC*) is calculated in Equation 17 in order to estimate the amount of taxes payable each year (*TAXPAY*) shown in Equation 18.

(17) $TAXINC = NI - DEPR - INT$,

where *DEPR* represents the annual depreciation (non-cash expense) of the system calculated using the MACRS five year cost recovery plan.

(18) $TAXPAY = TAXINC * TAX$,

where *TAX* represents the applicable marginal tax rate (in percentage).

Cash Flow and Cost Effectiveness

Annual net cash flows (*ANCF*) for each solar investment are calculated in Equation 19 to project the financial feasibility and cost effectiveness of each capital investment. The cash flows are defined as:

(19) $ANCF = NI - INT - TAXPAY$,

where *ANCF* is discounted each year at the appropriate discount rate (*DISC*) to estimate the present value of the annual net cash flows (*PVANCF*). Note that in year one of adoption the 30 percent federal business income tax credit is added to the *ANCF* calculation.

Other potential financial incentives, such as the 40 percent Tennessee Clean Energy Technology Grant and the 25 percent USDA Renewable Energy Grant, are calculated as overall system cost reductions in year 0, or at the beginning of the investment term.

One of the financial investment indicators estimated in this analysis is the net present value (NPV) of each solar heating system. NPV is a widely-used method for the financial appraisal of capital investment projects. Its calculation takes into account the

present value of annual net cash flows (*PVANCF*) and the initial cost of the investment, *COST*. It is defined in Equation 20 as:

(20) $NPV = \Sigma PVANCF - COST$.

Another investment performance measure estimated in this study is the internal rate of return or *IRR*. *IRR* is described as the discount rate that sets the *NPV* equal to zero when applied to the investment analysis. Values were calculated using the Excel spreadsheet program taking the *NPV* for each solar investment into effect. The benefit-to-cost ratio (*BC*) for each is estimated as well and is defined in Equation 21 as:

(21) $BC = \Sigma PVANCF / COST$.

An important factor when making capital investment decisions is the investment payback period. Both the discounted and undiscounted payback periods are reported for each system and scenario. The discounted payback period, *DPB*, is calculated by using the discounted annual net cash flows or *PVANCF* whereas the undiscounted payback calculation (*UPB*) does not take the discount rate into account and uses annual net cash flows (*ANCF*). Each calculation is derived from dividing the cumulative cash flows by the initial cost of the investment over the twenty year life until they are equivalent.

Solar Heating System Investment Decision Criteria

Solar heating systems which deliver a net present value (*NPV*) > 0, a benefit-to-cost (*BC*) ratio > 1, and result in an internal rate of return (*IRR*) > the discount rate (*DISC*), are considered positive and a financially beneficial investment. However, investment paybacks, both discounted and undiscounted, are also financial criteria to be analyzed. This is due to the production horizon for the individual Tennessee broiler producer. Broiler houses typically have a useful life of thirty to forty years. Therefore, a

twenty year solar heating system investment should take into account the current life of the broiler house along with age of the farmer and the farmer's desire to remain in broiler production for another twenty years.

Base Case Scenario

In order to compare alternative scenarios for economic feasibility of solar heating systems, a base case scenario of economic model parameters was developed. Table 3.6 displays the economic parameters used in the base case scenario as well as the range tested in the sensitivity analysis. The variables chosen for investigation are cost of system per square foot collector (*SOLFT*), the effective discount rate to which cash flows are discounted to present values (*DISC*), the annual propane price escalation rate ($PROP_{ESC}$), the effective tax rate (*TAX*), the insurance rate (*INS*), the maintenance rate (*MAINT*), property taxes (*PTAX*), the mortgage interest rate (*MIR*), and the federal and/or state financial incentive grants available for solar system adoption (*GRANT*). These parameters are hypothesized to have the greatest financial impact on the economic feasibility of adopting solar heating systems.

Chapter IV includes the results of the heating demand simulation, as well as the financial feasibility of adopting solar heating systems under the range of scenarios. Displaced propane costs serve as the financial benefit via reduced annual operating costs of the solar heating system. The base case scenario serves as the reference point for analysis. Thereafter, one parameter is altered at a time, in order to capture the effect of the change in the capital investment decision on financial performance measures. It should be noted that multiple parameters were not changed together. This was performed in order to demonstrate the exclusive financial impact of shifting one parameter at a time.

Financial performance measures include several capital investment decision criteria including, undiscounted and discounted payback, net present value (*NPV*), internal rate of return (*IRR*), and the benefit-to-cost ratio (*BC*).

CHAPTER IV

RESULTS AND SENSITIVITY ANALYSIS

Heating Demand Simulation

The simulated or derived heating demand for each county over the twenty year evaluation period is displayed in Figure 4.1. Results from the simulation model displayed that Bradley County broiler producers require an average of 4,834 gallons of propane to heat each house annually. The minimum propane heating requirement for Bradley County producers came in years 9 and 19 with 4,434 gallons. The maximum heating requirement came in years 1 and 11 with 5,660 gallons. Weakley County producers required an average of 3,459 gallons of propane annually. The minimum for Weakley County came in year 8 with 2,456 gallons and the maximum came in year 12 with 4,065 gallons.

Weakley County producers required a substantially less amount of heating demand due mainly to the differences in production and management practices by growers in the region. Weakley County producers grow larger broilers (6.15 pounds) which produce more sensible heat. Coupled with smaller broiler houses (17,640 ft^2) than Bradley County producers (20,000 ft^2), the model estimated that Weakley County producers would require less heat energy annually.

Percentage Solar Heat Delivered

An important performance metric of the solar heating systems was the amount of total heat that could be supplied by the given solar system. Solar heating systems in Weakley County delivered a higher percentage of solar heat deliverable compared to Bradley County across all system sizes. However, this is due to the fact that

Bradley County heating demand was estimated to be much higher, as reported previously. The actual amount of solar heat (in Btu) delivered or usable was much higher for Bradley County solar heating systems. This disparity in actual usable solar heat is illustrated in Table 4.1, which displays the estimated amount of propane displaced by each solar heating system over twenty years. As the solar collector system size increased to 2,000 ft^2, the system with collector tilt of latitude plus 15 degrees provided a slightly higher percentage of total heating demand. This is illustrated in Table 4.2. A 4,000 ft^2 system at a tilt of latitude plus 15 degrees located in Weakley County could deliver 83.3 percent of the heating needs over the twenty year period. The same system located in Bradley County could deliver 79.9 percent of the heating demand. The 1,000 ft^2 collector system provided roughly 30 and 33 percent of annual heating demand, for Bradley and Weakley County broiler houses, respectively. The 2,000 ft^2 collector system provided approximately 53 and 56 percent of annual heating requirements, for Bradley and Weakley County broiler houses, respectively. The 4,000 ft^2 collector system provided 78 and 83 percent of annual heating requirements, for Bradley and Weakley County broiler houses, respectively. Results of the percentage of total heat demand deliverable by each solar heating system are reported in Table 4.2.

Geographical and Production/Management Differences

It was hypothesized that Weakley County would have a warmer climate, due to its geographical positioning in the western part of the state. Daily average climatic data (SERCC 2007) confirm this assumption during the summer months. However, during the winter months of November through February, when heating demands are substantially higher, Bradley County's average temperatures are higher than Weakley County.

Heating demands were considerably higher for Bradley County producers even with the higher winter temperatures (average of 4,834 propane gallons needed annually versus 3,459 gallons for Weakley County producers).

PVWATTS' Solar Performance Calculator results (Table 3.5) illustrate that Bradley County receives higher amounts of solar radiation during the months of March, May, and November. During the remaining months, Weakley County is shown to have an advantage in solar radiation. Van Dyne (1976) and Tybout and Lof's (1970) findings with respect to the latitude plus 15 degree collector tilt supplying more heat during the winter months was verified. The latitude plus 15 degree collector tilt delivered more solar radiation (heat) for both counties during the traditional Tennessee winter months (November through February). Evidence of these results is shown in Table 3.5.

Time of flock placement for both counties' producers was January 1 for the first year of production. However, differences in flock grow-out periods and house clean-out periods (Tables 3.1 and 3.2) made future flock placement differ between the counties' producers. Weakley County broiler producers, integrated by Tyson Foods, Inc., produce a larger broiler at 6.15 pounds, whereas Bradley County producers grow a 3.85 pound broiler, integrated by Koch Foods, Inc. Growing larger birds requires longer grow-out cycles as well as more feed. As the broilers continue to grow, they produce more sensible heat and therefore, less propane (or solar) heat is needed to achieve the desired indoor temperature, T_i. This again factored into Weakley County producers having less heat demand annually.

Optimal Flock Placement

Due to the longer grow-out (*GROW*) and clean-out periods (*CLN*) for broiler production, the simulation resulted in fewer average flocks per year at 5.6 for Weakley County producers compared to Bradley County producers at 7.3 flocks per year. The optimal times of flock placement are determined by analyzing the year(s) with the least amount of heating demand. Annual heating demands (in Btu) are lowest for Bradley County broiler houses in years 9 and 19 at 4,434 gallons of propane. Optimal flock placement for Bradley County producers is therefore January 31, March 22, May 11, June 30, August 19, October 8, and November 27. Due to the overlapping of flocks on a continuous basis, broilers are in house during the first eighteen days of January during the first two years. Annual heating demands are lowest for Weakley County broiler houses in year 8 at 2,456 gallons of propane. Optimal flock placement for Weakley County producers is therefore February 15, April 21, June 25, August 29, and November 2.

Sensitivity Analysis

Base Case Scenario

The cost effectiveness of each solar heating system is evaluated by varying parameters that are expected to contribute significantly to capital investment decision criteria. A base case scenario (Table 3.6) was developed for comparison of the parameters' relative effectiveness on the economic feasibility of adoption. The base case results, shown in Table 4.3, illustrate that Bradley County solar heating systems result in a better financial investment than Weakley County systems. For example, a 1,000 ft^2 at Latitude in Bradley County yield a 7.3 percent internal rate of return (IRR) , whereas the same solar heating system in Weakley County resulted in a significantly lower IRR of 3.8

percent. Results also revealed that the smaller solar heating systems are more advantageous than the larger (4,000 ft²) solar heating systems (Figure 4.2). Additionally, results show that as the solar heating system size increases, the internal rate of return (*IRR*) decreases and the investment becomes less financially attractive. Specifically, the increased capital and operating costs of a larger system were shown to offset the gains in solar heat production. Results from the sensitivity analysis as well as the base case scenario are displayed in Tables 4.3 – 4.22 and Figures 4.2 – 4.11. Analyses of the individual parameters effect on the capital investment decision model are explained in the following sections. Also, Table 4.23 illustrates an example of the cash flow analysis for the base case scenario.

Cost of Solar System per Square Foot of Collector

The key driver of solar heating feasibility of broiler houses depends on the cost of the solar heating system. Due to anticipated economies of size, the lower range cost of $30 per ft² collector is used in the base case scenario. However, the model is adjusted to account for possible price variations between suppliers and or future price increases. As the collector cost per ft² increases, the financially feasibility of solar adoption decreases rapidly (Figure 4.3). In the base case analysis, only the small 1,000 ft² system located in Bradley County approached financial feasibility. At higher prices of $40 and $50 per ft² collector, the financial feasibility decreases significantly. Thus, as expected, installed cost is an important parameter in determining to adopt the technology. At the upper limit of installed costs, some financial incentives, a higher (15 percent) propane escalation rate, or a lower discount rate would be needed for broiler producers in the state to potentially benefit financially from adopting solar heating systems. Therefore, some combination of

favorable economic conditions must occur before adoption is economically advantageous to the producer.

Propane Price Escalation

Another parameter under analysis is the escalation rate in the propane price. As mentioned in previous literature, this parameter is significant in calculating the feasibility of solar heating alternatives. It is hypothesized that continued and sustained increases in propane prices annually would make adoption of solar heating systems more financially feasible. The base case scenario, shown in Table 4.3, uses a 10 percent annual propane price escalation rate, which was obtained from historical data from 1992 (DOE EIA 2008). Adjusting this rate to 5 and 7.5 percent had a large, negative impact on the *NPV* of each investment. No solar heating system investment generated a feasible payback period under these conditions. The annual price escalation was adjusted to reflect a potential 15 percent increase in propane prices and resulted in nearly all systems approaching financial feasibility with *IRR*'s as high as 13.8 percent for a 1,000 ft^2 Bradley County system. Propane prices included adjustments for inflation at a rate of 4 percent per year. The 4 percent inflation rate represents the current estimated inflation rate as well as the average annual inflation rate over the last twenty years (Capital Professional Services 2008). Propane prices, along with the initial cost of the solar heating system (including state and federal grant incentives that lower initial system costs), were estimated as the most significant parameters affecting the capital investment decisions.

The propane escalation rate was adjusted for possible future decreases and increases. Specific results are illustrated in Tables 4.6 – 4.9. Under the base case

conditions of 10 percent propane price escalation (Table 4.3), no system resulted in a positive investment. As the propane escalation rate approaches 12.5 and 15 percent, the smaller solar heating systems become positive investments and are feasible for adoption. The summary impacts of propane escalation rates on financial feasibility are illustrated in Figure 4.4.

Financial Incentives-Grants

Another parameter included in the sensitivity analysis deals with state and federal financial grants for adopting solar heating systems. These grants/incentives are program and applicant specific. Therefore, the analysis utilized the various levels of grants/incentives by comparing the following: 1) no financial grants (base case); 2) the 25 percent USDA Renewable Energy Grant; and 3) the 40 percent Tennessee Clean Energy Technology Grant. These incentives were not available during previous studies completed in the 1970's and 80's when solar energy systems were previously evaluated. All scenarios in this study assume that the MACRS investment recovery method and 30 percent federal tax credit were utilized. Any and all financial grants will either reduce the initial cost of the system or produce a positive cash flow rebate (in the form of a tax credit) in the following year after adoption.

As expected, increasing the level of incentives delivers an added benefit to the producer and makes solar adoption more financially viable. Under the 25% USDA Grant scenario, the two smaller systems (1,000 and 2,000 ft^2) in Bradley County become financially feasible delivering positive NPV's as well as BC ratios > 1. Increasing the grant amount to 40 percent (TN-CET) results in another solar heating system (Weakley County, 1,000 ft^2) becoming feasible with positive *NPV*, *BC* >1, and payback periods

within the twenty year evaluation period (Tables 4.10 and 4.11). The financial impact of receiving these grants is displayed in Figure 4.5.

However, state and federal grant program budget limitations will likely exclude the widespread adoption of such systems. These grant awards are considered to be a competitive process and not all applicants are guaranteed to receive grant funds. Nevertheless, if more than one financial incentive is awarded, the impact on the financial feasibility of adoption will increase significantly.

Discount Rate

The discount rate applied to future cash flows is considered to be an important parameter in the capital investment decision. The base case scenario uses a rate of 8 percent, which is accounted for by the current prime rate plus 2 percent (Wall Street Journal 2008). Lowering the discount rate to 6 percent in the investment decision model results in a beneficial investment environment because it lowers the expected future valuation of cash flows. Under the 6 percent discount rate scenario, only the 1,000 ft^2 solar heating system in Bradley County delivers a positive return (Table 4.12). The investment decision model was adjusted using the 10 percent discount rate to also reflect possible future increases in the prime rate (Table 4.13). Results show a negative effect on the financial feasibility of solar adoption. As the effective discount rate is increased from 6 to 8 and 10 percent, no systems deliver a positive return on investment. The discount rate's impact on financial feasibility is summarized in Figure 4.6. As expected, given a higher discount rate no solar system investment would be considered financially sound.

Tax Rate

The tax rate parameter results are shown in Tables 4.14 and 4.15. Due to the complexity in simulating the exact tax bracket for producers across the state, a tax rate bracket of 28, 31, and 34 percent were used to analyze the effect on financial performance measures. Results show very little variation in overall financial measures between the tax rates (Figure 4.7). Therefore, the tax rate was not considered to have a large impact on solar system investment feasibility.

