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WIND POWER FEASIBILITY STUDY FOR BALL STATE UNIVERSITY

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ABSTRACT. Based on two years of site-specific wind speed measurements and actual power curve performance estimates of five commercial wind turbines, a feasibility study of wind-power potential near Ball State University has been conducted. The measured wind speed data from the study site allow a more accurate estimate of the expected energy produced per year from a given turbine than would be obtained by just scaling the estimates based on the rated output power of the turbines. Results show that four out of the five selected turbines could be expected to achieve payoff of combined lifetime costs well within the turbines' estimated lifetimes. Expected savings on the cost of electrical energy range from $2 million to $4 million for a 25-year lifetime. Based on the predicted monetary savings from energy produced by a turbine over its expected lifetime, coupled with trends of decreasing costs and increasing turbine performance, the option of installing a wind turbine to supplement the electrical energy needs of Ball State University appears economically feasible. A renewable energy source, such as a wind turbine, also provides an opportunity for the University to profit from the sale of renewable energy credits (RECs).

Keywords: Wind power, economic feasibility, Muncie, Indiana

INTRODUCTION

Alternative and sustainable energy options have been prioritized at Ball State University (BSU), as exemplified by the Ball State geothermal energy system, the nation's largest ground-source, closed loop system (BSU 2015). Another sustainable energy option for north-central Indiana is wind power, which is expected to grow in production over the next decade (Swiatek 2015).

Currently, installed wind power facilities in Indiana have a combined capacity of nearly 1800 MW, mostly in larger utility wind farms, contributing 2.7% of Indiana's total electricity production (IOED 2015). In order to assess the wind power potential in various regions of the State, long-term records of wind speed data are preferred. One such study recorded wind speeds for a period of one year (2004–2005) on fixed towers at five locations throughout Indiana (Indiana Energy Group 2005). The tower sites were widely distributed throughout the State, with the closest one to BSU, or Muncie, IN, located approximately 35 miles to the southwest. Since wind speeds can vary substantially across geographical regions of this size, a local long-term wind speed study is necessary for assessing the feasibility of wind power for BSU.

Average annual wind speed maps are available for Indiana, and can be used to gain perspective on which regions of the State may produce the most wind energy. For example, regions northwest of Indianapolis show greater potential than regions directly south of Indianapolis (U.S. DOE 2015). The annual average wind speed in the Muncie area (at 80 m above ground level) is estimated at approximately 7.0 m/s. However, reliance on these model-derived estimates is not advised for preparing an economic feasibility study of installing a wind turbine in a given location. The practical reasons requiring a local long-term (non-averaged) study of wind speed in order to develop a wind power feasibility study are described in the data and analysis section.

Ball State University owns a rural property known as Cooper Farm located about 4 miles northwest of the main campus in Muncie, IN (BSU FSEEC 2015). In order to conduct a feasibility study of the wind power potential near the BSU campus, in June 2012, an anemometer was installed 15 m above ground level on an existing tower on the property. Wind speed data have been continuously recorded since then and are archived on a secure digital card and on a web site that receives the data via transmission from

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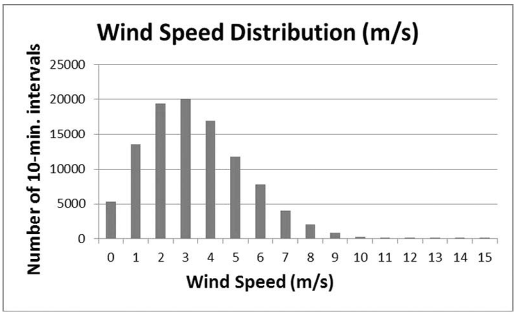

Figure 1.—Wind speed distribution plot in m/s for a two-year period at Ball State's Cooper Farm location, for a measurement height of 15 m.