Insurance Rate

Among the solar heating system parameters under investigation include the system operating costs. The annual insurance rate is considered one of the important operating cost parameters. The insurance rate was estimated as a percentage applied to the total system cost. A range of 0.5 percent to 1.0 percent is tested for disparities among the *NPV*. Results are shown in Tables 4.16 and 4.17. Figure 4.8 displays the impacts that the insurance rate has on financial feasibility when compared with the base case scenario. The difference in the return on the investment is small relative to the large investment risk. The insurance rate was found to have a minimal impact on financial feasibility and adoption.

Maintenance Rate

Another important operating cost parameter is the annual maintenance rate. Much like the insurance rate, the maintenance rate did not prove to significantly alter the relative changes in the investment criteria. Specific results are shown in Tables 4.18 and 4.19. All levels of the maintenance rate delivered negative investments, with minimal

variance when adjusting from the low range (0.4 percent) to the high range (0.8 percent). The relative impacts on financial feasibility are illustrated in Figure 4.9.

Property Tax Rate

The property tax is one parameter that is often ignored in solar investment analyses. The base case scenario included no property tax rate. However, a 4 percent property tax rate is included in the sensitivity analysis to determine the magnitude of the impact the rate has on financial performance measures. Van Zweden et al. (1985) used 4 percent as an upper limit for the property tax value when doing solar energy system analysis. Results, shown in Table 4.20, illustrate that the property tax rate has a substantial negative impact on *NPV* and solar heating system adoption. In summary, the application of a property tax on solar heating equipment can significantly impact the financial feasibility of the investment (Figure 4.10)..

Mortgage Interest Rate

The last parameter chosen for investigation was the mortgage or loan interest rate applied to the capital investment. Mortgage interest rates, as applied to the borrowed funds, were anticipated to have a negative impact on the feasibility and adoption of the solar investment as the rate increases. The interest rates used in this study were 5, 6.5, and 8 percent on borrowed capital (Tables 4.3, 4.21, and 4.22). Results (Figure 4.11) from the capital investment model illustrate that as the mortgage interest rate shifts, there is a small impact on the financial feasibility. Adjusting for future rate increases to 8 percent effectively decreases the NPV and BC ratio for each project.

Environmental Implications- Reduced Emissions

Given the current widespread concern over environmental emissions and global warming, the potential for solar heating systems to reduce emissions from conventional fuels such as propane was estimated. The Leonardo Academy Inc. (2007) prepared a report titled "Emissions Factors and Energy Prices for Leonardo Academy's Cleaner and Greener Program" with funding from the Wisconsin Department of Natural Resources and the U.S. Environmental Protection Agency. Their study results estimated that emissions factors of 12.5 pounds of carbon dioxide (CO_2) and 0.014 pounds of nitrogen oxides (NO_x) per gallon of propane replaced (Leonardo Academy Inc. 2007). These respective emissions factors were used to estimate the environmental benefit or reduced emissions from each of the solar heating systems evaluated in this study. Results are displayed in Table 4.24. The 4,000 ft^2 solar heating system at Latitude plus 15 degree collector tilt located in Bradley County displaced the most propane over the twenty year period at 77,119 gallons. This same system, when applying the emissions factors, reduces CO_2 emissions by 963,988 pounds over the twenty year expected useful life of the system. NO_x emissions were estimated to be reduced by 1,080 pounds over the same period. If future legislation places a carbon tax or limit on commercial industries and farmers, the reduced environmental emissions for a solar heating system could financially benefit broiler producers as well.

CHAPTER V

SUMMARY AND CONCLUSTIONS

The purpose of this research study has been to examine the financial feasibility of Tennessee broiler producers adopting solar heating systems for production. The scope or intent of the study is to assist Tennessee broiler producers in making capital investment decisions regarding solar heating and other renewable energy systems. Another goal of this study was to update the literature on solar thermal heating systems under current economic conditions and utilize Tennessee as the geographical location studied for solar heating applications in agricultural production. This study is unique in that it compares two specific counties with differing solar radiation (Bradley and Weakley) in one state, Tennessee.

This study utilizes simulation and capital investment decision support models to produce the outcomes and results of the analyses. Climate data along with integrator management specifications are integrated into the building heat demand simulation model to estimate daily and annual heating demand for individual broiler houses in each county. Solar heating performance data, extracted from a solar radiation model database developed by the National Renewable Energy Laboratory, is simulated over the life of the solar heating system to determine the amount of solar heat deliverable each day. A cost effectiveness study is performed for the various solar heating systems under various system parameters in the sensitivity analysis.

One of the objectives of the study was to simulate the annual heating needs for broiler house production in each county. It is estimated that Bradley County producers required an average of 4,834 gallons of propane annually to properly heat one broiler

house. Likewise, Weakley County producers required an average of 3,459 gallons of propane annually to properly heat one broiler house. The solar heating systems under analysis were estimated to deliver 30.2 to 79.9 percent of annual heating demand for Bradley County producers, as compared to 33.2 to 83.3 percent for Weakley County producers. Therefore, solar heating systems displaced a higher amount of propane input for Bradley County producers, since heating demands were estimated to be substantially higher.

Simulation and cost effectiveness results show that Bradley County producers hold a competitive advantage in adopting solar heating systems for broiler production. This is likely due to two factors which include: (1) Bradley County has higher average temperatures and higher average solar radiation in crucial winter heating months, although Weakley County maintains more solar radiation on average throughout the year; and (2) Bradley County producers have higher heating demand in part due to more flocks per year, and growing a smaller 3.85 pound broiler. Smaller birds give off less sensible heat, and Weakley County producers grow a larger bird (6.15 pound) which gives off more heat. The production and management differences between each county's producers are considered the primary determinant in financial feasibility and adoption. Since Bradley County producers demand more Btu on average, they can use more of the solar heat available. In effect, this makes the solar heating system utilize more generated heat and creates less overflow. This results in a shorter payback on system investment.

An outcome of this study is to determine the optimal size and collector tilt of the solar heating systems. Cost effectiveness results, measured by *NPV*, *IRR*, discounted payback, and benefit-cost ratio, displayed that the smaller 1,000 ft² solar heating systems

which deliver between 30 to 33 percent of annual heating needs are the optimal size. Previous literature (Van Dyne 1976; Tybout and Lof (1970) stated that the collector tilt of latitude plus 15 degrees was the optimal due to higher winter months of solar heat collection. Study results show that the 1,000 ft^2 systems are more cost effective at a collector tilt equal to latitude. At the 2,000 ft^2 system size, the difference between collector tilts was minimal, and at the large 4,000 ft^2 size, the latitude plus 15 degree collector tilt was more cost effective.

In summary, results from this study conclude that the potential for solar heating adoption across the state is highly dependent on the production and management characteristic of the specific broiler production operation. Small solar heating systems (1,000 ft^2) appear to be the most economical option given current technical and economic conditions. Significant parameters that affect the financial feasibility include the solar installed cost, financial grants and incentives, the propane price escalation rate in future years, the effective discount rate, and the application of a property tax on solar equipment. Bradley County producers also have a competitive advantage in solar heating adoption due primarily to the higher demand for heating sources. Solar heating can provide a small portion (approximately 30 percent) of producers' heating needs while delivering a positive return on investment. Also, a combination of grant incentives as well as rising propane prices will make solar heating options become more feasible. Results from this study are specific to the production areas chosen for this study and should be adjusted when applying to producers in other regions. Producers in areas with high heating demand and relatively good levels of solar resource will be good candidates for solar heating adoption.

The majority of broiler and poultry producers in the state and region currently use propane as the main heating source in production. In the past, propane prices were not an issue because producers and the economy enjoyed relatively low propane prices. However, as energy and propane prices continue to rise due to limited resources, national security, and environmental concerns, alternative heating sources such as solar heating systems could gain market share and be considered a viable alternative. The results from the sensitivity analyses illustrate that solar system cost along with the financial incentives available show potential for solar heating systems to be adopted by Tennessee broiler producers across the state. As long as propane prices continue to rise, investment in solar heating systems deserves attention when comparing new alternatives. However, solar heating systems should not be designed to deliver 100 percent of heating demand unless storage of solar energy becomes unlimited and economically feasible. Auxiliary propane or other heating sources will remain as alternatives for backup and supplemental heat.

One barrier to adoption for broiler producers is the age of the existing broiler house(s) currently owned. Broiler houses typically have a lifetime of thirty to forty years. The solar heating analysis includes an expected useful lifetime of twenty years, which is conservatively low. A producer is not expected to invest in an expensive capital purchase if he or she is about to get out of production. All relevant information and knowledge is critical when evaluating capital investment decisions such as a solar heating system.

Currently, producers across Tennessee are feeling the pinch of high energy costs, while their on-farm income remains relatively stable. In order to keep broiler production a viable option in Tennessee, research needs to address alternative sources of income and/or reduced production/operating costs. Solar heating systems, under the results of

this study, have the potential to benefit individual producers financially over the life of the system. Also, given a substantial level of market penetration or rural adoption of solar heating systems, rural development impacts could potentially be considerable across the state and region. Producers interested in obtaining specific cost and installation information should refer to the Solar Rating and Certification Corporation (SRCC 2007) to find companies involved with solar heating systems. There are also environmental benefits to solar heating systems such as reduced carbon dioxide (CO_2) and nitrogen oxide (NO_x) emissions, as described previously. However, capital constraints remain and represent the largest barrier to adopting solar heating systems since many producers have poured hundreds of thousands of dollars into broiler house construction and mortgages. Future changes in policy at the integrator, state, and federal level, are needed to address broiler producers' financial issues regarding energy expenses and the current support for alternative heating systems.

RECOMMENDATIONS FOR FUTURE RESEARCH

Future suggestions for research include analyzing an on-farm demonstration solar heating system to obtain primary data; analyzing other renewable heating source equipment mentioned in this study (i.e., wood pellets, switchgrass pellets, and broiler litter) and the respective capital investments in furnaces and other equipment; completing a similar study for other geographic regions (North Georgia, Mississippi, and Alabama); and studying the potential for solar photovoltaic (PV) systems to provide broiler houses with their electricity needs (e.g., lights, fans, motors, etc.) and the regional electric load impacts on regional utility providers.

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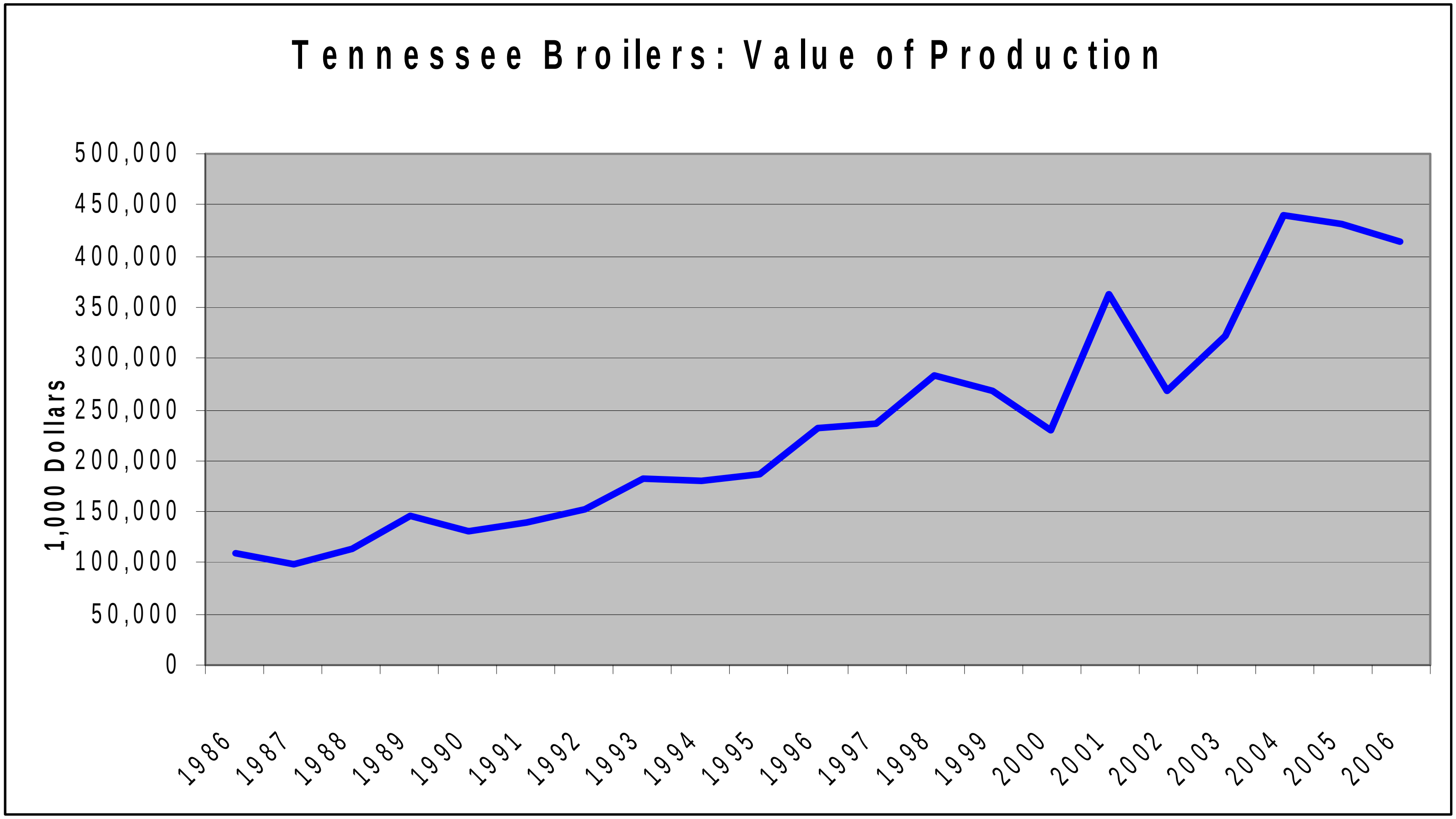
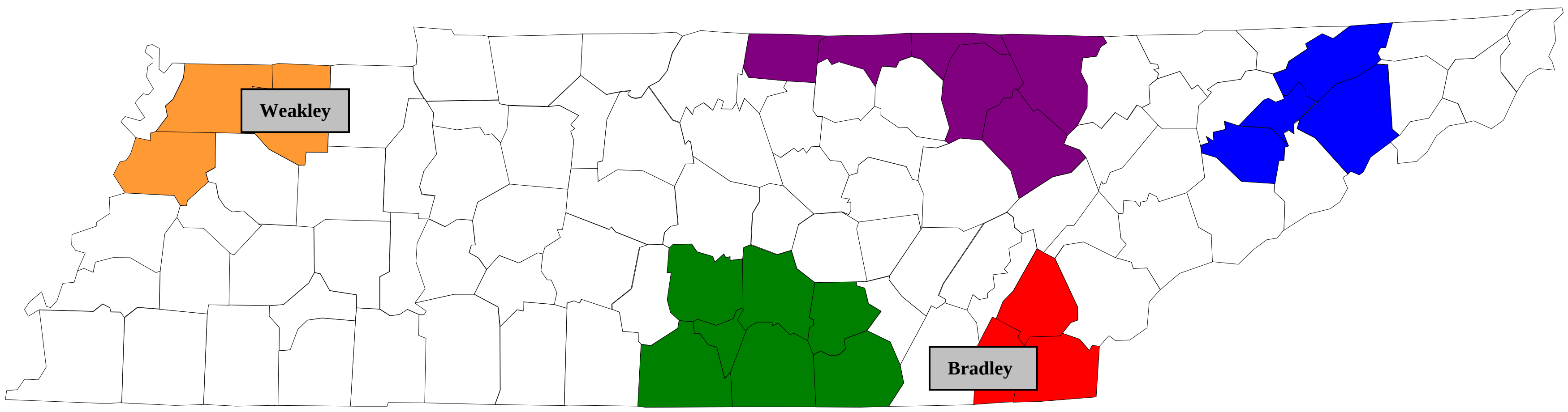
APPENDIX

Figure 1.1



Source: U.S. Department of Agriculture, 1986-2006. "Poultry: Production and Value- 1986-2006 Summaries."

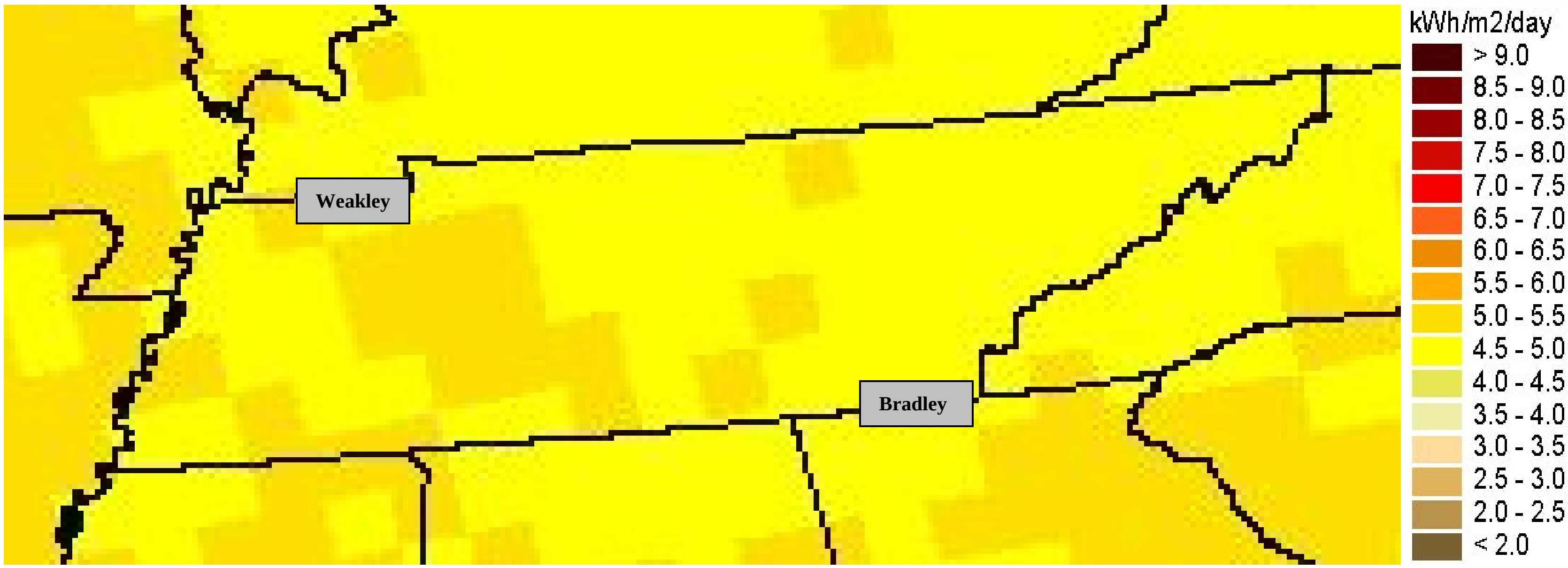
Figure 1.2



POULTRY PRODUCTION CLUSTERS ACROSS TENNESSEE

Source: Adapted from data provided by H.C. Goan, University of Tennessee-Knoxville Extension Dean

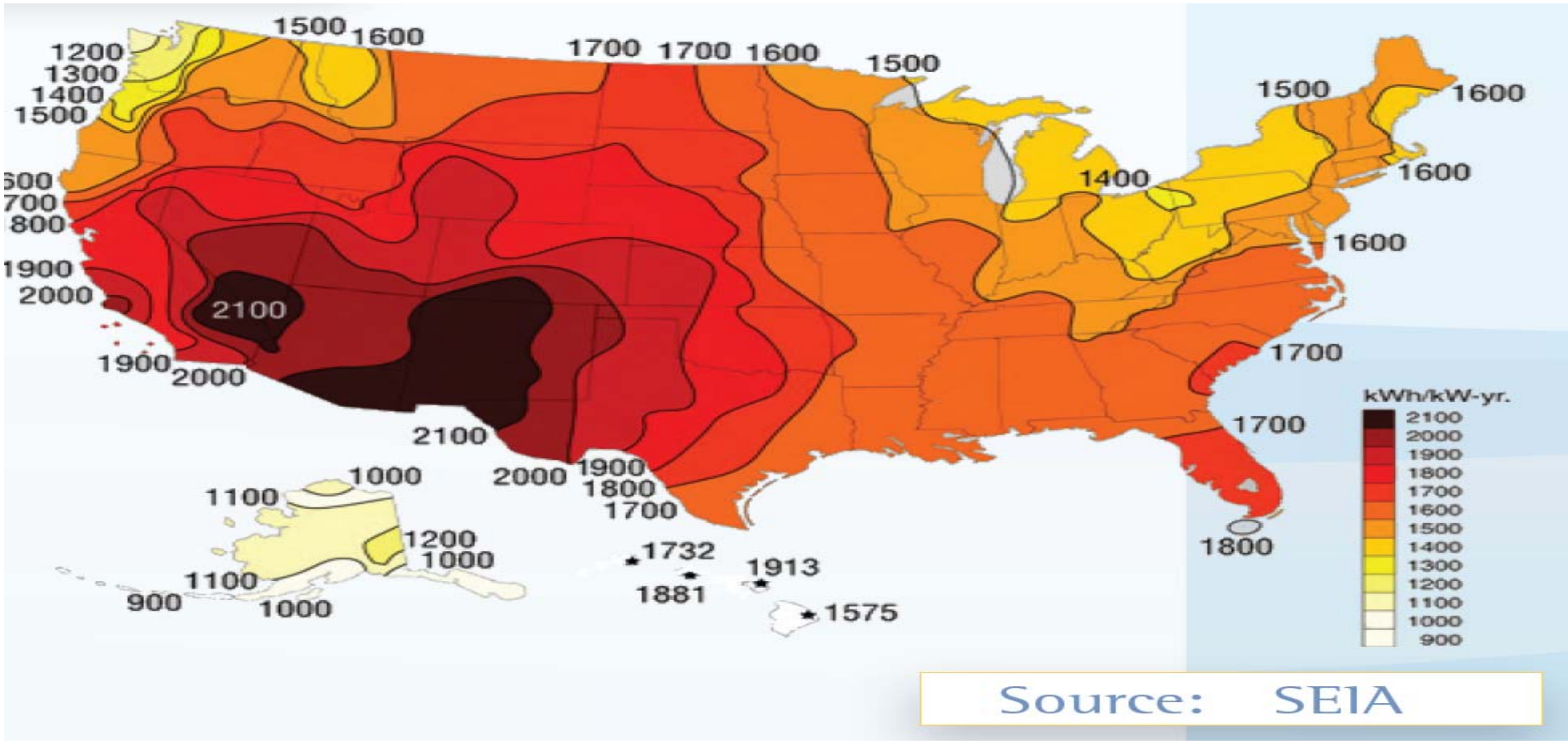
Figure 1.3



PVWATTS ANNUAL SOLAR RADIATION (FLAT PLATE COLLECTOR, FACING SOUTH, LATITUDE TILT)

Source: National Renewable Energy Laboratory, PV Solar Radiation (Flat Plate, Facing South, Latitude Tilt) - Static Maps- Annual. Solar Radiation data measured in 40 km by 40 km cells and used in PVWATTS Solar Energy Calculator.
Internet Site: http://www.nrel.gov/gis/solar.html#collector

Figure 1.4



SOLAR RESOURCES-U.S.

Source: Solar Energy Industries Association, 2006. U.S. Solar Industry-Year in Review:2006.
Internet Site: http://www.seia.org/Year_in_Solar_2006.pdf

Table 3.1

TARGET BROILER PRODUCTION SPECIFICATIONS

County	Bradley	Weakley
Integrator	Koch Foods	Tyson Foods
Typical Broiler House Size	40' x 500'	42' x 420'
Total Square Footage	20,000	17,640
Number of Birds per Flock	29,400	22,600
Typical Mortality Rate	4.50%	4.50%
Size of Bird (lbs)	3.85	6.15
Typical Growout Length	38 days	51 days
Typical Cleanout Length	12 days	14 days
# Growers	NA	9
# Broiler Houses	NA	46

Note: "NA" denotes that either current data was not available from company or was not able to be released at time of telephone interview.

Source: Telephone interviews with poultry production specialists from Koch Foods, Inc. and Tyson Foods, Inc. (July 2007).

Table 3.2

DESIRED BROILER HOUSE TEMPERATURE BY WEEK

Desired Indoor Temperature °F		
County	Bradley	Weakley
Week	T_i	T_i
1	90	90
2	85	85
3	80	82
4	75	80
5	73	75
6	70	72
7	-	70
8	-	70

Source: Telephone interviews with poultry production specialists from Koch Foods, Inc. and Tyson Foods, Inc. (2007).

Table 3.3

BROILER PRODUCTION AND CLIMATE PARAMETERS

Simulation Parameter	Description	Unit	Equation/Source
B	# of broilers placed in house at beginning of flock	# birds	Poultry Integrator Information
MRT	Average mortality rates of each flock.	%	Poultry Integrator Information
B_{LOSS}	Average number of broilers lost per day.	# birds	BLOSS = (B – (B * MRT)) / GROW
BGR	Individual broiler daily growth rate.	lbs/day	Poultry Integrator Information
B_{SIZE}	Target individual broiler weight at end of grow-out.	lbs	BSIZE = BGR * GROW
GROW	# of days each flock in house during grow-out.	# days	Poultry Integrator Information
CLN	# of days between each flock when house is cleaned.	# days	Poultry Integrator Information
TBW	Total live weight in broilers daily.	lbs	TBW = (B – (BLOSS * n) * (BGR * n)
n	Number of days into each total flock grow-out.	# days	-
T_a	Average daily outside (ambient) temperature.	°F	SERCC Historical Data
T_i	Desired daily broiler house temperature.	°F	Poultry Integrator Information
ΔT	Temperature difference.	°F	ΔT = Ti - Ta
HPB	Heat production from broilers in house daily.	Btu	HPB = TBW(5)(24)

Table 3.4

BUILDING HEAT LOSS AND DAILY HEAT NEED PARAMETERS

Simulation Parameter	Description	Unit	Equation/Source
SHL	Surface heat loss	Btu	SHL = CL + SL + EL
CL	Ceiling heat loss	Btu	$CL = (SA_C / R_C)(\Delta T)(24)$
SL	Sidewall heat loss	Btu	$SL = (SA_S / R_S)(\Delta T)(24)$
EL	Endwall heat loss	Btu	$EL = (SA_E / R_E)(\Delta T)(24)$
SA_X	Surface area of respective section of broiler house.	ft^2	$\Sigma (SA_X)$
R_X	R-value in each section of broiler house.	#	Simpson and Donald (2005)
VHL	Ventilation heat loss	Btu	$VHL = SA_F(\Delta T)(VCFM)(24)$
SA_F	Total floor area of broiler house.	ft^2	SA_F = Length * Width (of house)
VCFM	Ventilation coefficient	ft^3/min	Czarick (2001)
HN	Heat demand per day	Btu	HN = VHL + SHL – HPB

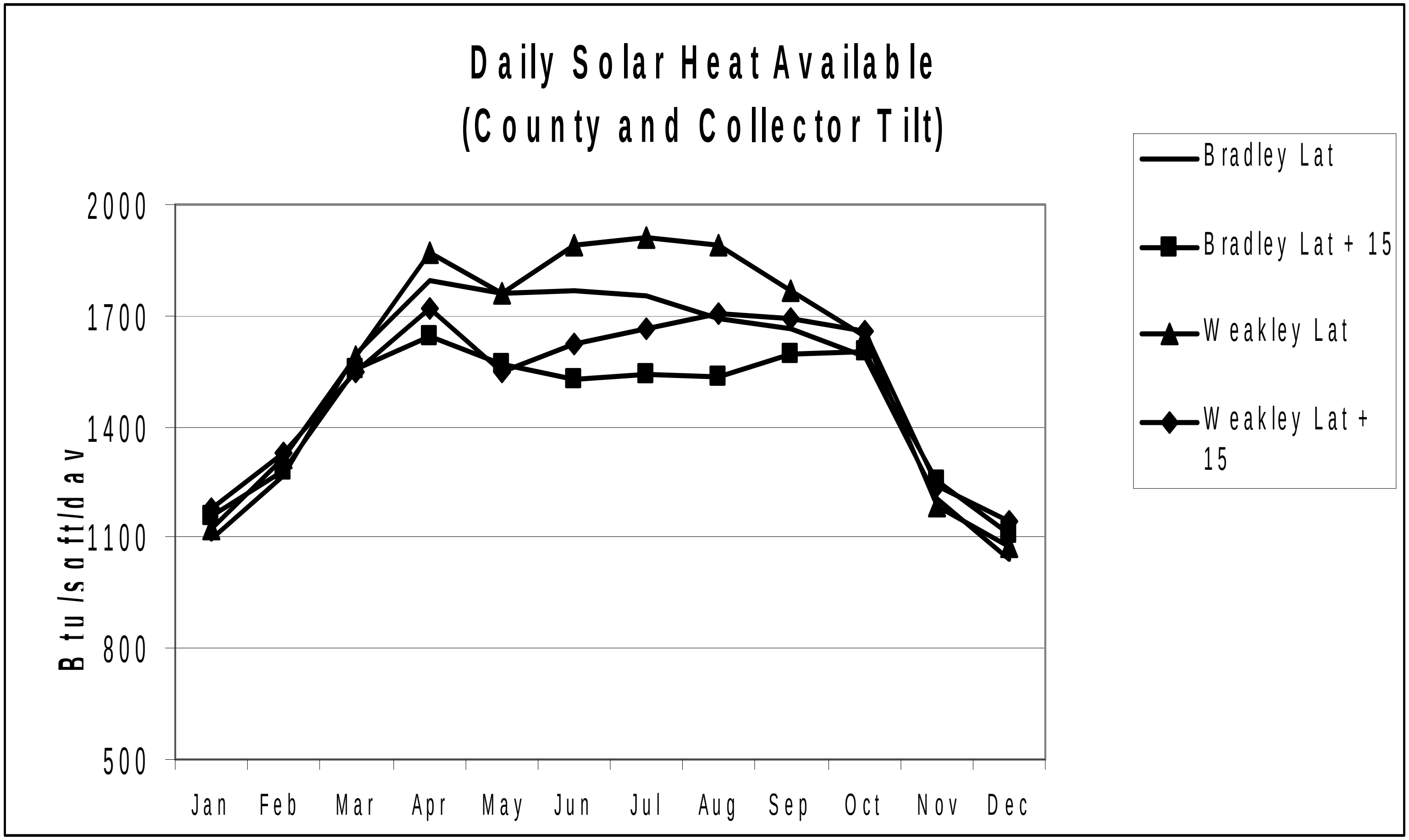
Table 3.5

PVWATTS AVERAGE MONTHLY SOLAR HEAT ENERGY OUTPUT

Solar Radiation for Flat-Plate Collectors Facing South at a Fixed Tilt (Btu/ft²/day)														
County	Tilt (°)	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Year
Bradley	Bradley Lat	1099	1267	1596	1795	1764	1766	1756	1691	1664	1587	1205	1044	1521
	Bradley Lat + 15	1156	1284	1552	1645	1566	1527	1539	1537	1596	1603	1255	1106	1448
Weakley	Weakley Lat	1124	1312	1592	1873	1760	1889	1913	1888	1769	1644	1188	1074	1587
	Weakley Lat + 15	1181	1329	1548	1721	1551	1626	1665	1707	1691	1658	1240	1141	1506

Source: National Renewable Energy Laboratory, Renewable Resource Data Center, PVWATTS Solar Energy Calculator, Results estimated in 2007.