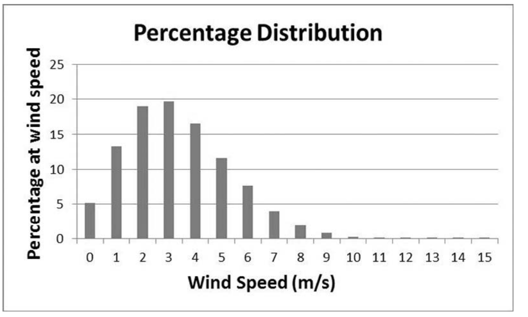

Figure 2.—Percentage wind speed distribution (giving the percentage of time that the wind blew at each speed) for a two-year period at Ball State's Cooper Farm (15 m height).

the wind data logger to a wireless internet site on the property.

DATA AND ANALYSIS

The wind speed data analyzed for this feasibility study covered a two-year period from 26 February 2013 through 25 February 2015. For accurate annual average wind power estimates, it is important that the data window cover an integral number of years, and not include a fraction of an integral number of years. The reason for this is that wind speeds vary significantly for different seasons of the year, and analyzing a fractional year would yield skewed annual wind power estimates. The raw wind data from the anemometer at Cooper Farm are archived in the form of a number equal to the number of rotations, N_r, of the anemometer during a 10-min interval, yielding 144 data points per day. Over the two-year data window, a total of 102,126 wind speed data points were available, corresponding to 97.2% coverage. The slight variation from 100% coverage is due to intermittent loss of the wi-fi connection between the on-site data logger and the BSU wireless internet connection in the residential classroom facility at Cooper Farm.

To conduct the data analysis, raw data were downloaded into a spreadsheet where N_r was converted into a wind speed in m/s, according to the manufacturer's conversion formula for the anemometer. The unit installed at Cooper Farm is a solar-powered, self-contained wind data logger unit from APRS World (APRS6063) with anemometer #40R (current cost of about $900). The number of rotations of the anemometer is typically many thousands during the 10 min sampling interval. For example, a wind speed of 15.0 mph (6.7 m/s) corresponds to $N_r = 10{,}000$. In order to make sense of the large number of data points over the two-year period, a distribution plot of the wind speed data is produced, in which the wind speed is binned in increments of 1 m/s (Fig. 1). The wind speed distribution exhibits a typical Weibull distribution, which is sometimes used to approximate wind speeds when actual data are unavailable (Wizelius 2007).

From the wind speed distribution data, one may obtain the number of hours that the wind blew at a given speed by dividing the distribution data by six intervals per hour. Then, the percentage of time that the wind blew at a given speed is obtained by dividing this result by the number of hours in a two-year period (corrected for 97.2% coverage). The result for the percentage wind speed distribution in m/s is shown in Fig. 2.

The power available from the wind is proportional to the wind speed cubed (v^3), meaning that a disproportionate fraction of the total power available from the wind occurs when wind speeds are highest. For example, the power output of a turbine for a wind speed of 2 m/s is eight times higher compared to the power output for a wind speed of 1 m/s. The cubic dependence of wind power on wind speed is one of the underlying reasons why actual wind speed distributions are necessary for accurate power estimates at a given site, rather than relying on an estimation of average wind speeds.

Another factor that must be taken into account when determining the power output expected from a given wind turbine is the hub height of the turbine. Wind speed typically increases with distance above the ground (or water) level according to a standard formula, depending only

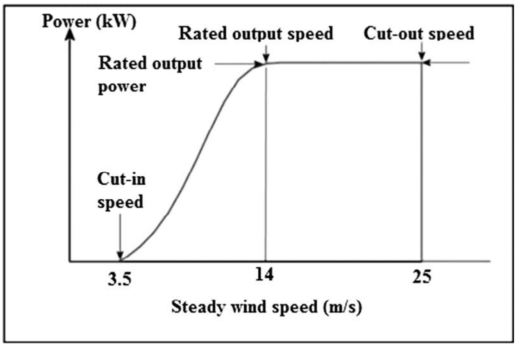

Figure 3.—A typical power curve for a wind turbine, showing the power produced as a function of wind speed (graph adapted from Wind Power Program 2015).