Figure 3.1



Source: National Renewable Energy Laboratory, Renewable Resource Data Center, PVWATTS Solar Energy Calculator, Results estimated in 2007.

Table 3.6

Base Case Scenario and Ranges Tested for Sensitivity Analysis

Economic Parameter	Description	Unit	Base Case Value	Range Tested		
				Low	Mid	High
SOLFT	Cost per square foot solar collector	$/ft²	30	30	40	50
DISC	Discount Rate	%	8	6	8	10
TAX	Marginal Tax Rate	%	31	28	31	34
PROPesc	Annual Propane Inflation Rate	%	10	5	10	15
INS	Insurance Cost (% of total system cost)	%	0.75	0.5	0.75	1.0
MAINT	Maintenance Cost (% of total system cost)	%	0.6	0.4	0.6	0.8
MIR	Mortgage Interest Rate	%	6.5	5	6.5	8
PTAX	Property Tax Rate	%	0	0	-	4
GRANT	Percent of System Cost funded by Grants	%	0	0	25	40

Figure 4.1

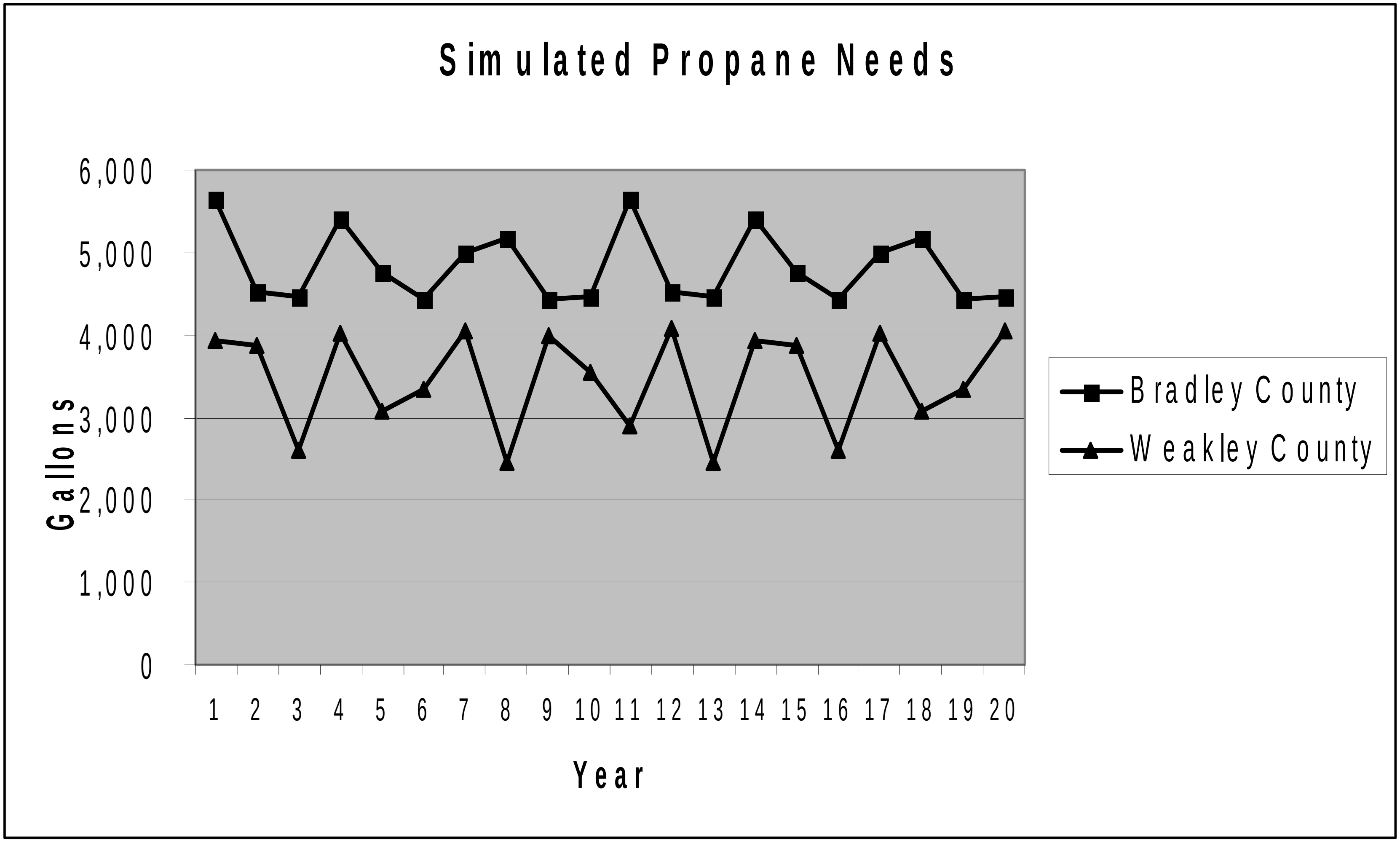

Simulated Propane Needs
6,000
5,000
4,000
3,000
2,000
1,000
0
Gallons
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20
Year
Bradley County
Weakley County

Table 4.1

TWENTY YEAR PROPANE DISPLACEMENT OF SOLAR HEATING SYSTEM

Collector Size	**1,000 ft²**		**2,000 ft²**		**4,000 ft²**	
County	Latitude	Latitude + 15	Latitude	Latitude + 15	Latitude	Latitude + 15
	(In Gallons)					
Bradley	29,458	29,072	50,595	50,642	76,082	77,119
Weakley	22,815	22,661	38,430	38,651	56,358	57,218

Table 4.2

PERCENTAGE OF HEAT DEMAND DELIVERABLE BY SOLAR HEATING SYSTEM

System Size	**1,000 ft^2**		**2,000 ft^2**		**4,000 ft^2**	
Collector Tilt	Lat	Lat + 15	Lat	Lat + 15	Lat	Lat + 15
	(Percentage)					
Bradley County	30.6	30.2	52.5	52.5	78.9	79.9
Weakley County	33.5	33.2	56.2	56.5	82.1	83.3

Table 4.3

BASE CASE COST EFFECTIVENESS RESULTS

County	System Size (ft^2)	Collector Tilt	NPV	IRR	Discounted PB (in years)	Undiscounted PB (in years)	B-C Ratio
Bradley	1,000	Latitude	($2,313)	7.3%	*	14.2	0.92
		Latitude + 15	($2,941)	7.1%	*	14.3	0.90
	2,000	Latitude	($18,204)	5.1%	*	15.7	0.70
		Latitude + 15	($18,126)	5.2%	*	15.7	0.70
	4,000	Latitude	($77,385)	1.5%	*	18.6	0.36
		Latitude + 15	($75,672)	1.7%	*	18.4	0.37
Weakley	1,000	Latitude	($13,173)	3.8%	*	17.1	0.56
		Latitude + 15	($13,415)	3.7%	*	17.2	0.55
	2,000	Latitude	($38,040)	1.6%	*	18.8	0.37
		Latitude + 15	($37,677)	1.7%	*	18.8	0.37
	4,000	Latitude	($109,954)	-2.0%	*	0.0	0.08
		Latitude + 15	($108,535)	-1.8%	*	0.0	0.10

*** represents investment that did not pay back within twenty year evaluation period.**

Figure 4.2

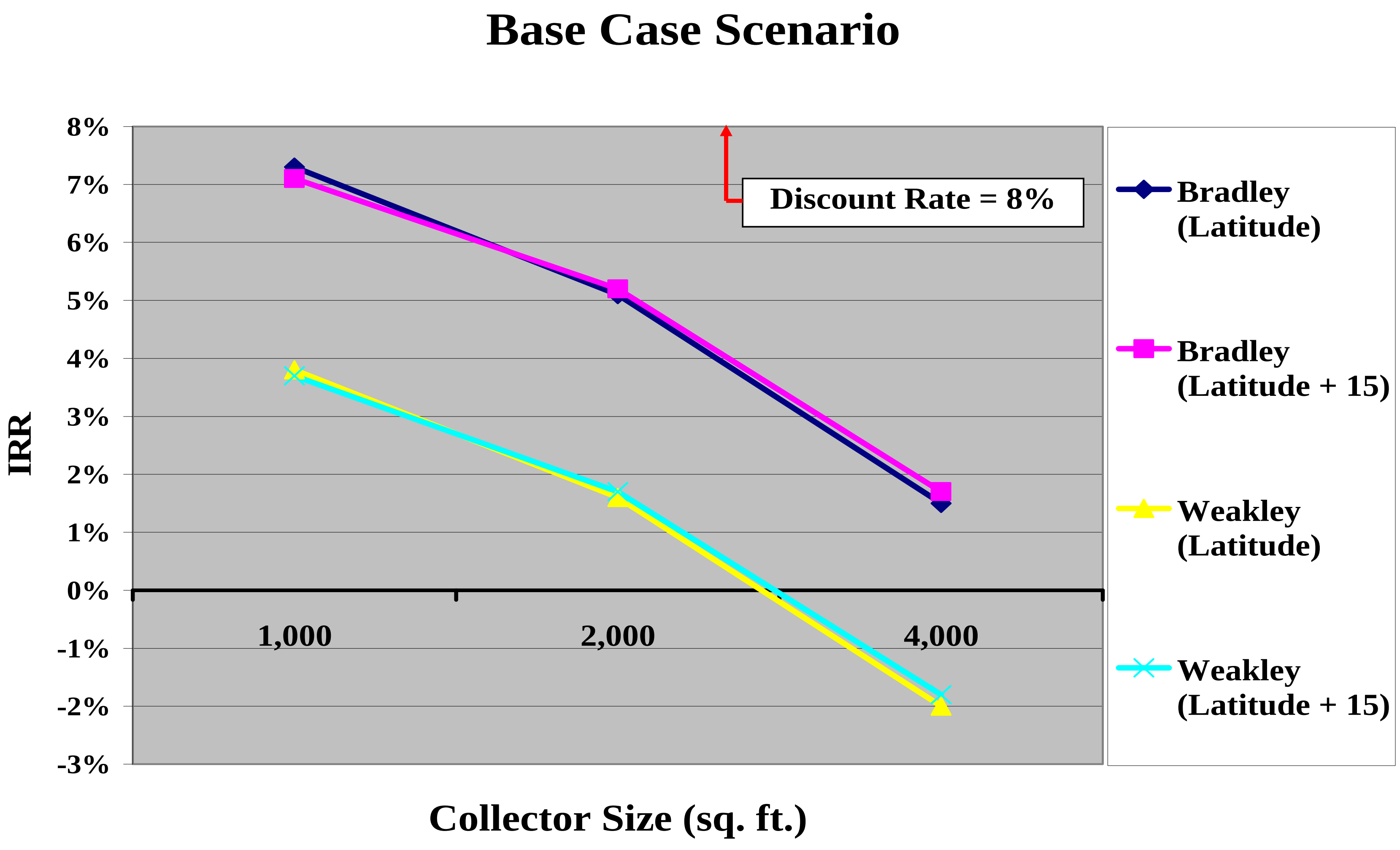

Base Case Scenario
IRR
8%
7%
6%
5%
4%
3%
2%
1%
0%
-1%
-2%
-3%
1,000
2,000
4,000
Discount Rate = 8%
Bradley (Latitude)
Bradley (Latitude + 15)
Weakley (Latitude)
Weakley (Latitude + 15)
Collector Size (sq. ft.)

Table 4.4

BASE CASE WITH SOLAR COST OF $40/FT² COLLECTOR

County	System Size (ft²)	Collector Tilt	NPV	IRR	Discounted PB (in years)	Undiscounted PB (in years)	B-C Ratio
Bradley	1,000	Latitude	($19,067)	3.3%	*	17.1	0.52
		Latitude + 15	($19,696)	3.1%	*	17.3	0.51
	2,000	Latitude	($51,752)	1.4%	*	18.6	0.35
		Latitude + 15	($51,674)	1.4%	*	18.6	0.35
	4,000	Latitude	($145,178)	-1.9%	*	*	0.09
		Latitude + 15	($143,465)	-1.8%	*	*	0.10
Weakley	1,000	Latitude	($29,965)	0.2%	*	20.0	0.25
		Latitude + 15	($30,212)	0.1%	*	20.1	0.24
	2,000	Latitude	($71,850)	-1.8%	*	*	0.10
		Latitude + 15	($71,482)	-1.7%	*	*	0.11
	4,000	Latitude	($177,747)	-5.2%	*	*	-0.11
		Latitude + 15	($176,328)	-5.0%	*	*	-0.10

*** represents investment that did not pay back within twenty year evaluation period.**

Table 4.5

BASE CASE WITH SOLAR COST OF $50/FT² COLLECTOR

County	System Size (ft²)	Collector Tilt	NPV	IRR	Discounted PB (in years)	Undiscounted PB (in years)	B-C Ratio
Bradley	1,000	Latitude	($35,899)	0.5%	*	19.6	0.28
		Latitude + 15	($36,539)	0.3%	*	19.7	0.27
	2,000	Latitude	($85,649)	-1.3%	*	*	0.14
		Latitude + 15	($85,570)	-1.3%	*	*	0.14
	4,000	Latitude	($212,972)	-4.5%	*	*	-0.06
		Latitude + 15	($211,259)	-4.3%	*	*	-0.06
Weakley	1,000	Latitude	($46,913)	-2.5%	*	*	0.06
		Latitude + 15	($47,160)	-2.5%	*	*	0.06
	2,000	Latitude	($105,747)	-4.3%	*	*	-0.06
		Latitude + 15	($105,379)	-4.3%	*	*	-0.05
	4,000	Latitude	($245,541)	-7.6%	*	*	-0.23
		Latitude + 15	($244,122)	-7.4%	*	*	-0.22

*** represents investment that did not pay back within twenty year evaluation period.**

Figure 4.3

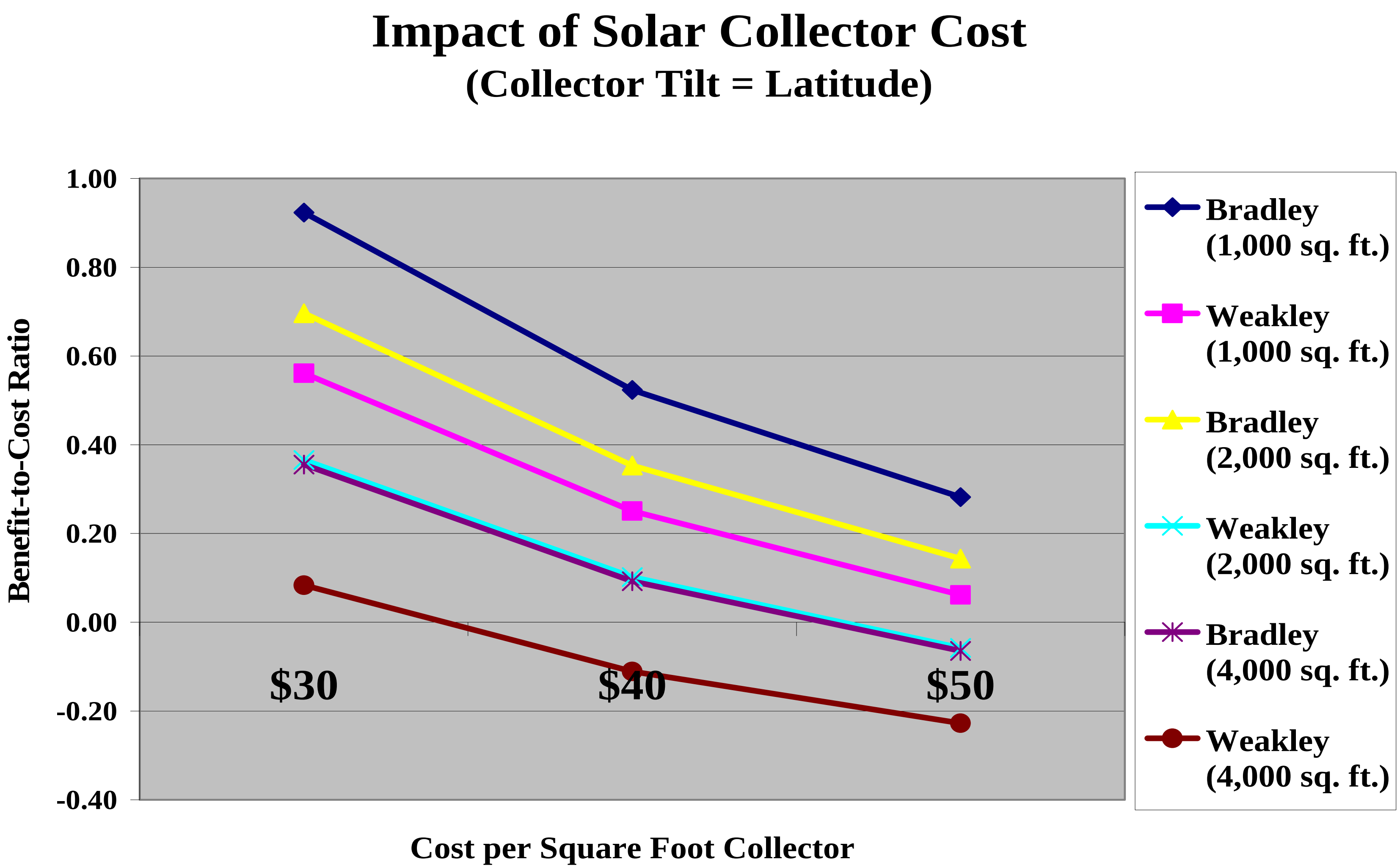

Impact of Solar Collector Cost
(Collector Tilt = Latitude)
Benefit-to-Cost Ratio
1.00
0.80
0.60
0.40
0.20
0.00
-0.20
-0.40
$30
$40
$50
Cost per Square Foot Collector
Bradley (1,000 sq. ft.)
Weakley (1,000 sq. ft.)
Bradley (2,000 sq. ft.)
Weakley (2,000 sq. ft.)
Bradley (4,000 sq. ft.)
Weakley (4,000 sq. ft.)

Table 4.6

BASE CASE WITH 5% ANNUAL PROPANE PRICE INFLATION

County	System Size (ft²)	Collector Tilt	NPV	IRR	Discounted PB (in years)	Undiscounted PB (in years)	B-C Ratio
Bradley	1,000	Latitude	($19,003)	0.0%	*	*	0.37
		Latitude + 15	($19,400)	-0.2%	*	*	0.35
	2,000	Latitude	($47,023)	-2.2%	*	*	0.22
		Latitude + 15	($46,943)	-2.2%	*	*	0.22
	4,000	Latitude	($121,483)	-6.0%	*	*	-0.01
		Latitude + 15	($120,339)	-5.8%	*	*	0.00
Weakley	1,000	Latitude	($26,157)	-3.6%	*	*	0.13
		Latitude + 15	($26,308)	-3.7%	*	*	0.12
	2,000	Latitude	($60,192)	-5.8%	*	*	0.00
		Latitude + 15	($59,941)	-5.7%	*	*	0.00
	4,000	Latitude	($142,803)	*	*	*	-0.19
		Latitude + 15	($141,879)	*	*	*	-0.18

*** represents investment that did not pay back within twenty year evaluation period.**

Table 4.7

BASE CASE WITH 7.5% ANNUAL PROPANE PRICE INFLATION

County	System Size (ft²)	Collector Tilt	NPV	IRR	Discounted PB (in years)	Undiscounted PB (in years)	B-C Ratio
Bradley	1,000	Latitude	($11,810)	3.8%	*	16.5	0.61
		Latitude + 15	($12,306)	3.6%	*	16.7	0.59
	2,000	Latitude	($34,600)	1.6%	*	18.3	0.42
		Latitude + 15	($34,519)	1.6%	*	18.3	0.42
	4,000	Latitude	($102,483)	-2.1%	*	*	0.15
		Latitude + 15	($101,092)	-1.9%	*	*	0.16
Weakley	1,000	Latitude	($20,555)	0.2%	*	19.9	0.31
		Latitude + 15	($20,743)	0.1%	*	20.0	0.31
	2,000	Latitude	($50,614)	-1.9%	*	*	0.16
		Latitude + 15	($50,313)	-1.9%	*	*	0.16
	4,000	Latitude	($128,672)	-5.6%	*	*	-0.07
		Latitude + 15	($127,535)	-5.4%	*	*	-0.06

*** represents investment that did not pay back within twenty year evaluation period.**

Table 4.8

BASE CASE WITH 12.5% ANNUAL PROPANE PRICE INFLATION

County	System Size (ft²)	Collector Tilt	NPV	IRR	Discounted PB (in years)	Undiscounted PB (in years)	B-C Ratio
Bradley	1,000	Latitude	$10,201	10.6%	17.0	12.6	1.34
		Latitude + 15	$9,408	10.4%	17.2	12.7	1.31
	2,000	Latitude	$3,620	8.5%	19.4	14.0	1.06
		Latitude + 15	$3,691	8.5%	19.4	14.0	1.06
	4,000	Latitude	($44,239)	4.8%	*	16.3	0.63
		Latitude + 15	($42,129)	5.0%	*	16.2	0.65
Weakley	1,000	Latitude	($3,335)	7.1%	*	14.8	0.89
		Latitude + 15	($3,650)	7.0%	*	14.9	0.88
	2,000	Latitude	($21,361)	4.9%	*	16.4	0.64
		Latitude + 15	($20,912)	5.0%	*	16.4	0.65
	4,000	Latitude	($84,982)	1.4%	*	19.3	0.29
		Latitude + 15	($83,187)	1.6%	*	19.1	0.31

*** represents investment that did not pay back within twenty year evaluation period.**

Table 4.9

BASE CASE WITH 15% ANNUAL PROPANE PRICE INFLATION

County	System Size (ft²)	Collector Tilt	NPV	IRR	Discounted PB (in years)	Undiscounted PB (in years)	B-C Ratio
Bradley	1,000	Latitude	$26,926	13.8%	14.5	11.4	1.90
		Latitude + 15	$25,906	13.6%	14.7	11.5	1.86
	2,000	Latitude	$32,745	11.7%	16.4	12.5	1.55
		Latitude + 15	$32,796	11.7%	16.4	12.5	1.55
	4,000	Latitude	$63	8.0%	20.0	14.6	1.00
		Latitude + 15	$2,731	8.2%	19.8	14.5	1.02
Weakley	1,000	Latitude	$9,851	10.3%	17.6	13.5	1.33
		Latitude + 15	$9,438	10.2%	17.7	13.5	1.31
	2,000	Latitude	$1,020	8.1%	20.0	14.5	1.02
		Latitude + 15	$1,585	8.2%	19.9	14.5	1.03
	4,000	Latitude	($51,512)	4.6%	*	17.3	0.57
		Latitude + 15	($49,237)	4.8%	*	17.1	0.59

*** represents investment that did not pay back within twenty year evaluation period.**

Figure 4.4

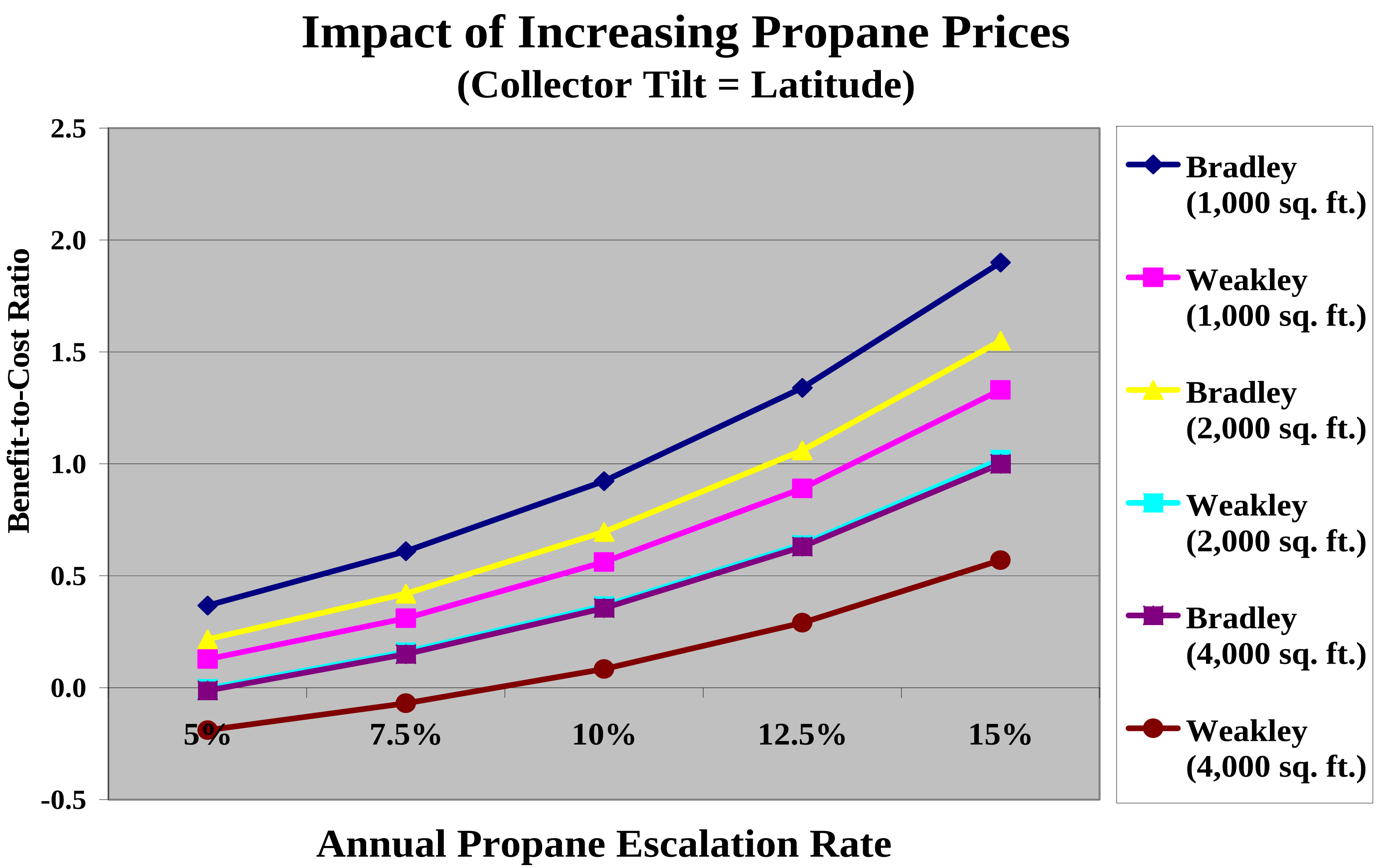

Impact of Increasing Propane Prices
(Collector Tilt = Latitude)
Benefit-to-Cost Ratio
2.5
2.0
1.5
1.0
0.5
0.0
-0.5
5%
7.5%
10%
12.5%
15%
Annual Propane Escalation Rate
Bradley (1,000 sq. ft.)
Weakley (1,000 sq. ft.)
Bradley (2,000 sq. ft.)
Weakley (2,000 sq. ft.)
Bradley (4,000 sq. ft.)
Weakley (4,000 sq. ft.)

Table 4.10

BASE CASE WITH 25% USDA RENEWABLE ENERGY GRANT

County	System Size (ft^2)	Collector Tilt	NPV	IRR	Discounted PB (in years)	Undiscounted PB (in years)	B-C Ratio
Bradley	1,000	Latitude	$9,242	11.5%	15.7	11.7	1.41
		Latitude + 15	$8,626	11.3%	15.9	11.8	1.38
	2,000	Latitude	$4,976	9.0%	18.6	13.2	1.11
		Latitude + 15	$5,054	9.0%	18.5	13.2	1.11
	4,000	Latitude	($30,943)	4.8%	*	16.0	0.66
		Latitude + 15	($29,253)	5.0%	*	15.9	0.67
Weakley	1,000	Latitude	($1,583)	7.4%	*	14.2	0.93
		Latitude + 15	($1,825)	7.3%	*	14.3	0.92
	2,000	Latitude	($14,860)	4.9%	*	16.1	0.67
		Latitude + 15	($14,497)	5.0%	*	16.0	0.68
	4,000	Latitude	($63,447)	0.9%	*	19.3	0.30
		Latitude + 15	($62,028)	1.1%	*	19.2	0.31

*** represents investment that did not pay back within twenty year evaluation period.**

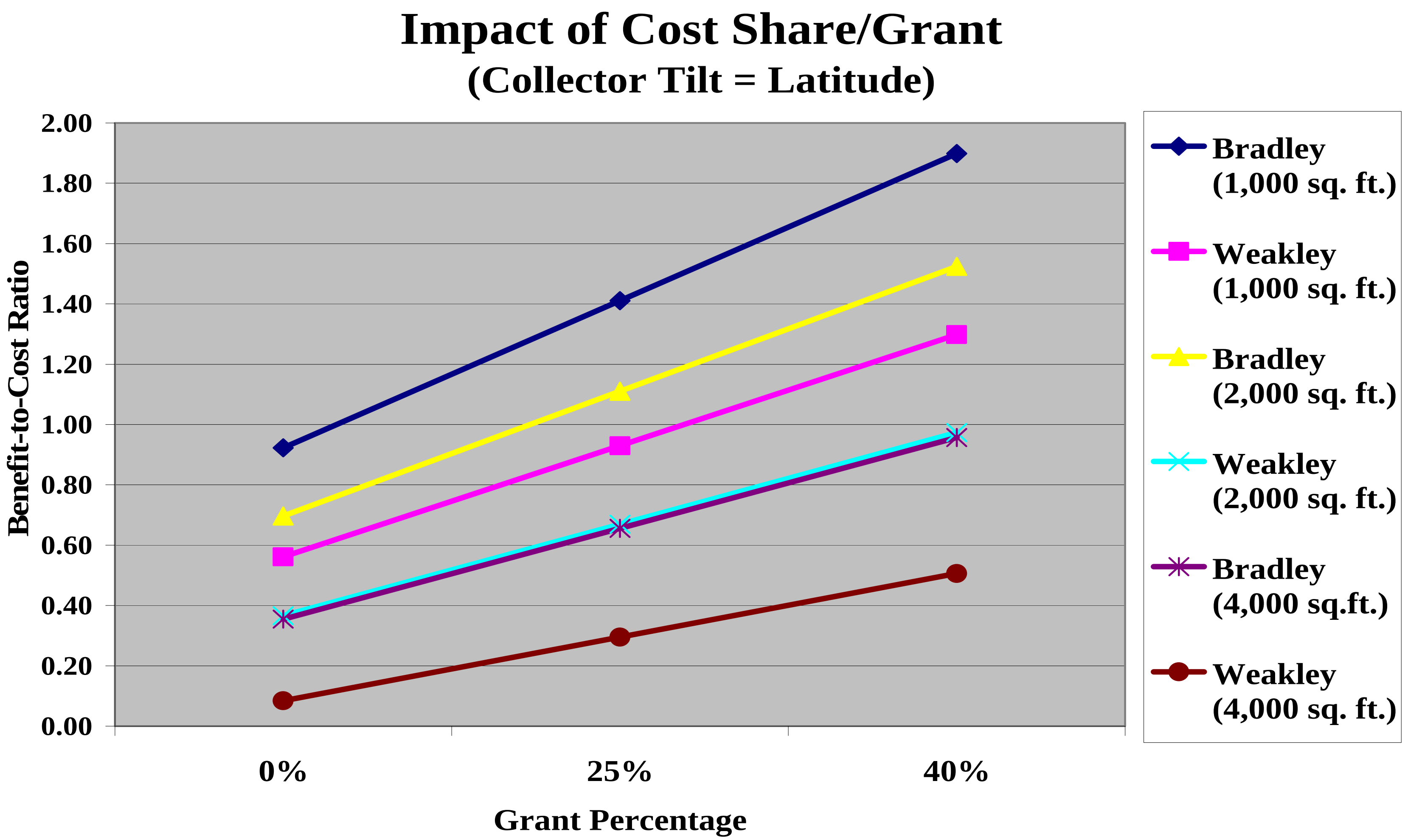
Table 4.11

BASE CASE WITH 40% TENNESSEE CLEAN ENERGY TECHNOLOGY GRANT

County	System Size (ft²)	Collector Tilt	NPV	IRR	Discounted PB (in years)	Undiscounted PB (in years)	B-C Ratio
Bradley	1,000	Latitude	$16,174	15.4%	12.4	10.1	1.90
		Latitude + 15	$15,559	15.1%	12.6	10.2	1.86
	2,000	Latitude	$18,884	12.4%	14.9	11.3	1.52
		Latitude + 15	$18,962	12.4%	14.9	11.2	1.53
	4,000	Latitude	($3,127)	7.6%	*	14.1	0.96
		Latitude + 15	($1,437)	7.8%	*	14.2	0.98
Weakley	1,000	Latitude	$5,371	10.6%	17.0	12.2	1.30
		Latitude + 15	$5,129	10.4%	17.2	12.2	1.28
	2,000	Latitude	($952)	7.8%	*	14.0	0.97
		Latitude + 15	($590)	7.9%	*	14.6	0.98
	4,000	Latitude	($35,542)	3.3%	*	17.2	0.51
		Latitude + 15	($34,123)	3.5%	*	17.1	0.53