upon the height and the type of surrounding terrain. The wind gradient is greatest when the surrounding region has tall obstacles (such as a city or a forest), and it is least when the surrounding terrain is relatively flat and smooth (such as open farmland or water). To estimate the wind speed, v, at a height h compared to the wind speed v_0 at height h_0, the following formula is used (Wizelius 2007),

$$v = v_0\left(\frac{h}{h_0}\right)^{\alpha}. \quad (1)$$

The parameter α is determined by the roughness category of the surrounding terrain. For the Cooper Farm location, the terrain is open farmland along with some trees and a couple of one-level structures, for which $\alpha = 0.25$. Using Eq. (1) with this factor of α indicates that the wind speed at, for example, 100 m is 1.6 times greater than it is at 15 m. For the given hub height of a selected commercial wind turbine, Eq. (1) will be used to adjust the raw wind speed data shown in Figs. 1 & 2. Employing an estimated correction for height, instead of measuring the wind speeds at the actual turbine hub heights, is a source of uncertainty in the analysis. Nonetheless, with the small value of the exponent α, errors in the height correction for the wind speed should be less than 10%. But since the wind power varies as the wind speed cubed, inaccuracies in the estimated power could be as much as 30%. More accurate data and results would require installing anemometers on a tower and collecting long term wind speed data at increments of about 20 m (from 80 m to 140 m height). The main expense for collecting data at heights relevant for commercial wind turbines would be the installation of the tower itself, but compared to the cost of a commercial turbine, it would be a reasonable initial investment.

COMMERCIAL WIND TURBINES

In order to transform the wind speed distribution data into potential electrical power produced, wind turbine specifications need to be obtained for various commercially available models. The two most important specifications are the turbine hub height (to be used in Eq. 1) and the *power curve* of the turbine. The turbine's power curve is determined by the manufacturer and shows how much power the turbine will actually produce at different wind speeds. At higher wind speeds, there is a cut-out speed above which the turbine will shut down in order to avoid possible mechanical damage. A typical power curve is shown in Fig. 3. The power produced increases with wind speed up to a rated maximum. Below a threshold wind speed, the turbine will not turn and produces no power output.

New wind turbine models are continually being developed by manufacturers. For this study, wind turbine power curve data were obtained for turbines from five different manufacturers (The Wind Power 2016): Vestas, General Electric (GE), Nordex, Repower, and Gamesa. At this step in the wind power analysis, the procedure begins with the data of Fig. 2 and first calculates the adjusted wind speed at the hub height of the particular turbine, using Eq. (1). This result yields the percentage of time that the wind blows at a given speed at the specified turbine hub height. Next, using the power curve data for a particular turbine, the percentage fraction at each wind speed is multiplied by the turbine output power at that wind speed, and then multiplied by the number of hours in a year to obtain the output energy per year at each wind speed. These results are shown in Fig. 4 for each of the selected wind turbines.

The total estimated output energy per year for each of the five commercial wind turbines is found by summing data points shown in Fig. 4 across the total range of wind speeds (0–25 m/s) (Table 1).

ECONOMIC ANALYSIS OF WIND TURBINE POTENTIAL

On the basis of total energy production (Table 1) the Vestas 126, 3.3 MW turbine would be the best pick; however, other factors, collectively known as Total Cost of Ownership (TCO), factor