*** represents investment that did not pay back within twenty year evaluation period.**

Figure 4.5



Impact of Cost Share/Grant
(Collector Tilt = Latitude)
Benefit-to-Cost Ratio
2.00
1.80
1.60
1.40
1.20
1.00
0.80
0.60
0.40
0.20
0.00
0%
25%
40%
Grant Percentage
Bradley (1,000 sq. ft.)
Weakley (1,000 sq. ft.)
Bradley (2,000 sq. ft.)
Weakley (2,000 sq. ft.)
Bradley (4,000 sq.ft.)
Weakley (4,000 sq. ft.)

Table 4.12

BASE CASE WITH 6% DISCOUNT RATE

County	System Size (ft²)	Collector Tilt	NPV	IRR	Discounted PB (in years)	Undiscounted PB (in years)	B-C Ratio
Bradley	1,000	Latitude	$4,983	7.3%	18.3	14.2	1.17
		Latitude + 15	$4,212	7.1%	18.6	14.3	1.14
	2,000	Latitude	($6,392)	5.1%	*	15.7	0.89
		Latitude + 15	($6,320)	5.2%	*	15.7	0.89
	4,000	Latitude	($62,338)	1.5%	*	18.6	0.48
		Latitude + 15	($60,282)	1.7%	*	18.4	0.50
Weakley	1,000	Latitude	($8,137)	3.8%	*	17.1	0.73
		Latitude + 15	($8,438)	3.7%	*	17.2	0.72
	2,000	Latitude	($30,394)	1.6%	*	18.8	0.49
		Latitude + 15	($29,961)	1.7%	*	18.8	0.50
	4,000	Latitude	($101,722)	-2.0%	*	*	0.15
		Latitude + 15	($99,999)	-1.8%	*	*	0.17

*** represents investment that did not pay back within twenty year evaluation period.**

Table 4.13

BASE CASE WITH 10% DISCOUNT RATE

County	System Size (ft²)	Collector Tilt	NPV	IRR	Discounted PB (in years)	Undiscounted PB (in years)	B-C Ratio
Bradley	1,000	Latitude	($7,656)	7.3%	*	14.2	0.74
		Latitude + 15	($8,175)	7.1%	*	14.3	0.73
	2,000	Latitude	($26,755)	5.1%	*	15.7	0.55
		Latitude + 15	($26,674)	5.2%	*	15.7	0.56
	4,000	Latitude	($87,920)	1.5%	*	18.6	0.27
		Latitude + 15	($86,471)	1.7%	*	18.4	0.28
Weakley	1,000	Latitude	($16,778)	3.8%	*	17.1	0.44
		Latitude + 15	($16,976)	3.7%	*	17.2	0.43
	2,000	Latitude	($43,391)	1.6%	*	18.8	0.28
		Latitude + 15	($43,082)	1.7%	*	18.8	0.28
	4,000	Latitude	($115,249)	-2.0%	*	*	0.04
		Latitude + 15	($114,062)	-1.8%	*	*	0.05

*** represents investment that did not pay back within twenty year evaluation period.**

Figure 4.6

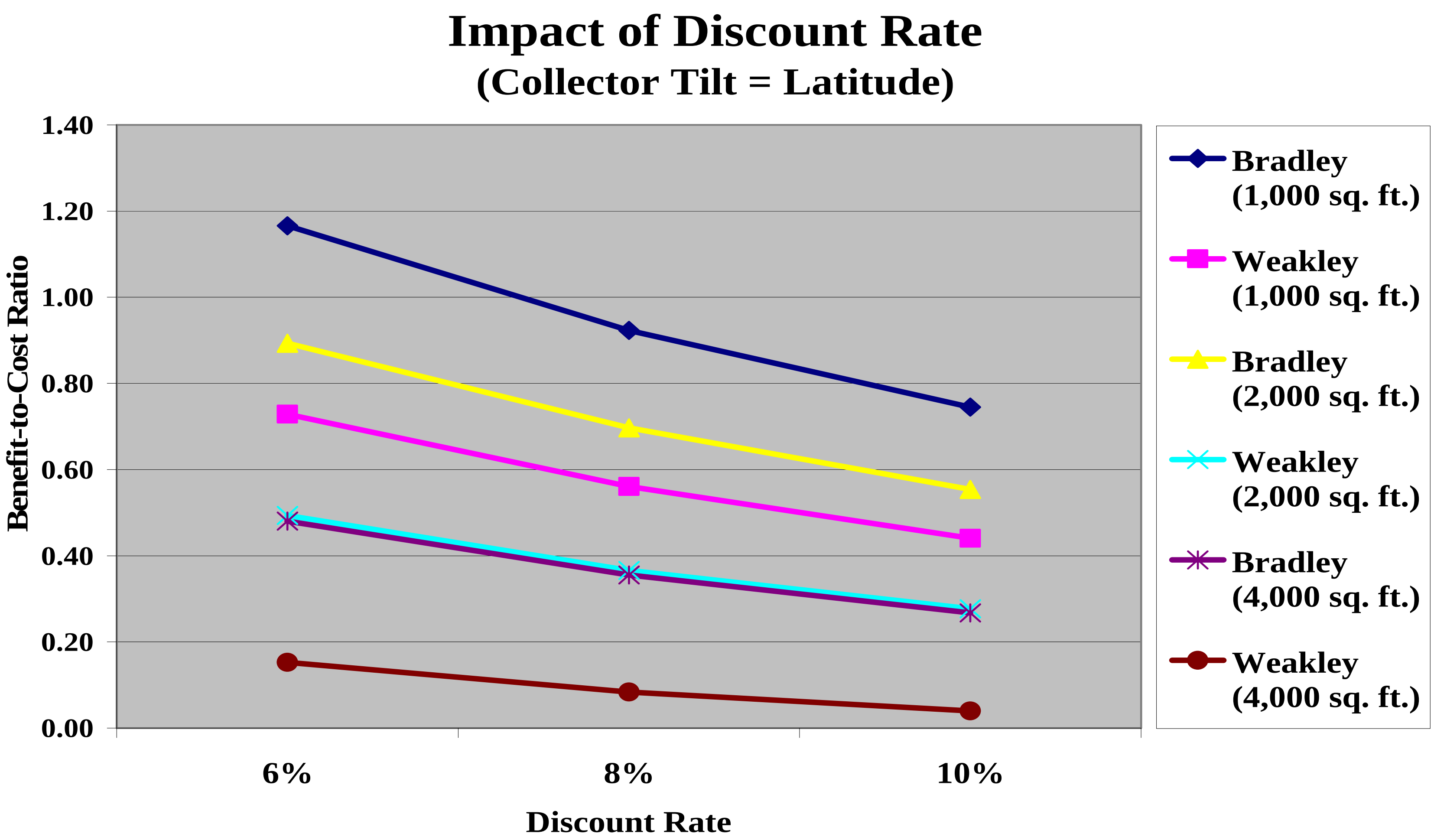

Impact of Discount Rate
(Collector Tilt = Latitude)
1.40
1.20
1.00
0.80
0.60
0.40
0.20
0.00
Benefit-to-Cost Ratio
6%
8%
10%
Discount Rate
Bradley (1,000 sq. ft.)
Weakley (1,000 sq. ft.)
Bradley (2,000 sq. ft.)
Weakley (2,000 sq. ft.)
Bradley (4,000 sq. ft.)
Weakley (4,000 sq. ft.)

Table 4.14

BASE CASE WITH 28% TAX RATE

County	System Size (ft²)	Collector Tilt	NPV	IRR	Discounted PB (in years)	Undiscounted PB (in years)	B-C Ratio
Bradley	1,000	Latitude	($1,067)	7.7%	*	14.1	0.96
		Latitude + 15	($1,714)	7.5%	*	14.1	0.94
	2,000	Latitude	($16,103)	5.5%	*	15.4	0.73
		Latitude + 15	($16,025)	5.5%	*	15.4	0.73
	4,000	Latitude	($74,383)	1.8%	*	18.3	0.38
		Latitude + 15	($72,624)	2.0%	*	18.1	0.39
Weakley	1,000	Latitude	($12,242)	4.1%	*	16.7	0.59
		Latitude + 15	($12,493)	4.0%	*	16.8	0.58
	2,000	Latitude	($36,525)	2.0%	*	18.5	0.39
		Latitude + 15	($36,152)	2.0%	*	18.4	0.40
	4,000	Latitude	($107,864)	-1.6%	*	*	0.10
		Latitude + 15	($106,404)	-1.4%	*	*	0.11

*** represents investment that did not pay back within twenty year evaluation period.**

Table 4.15

BASE CASE WITH 34% TAX RATE

County	System Size (ft^2)	Collector Tilt	NPV	IRR	Discounted PB (in years)	Undiscounted PB (in years)	B-C Ratio
Bradley	1,000	Latitude	($3,560)	6.9%	*	14.5	0.88
		Latitude + 15	($4,168)	6.7%	*	14.6	0.86
	2,000	Latitude	($20,304)	4.8%	*	16.0	0.66
		Latitude + 15	($20,226)	4.8%	*	16.0	0.66
	4,000	Latitude	($80,386)	1.1%	*	18.9	0.33
		Latitude + 15	($78,720)	1.3%	*	18.7	0.34
Weakley	1,000	Latitude	($14,104)	3.4%	*	17.1	0.53
		Latitude + 15	($14,337)	3.3%	*	17.2	0.52
	2,000	Latitude	($39,555)	1.3%	*	19.2	0.34
		Latitude + 15	($39,202)	1.3%	*	19.2	0.35
	4,000	Latitude	($112,044)	-2.3%	*	*	0.07
		Latitude + 15	($110,666)	-2.1%	*	*	0.08

*** represents investment that did not pay back within twenty year evaluation period.**

Figure 4.7

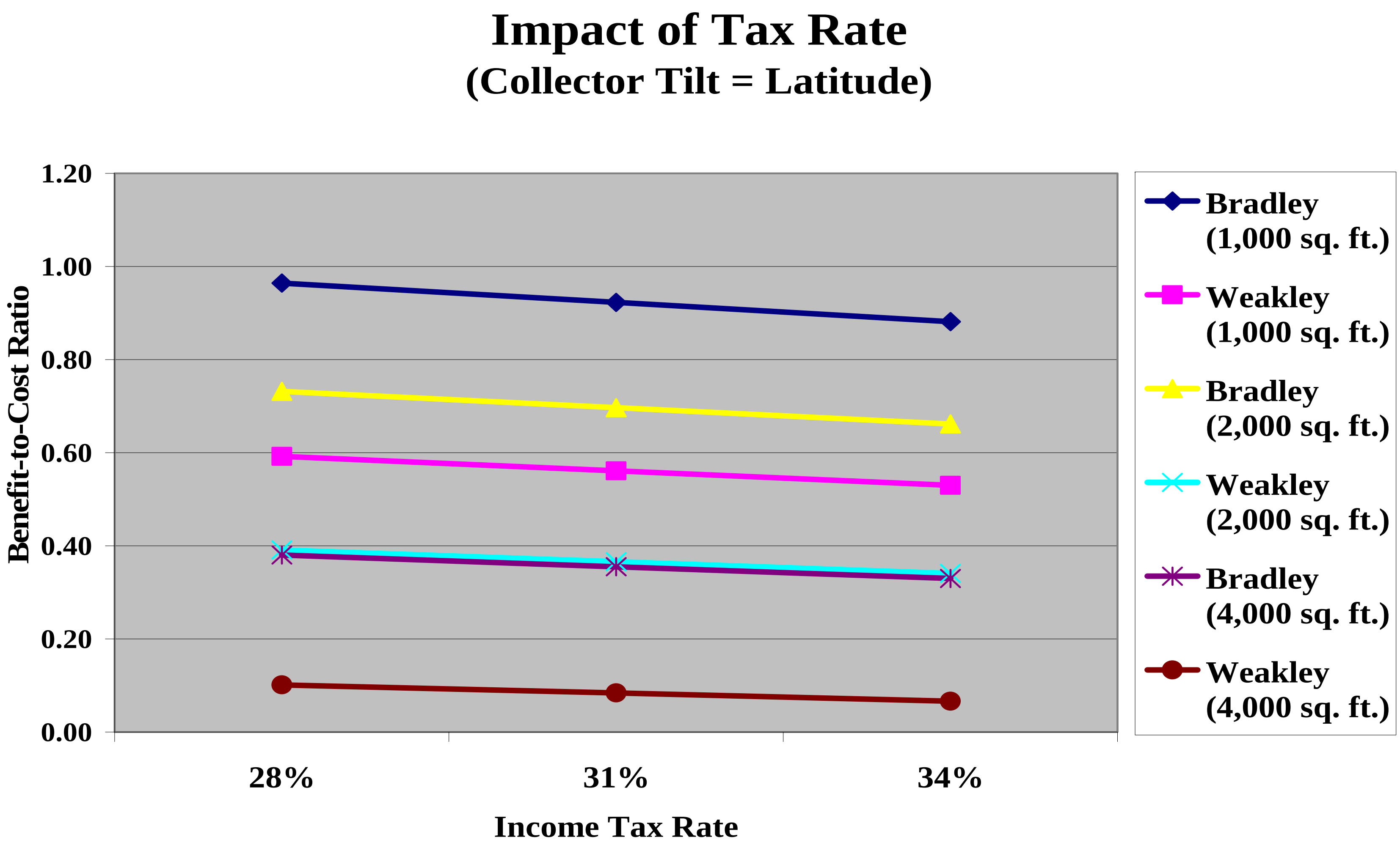

Impact of Tax Rate
(Collector Tilt = Latitude)
1.20
1.00
0.80
0.60
0.40
0.20
0.00
Benefit-to-Cost Ratio
28%
31%
34%
Income Tax Rate
Bradley (1,000 sq. ft.)
Weakley (1,000 sq. ft.)
Bradley (2,000 sq. ft.)
Weakley (2,000 sq. ft.)
Bradley (4,000 sq. ft.)
Weakley (4,000 sq. ft.)

Table 4.16

BASE CASE WITH 0.5% ANNUAL INSURANCE RATE[1]

County	System Size (ft²)	Collector Tilt	NPV	IRR	Discounted PB (in years)	Undiscounted PB (in years)	B-C Ratio
Bradley	1,000	Latitude	($1,546)	7.5%	*	14.0	0.95
		Latitude + 15	($2,162)	7.3%	*	14.1	0.93
	2,000	Latitude	($16,633)	5.4%	*	15.5	0.72
		Latitude + 15	($16,554)	5.4%	*	15.5	0.72
	4,000	Latitude	($74,171)	1.8%	*	18.3	0.38
		Latitude + 15	($72,471)	1.9%	*	18.2	0.40
Weakley	1,000	Latitude	($12,387)	4.0%	*	16.8	0.59
		Latitude + 15	($12,629)	3.9%	*	16.9	0.58
	2,000	Latitude	($36,469)	1.9%	*	18.5	0.39
		Latitude + 15	($36,106)	2.0%	*	18.5	0.40
	4,000	Latitude	($106,740)	-1.6%	*	*	0.11
		Latitude + 15	($105,321)	-1.5%	*	*	0.12

[1] The annual insurance rate was applied to the total system cost.
*** represents investment that did not pay back within twenty year evaluation period.**

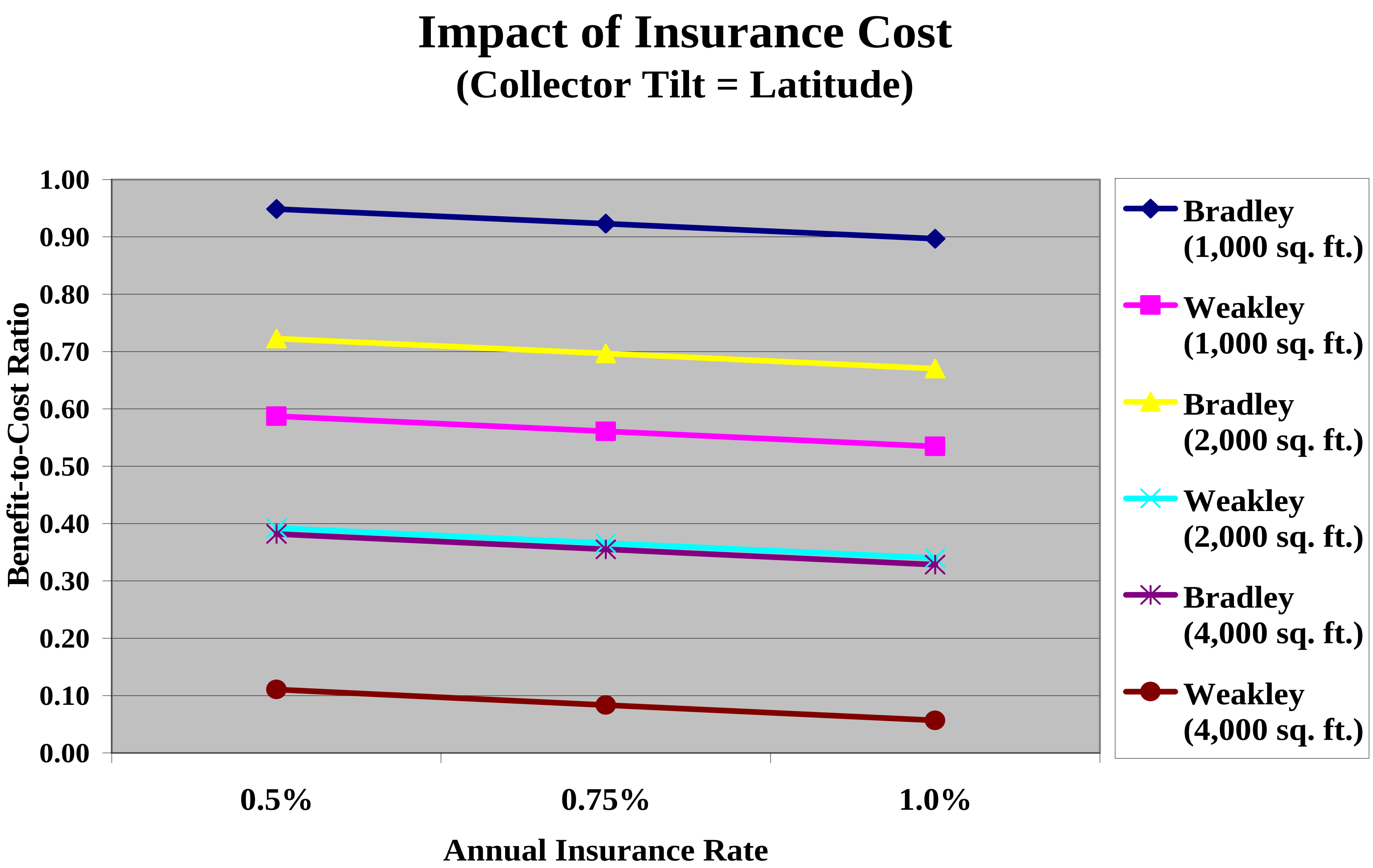
Table 4.17

BASE CASE WITH 1.0% ANNUAL INSURANCE RATE[1]

County	System Size (ft^2)	Collector Tilt	NPV	IRR	Discounted PB (in years)	Undiscounted PB (in years)	B-C Ratio
Bradley	1,000	Latitude	($3,098)	7.1%	*	14.4	0.90
		Latitude + 15	($3,727)	6.9%	*	14.5	0.88
	2,000	Latitude	($19,775)	4.9%	*	15.9	0.67
		Latitude + 15	($19,697)	4.9%	*	15.9	0.67
	4,000	Latitude	($80,598)	1.2%	*	18.8	0.33
		Latitude + 15	($78,885)	1.4%	*	18.7	0.34
Weakley	1,000	Latitude	($13,958)	3.5%	*	17.0	0.53
		Latitude + 15	($14,200)	3.4%	*	17.1	0.53
	2,000	Latitude	($39,611)	1.3%	*	19.2	0.34
		Latitude + 15	($39,248)	1.4%	*	19.1	0.35
	4,000	Latitude	($113,167)	-2.3%	*	*	0.06
		Latitude + 15	($111,748)	-2.1%	*	*	0.07

[1] The annual insurance rate was applied to the total system cost.
*** represents investment that did not pay back within twenty year evaluation period.**

Figure 4.8



Impact of Insurance Cost
(Collector Tilt = Latitude)
Benefit-to-Cost Ratio
1.00
0.90
0.80
0.70
0.60
0.50
0.40
0.30
0.20
0.10
0.00
0.5%
0.75%
1.0%
Annual Insurance Rate
Bradley (1,000 sq. ft.)
Weakley (1,000 sq. ft.)
Bradley (2,000 sq. ft.)
Weakley (2,000 sq. ft.)
Bradley (4,000 sq. ft.)
Weakley (4,000 sq. ft.)

Table 4.18

BASE CASE WITH 0.4% ANNUAL MAINTENANCE COST[1]

County	System Size (ft²)	Collector Tilt	NPV	IRR	Discounted PB (in years)	Undiscounted PB (in years)	B-C Ratio
Bradley	1,000	Latitude	($1,700)	7.5%	*	14.1	0.94
		Latitude + 15	($2,316)	7.3%	*	14.2	0.92
	2,000	Latitude	($16,947)	5.3%	*	15.5	0.72
		Latitude + 15	($16,869)	5.3%	*	15.5	0.72
	4,000	Latitude	($74,814)	1.7%	*	18.4	0.38
		Latitude + 15	($73,101)	1.9%	*	18.2	0.39
Weakley	1,000	Latitude	($12,544)	4.0%	*	16.9	0.58
		Latitude + 15	($12,786)	3.9%	*	17.0	0.57
	2,000	Latitude	($36,783)	1.8%	*	18.6	0.39
		Latitude + 15	($36,420)	1.9%	*	18.5	0.39
	4,000	Latitude	($107,383)	-1.7%	*	*	0.11
		Latitude + 15	($105,964)	-1.5%	*	*	0.12

[1] The annual maintenance cost rate was applied to the total system cost.
*** represents investment that did not pay back within twenty year evaluation period.**

Table 4.19

BASE CASE WITH 0.8% ANNUAL MAINTENANCE COST[1]

County	System Size (ft^2)	Collector Tilt	NPV	IRR	Discounted PB (in years)	Undiscounted PB (in years)	B-C Ratio
Bradley	1,000	Latitude	($2,941)	7.1%	*	14.3	0.90
		Latitude + 15	($3,569)	6.9%	*	14.5	0.88
	2,000	Latitude	($19,461)	4.9%	*	15.9	0.68
		Latitude + 15	($19,382)	5.0%	*	15.9	0.68
	4,000	Latitude	($79,955)	1.3%	*	18.8	0.33
		Latitude + 15	($78,243)	1.4%	*	18.6	0.35
Weakley	1,000	Latitude	($13,801)	3.5%	*	17.3	0.54
		Latitude + 15	($14,043)	3.5%	*	17.0	0.53
	2,000	Latitude	($39,297)	1.4%	*	19.1	0.35
		Latitude + 15	($38,934)	1.5%	*	19.1	0.35
	4,000	Latitude	($112,524)	-2.2%	*	*	0.06
		Latitude + 15	($111,105)	-2.1%	*	*	0.07

[1] The annual maintenance cost rate was applied to the total system cost.
*** represents investment that did not pay back within twenty year evaluation period.**

Figure 4.9

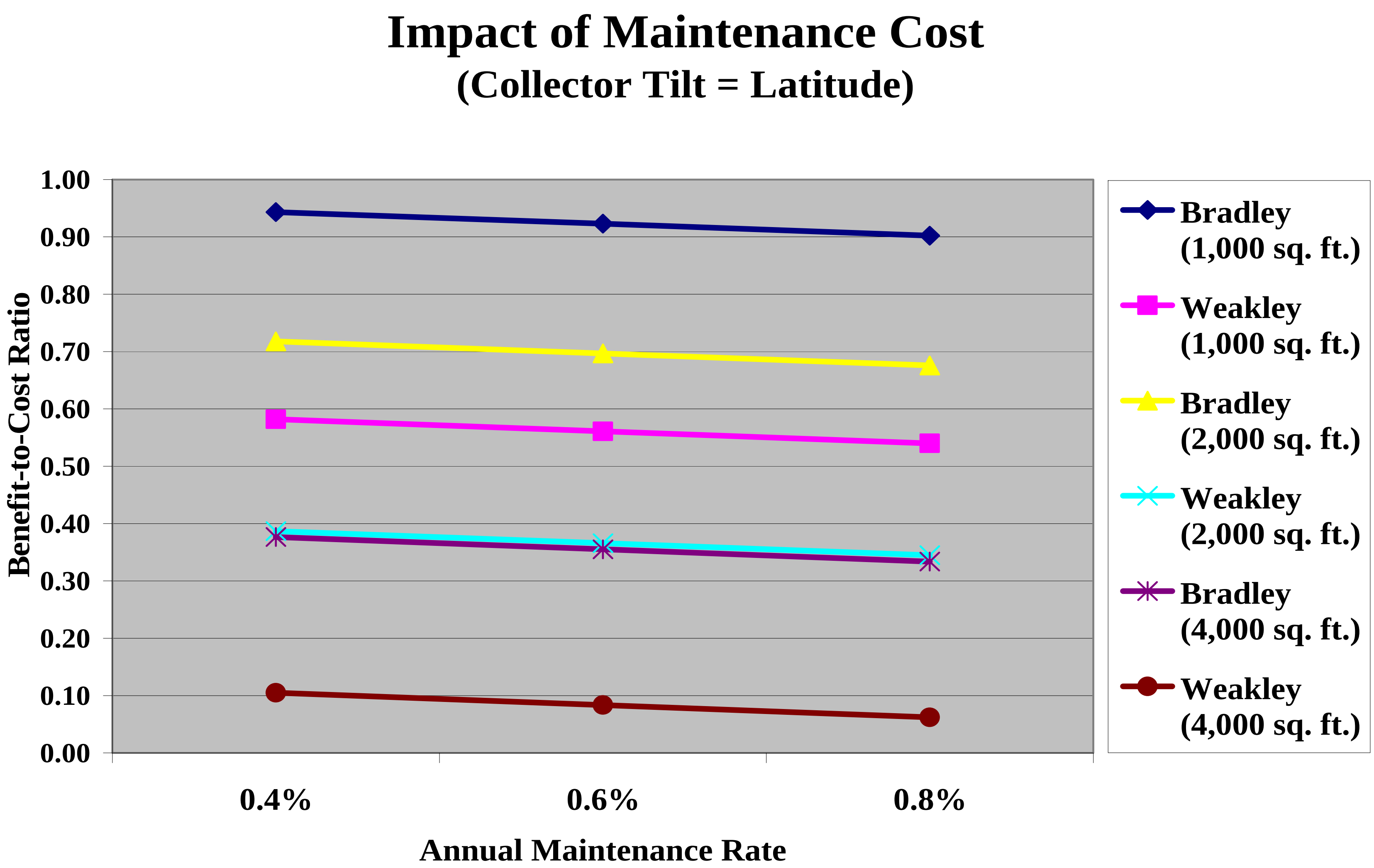

Impact of Maintenance Cost
(Collector Tilt = Latitude)
Benefit-to-Cost Ratio
1.00
0.90
0.80
0.70
0.60
0.50
0.40
0.30
0.20
0.10
0.00
0.4%
0.6%
0.8%
Annual Maintenance Rate
Bradley (1,000 sq. ft.)
Weakley (1,000 sq. ft.)
Bradley (2,000 sq. ft.)
Weakley (2,000 sq. ft.)
Bradley (4,000 sq. ft.)
Weakley (4,000 sq. ft.)

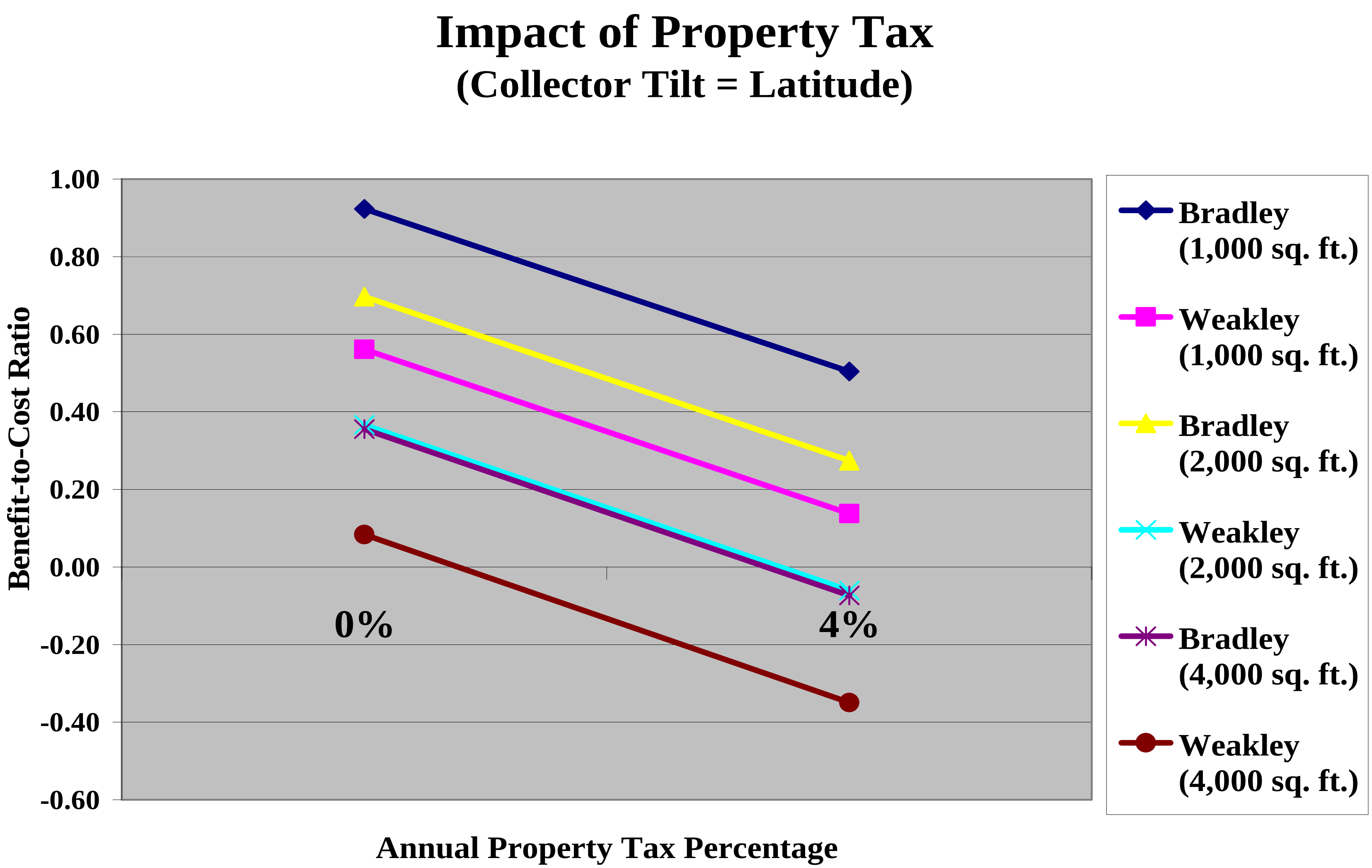
Table 4.20

BASE CASE WITH 4% ANNUAL PROPERTY TAX[1]

County	System Size (ft^2)	Collector Tilt	NPV	IRR	Discounted PB (in years)	Undiscounted PB (in years)	B-C Ratio
Bradley	1,000	Latitude	($14,881)	3.4%	*	17.2	0.50
		Latitude + 15	($15,509)	3.2%	*	17.4	0.48
	2,000	Latitude	($43,562)	1.0%	*	19.1	0.27
		Latitude + 15	($43,484)	1.0%	*	19.1	0.28
	4,000	Latitude	($128,798)	-3.4%	*	*	-0.07
		Latitude + 15	($127,086)	-3.2%	*	*	-0.06
Weakley	1,000	Latitude	($25,870)	-0.6%	*	*	0.14
		Latitude + 15	($26,117)	-0.7%	*	*	0.13
	2,000	Latitude	($63,660)	-3.2%	*	*	-0.06
		Latitude + 15	($63,292)	-3.1%	*	*	-0.05
	4,000	Latitude	($161,936)	-8.0%	*	*	-0.35
		Latitude + 15	($160,462)	-7.7%	*	*	-0.34

[1] The annual property tax rate was applied to the total system cost.
*** represents investment that did not pay back within twenty year evaluation period.**

Figure 4.10



Impact of Property Tax
(Collector Tilt = Latitude)
1.00
0.80
0.60
0.40
0.20
0.00
-0.20
-0.40
-0.60
Benefit-to-Cost Ratio
0%
4%
Annual Property Tax Percentage
Bradley (1,000 sq. ft.)
Weakley (1,000 sq. ft.)
Bradley (2,000 sq. ft.)
Weakley (2,000 sq. ft.)
Bradley (4,000 sq. ft.)
Weakley (4,000 sq. ft.)

Table 4.21

BASE CASE WITH 5% MORTGAGE INTEREST RATE

County	System Size (ft^2)	Collector Tilt	NPV	IRR	Discounted PB (in years)	Undiscounted PB (in years)	B-C Ratio
Bradley	1,000	Latitude	($782)	7.8%	*	14.0	0.97
		Latitude + 15	($1,398)	7.6%	*	14.1	0.95
	2,000	Latitude	($15,016)	5.6%	*	15.3	0.75
		Latitude + 15	($14,938)	5.6%	*	15.3	0.75
	4,000	Latitude	($70,928)	1.9%	*	18.2	0.41
		Latitude + 15	($69,238)	2.1%	*	18.0	0.42
Weakley	1,000	Latitude	($11,579)	4.2%	*	16.6	0.61
		Latitude + 15	($11,821)	4.1%	*	16.7	0.61
	2,000	Latitude	($34,852)	2.1%	*	18.4	0.42
		Latitude + 15	($34,490)	2.1%	*	18.3	0.43
	4,000	Latitude	($103,378)	-1.5%	*	*	0.14
		Latitude + 15	($101,958)	-1.4%	*	*	0.15

*** represents investment that did not pay back within twenty year evaluation period.**

Table 4.22

BASE CASE WITH 8% MORTGAGE INTEREST RATE

County	System Size (ft²)	Collector Tilt	NPV	IRR	Discounted PB (in years)	Undiscounted PB (in years)	B-C Ratio
Bradley	1,000	Latitude	($3,955)	6.8%	*	14.6	0.87
		Latitude + 15	($4,584)	6.6%	*	14.7	0.85
	2,000	Latitude	($21,490)	4.7%	*	16.1	0.64
		Latitude + 15	($21,412)	4.7%	*	16.1	0.64
	4,000	Latitude	($84,168)	1.0%	*	19.0	0.30
		Latitude + 15	($82,455)	1.2%	*	18.8	0.31
Weakley	1,000	Latitude	($14,816)	3.3%	*	17.2	0.51
		Latitude + 15	($15,058)	3.2%	*	17.2	0.50
	2,000	Latitude	($41,345)	1.2%	*	19.0	0.31
		Latitude + 15	($40,977)	1.3%	*	19.3	0.32
	4,000	Latitude	($116,737)	-2.4%	*	*	0.03
		Latitude + 15	($115,318)	-2.2%	*	*	0.04

*** represents investment that did not pay back within twenty year evaluation period.**

Figure 4.11

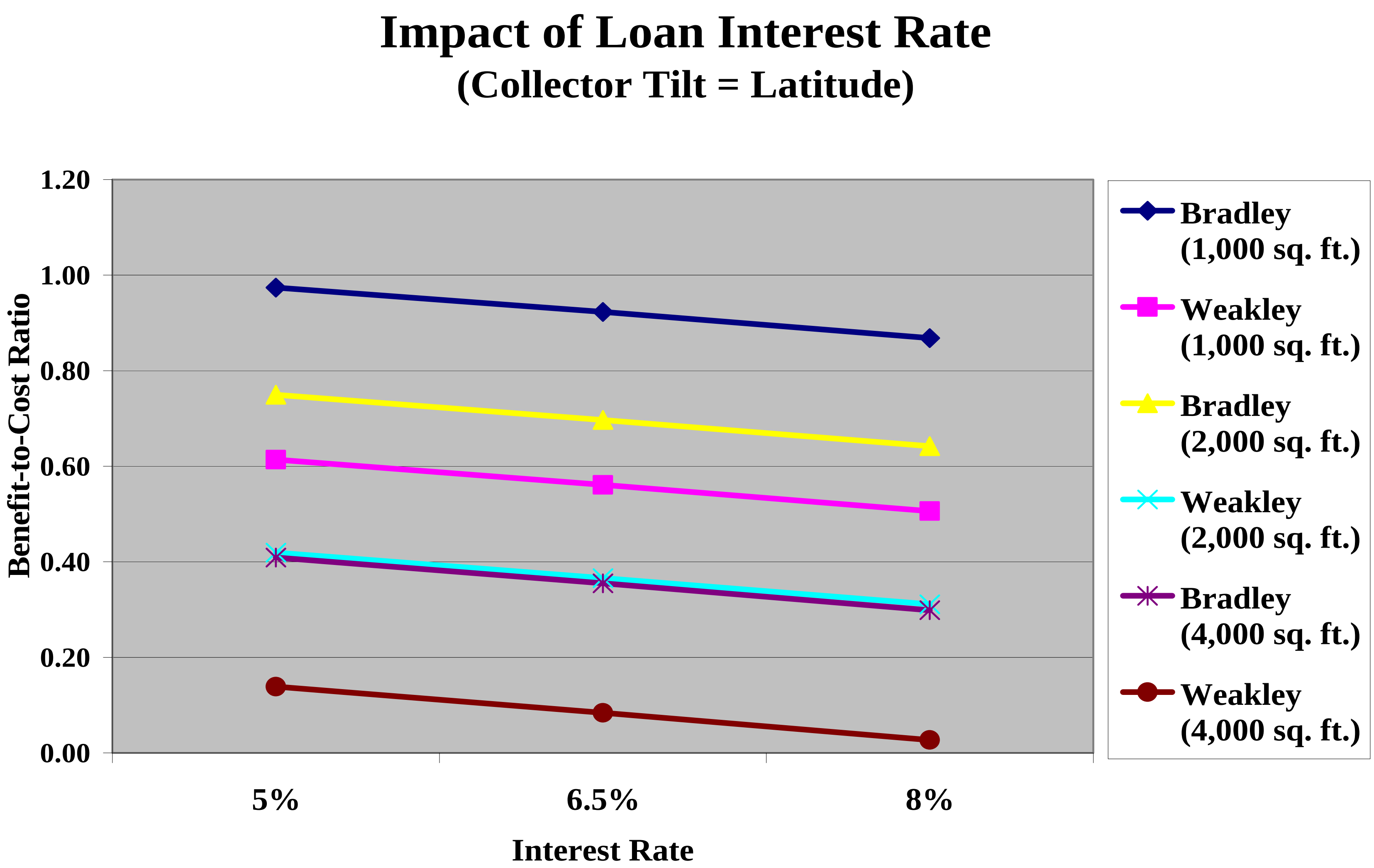

Impact of Loan Interest Rate
(Collector Tilt = Latitude)
1.20
1.00
0.80
0.60
0.40
0.20
0.00
Benefit-to-Cost Ratio
5%
6.5%
8%
Interest Rate
Bradley (1,000 sq. ft.)
Weakley (1,000 sq. ft.)
Bradley (2,000 sq. ft.)
Weakley (2,000 sq. ft.)
Bradley (4,000 sq. ft.)
Weakley (4,000 sq. ft.)

Table 4.23

BASE CASE CASH FLOW EXAMPLE (BRADLEY, 1,000 FT², LATITUDE)

Year	Initial Cash Outlay	Net Income [A]	Depreciation[B]	Total Loan Payment	Interest	Principle	Remaining Balance	Taxable Income	Taxes	ANCF	PV Factor	PV of ANCF
0	$3,000						$27,000				1.0000	
1		$3,289.73	$5,100	$3,756	$1,755	$2,001	$24,999	$0.00	$0.00	$8,129	0.9259	$7,527
2		$3,393.18	$8,160	$3,756	$1,625	$2,131	$22,868	$0.00	$0.00	-$784	0.8573	-$672
3		$3,529.40	$4,896	$3,756	$1,486	$2,269	$20,599	$0.00	$0.00	-$664	0.7938	-$527
4		$4,102.97	$2,938	$3,756	$1,339	$2,417	$18,182	$0.00	$0.00	-$108	0.7350	-$80
5		$4,597.72	$2,938	$3,756	$1,182	$2,574	$15,608	$4.49	$1.39	$367	0.6806	$250
6		$4,565.22	$1,469	$3,756	$1,015	$2,741	$12,867	$1,589.15	$492.64	-$176	0.6302	-$111
7		$5,133.71		$3,756	$836	$2,919	$9,947	$3,784.92	$1,173.32	-$308	0.5835	-$180
8		$6,049.49		$3,756	$647	$3,109	$6,838	$4,869.97	$1,509.69	$251	0.5403	$136
9		$5,967.63		$3,756	$444	$3,311	$3,527	$4,968.89	$1,540.36	$117	0.5002	$59
10		$6,443.16		$3,756	$229	$3,527	$0	$5,637.49	$1,747.62	$363	0.4632	$168
11		$7,774.02						$7,174.52	$2,224.10	$4,950	0.4289	$2,123
12		$8,052.85						$7,429.37	$2,303.10	$5,126	0.3971	$2,036
13		$8,361.24						$7,712.82	$2,390.97	$5,322	0.3677	$1,957
14		$9,670.93						$8,996.57	$2,788.94	$6,208	0.3405	$2,113
15		$10,849.79						$10,148.46	$3,146.02	$7,002	0.3152	$2,207
16		$10,783.99						$10,054.61	$3,116.93	$6,938	0.2919	$2,025
17		$12,079.04						$11,320.48	$3,509.35	$7,811	0.2703	$2,111
18		$14,188.16						$13,399.26	$4,153.77	$9,245	0.2502	$2,314
19		$14,054.03						$13,233.57	$4,102.41	$9,131	0.2317	$2,116
20		$15,142.12						$14,288.84	$4,429.54	$9,859	0.2145	$2,115

A- Net Income equals Reduced Propane Expense minus Maintenance and Insurance Costs. B- Estimated using Modified Accelerated Cost Recovery System.

Table 4.24

REDUCED ENVIRONMENTAL EMISSIONS FROM SOLAR ADOPTION

County	Collector Size	Collector Tilt	Displaced Propane over 20 years (in gallons)	Reduced Emissions (lbs)	
				CO_2	NO_x
Bradley	1,000	Latitude	29,458	368,225	412
		Latitude + 15	29,072	363,400	407
	2,000	Latitude	50,595	632,438	708
		Latitude + 15	50,642	633,025	709
	4,000	Latitude	76,082	951,025	1,065
		Latitude + 15	77,119	963,988	1,080
Weakley	1,000	Latitude	22,815	285,188	319
		Latitude + 15	22,661	283,263	317
	2,000	Latitude	38,430	480,375	538
		Latitude + 15	38,651	483,138	541
	4,000	Latitude	56,358	704,475	789
		Latitude + 15	57,218	715,225	801

Source: Leonardo Academy, Inc. (2007). "Emissions Factors and Energy Prices for Leonardo Academy's Cleaner and Greener Program". Emissions factors for propane include 12.5 pounds of carbon dioxide and 0.014 pounds of nitrogen oxides per gallon of propane.

VITA

Matthew Austin Brown was born in Hendersonville, TN on May 10, 1984. He was raised in Hendersonville and attended Lakeside Park Elementary for grade school and Hawkins Middle School for junior high. He graduated from Hendersonville High School in May 2002. From there, he went to the University of Tennessee, Knoxville and received a B.S. in Agricultural Economics and Business in 2006 and a M.S. in Agricultural Economics with a Minor in Statistics in 2008.

Matthew is currently working with the Tennessee Valley Authority in Market Research and evaluating the possibility of pursuing his doctorate in economics.

Professional Experience

2007-present Tennessee Valley Authority, Nashville, TN

Market Research Analyst

2006-2008 University of Tennessee, Knoxville, TN

Graduate Assistant

Paper and Poster Presentations

1. Bazen, E. and M. Brown. "Estimating the Economic Feasibility of Heating Tennessee Broiler Houses with Solar Energy." Selected Poster, Southern Agricultural Economics Association Annual Meeting, Dallas, TX, February 2 - 5, 2008.

2. Bazen, E. and M. Brown "Feasibility of Solar Technology (Photovoltaic) Adoption: A Case Study on Tennessee's Poultry Industry." 2007 American Agricultural Economics Association, Western Agricultural Economics Association, Canadian Agricultural Economics Society Joint Annual Meeting, Portland, Oregon, July 29 - August 1, 2007.