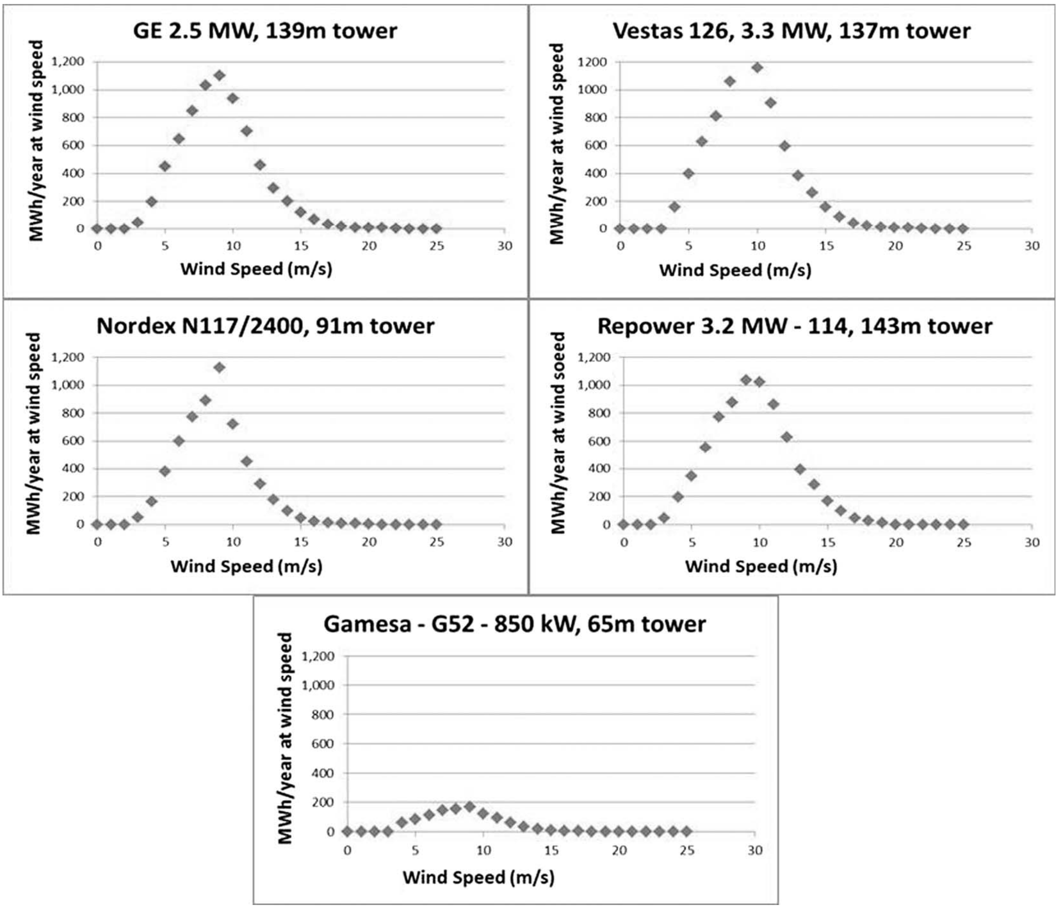

Figure 4.—Estimated wind turbine output energy per year (in megawatt-hours per year) versus wind speed at the specified hub heights for five commercial turbines.

into a turbine's overall economic feasibility. TCO includes the initial cost of the turbine, the on-site installation cost of the turbine, and its lifetime maintenance cost. Commercial-grade wind turbine pricing is available on an average dollars-per-kilowatt basis, and has shown significant variation over the last 10 years (IRENA 2012). Department of Energy data give an average *installed* capital turbine cost of $1940/kW for 2012 (AWEA 2016). Installed costs include, in addition to the turbine itself, the tower foundation, grid connection, site preparation, consulting, and permits, totaling an average of $700/kW, increasing the total capital cost of a turbine from about $1240/kW to $1940/kW. The estimated capital cost of wind turbines is expected to decline over the next several decades, with costs in the year 2020 estimated at 85% of 2011 costs, and the cost in 2040 estimated at 72% of 2011 costs (IRENA 2012). Reducing the 2012 capital costs for a wind turbine by 15% yields an estimated capital cost in 2020 of approximately $1054/kW. Possible reductions in the installation costs of a turbine are expected to be modest over the decade from 2011 to 2020 and are not considered here. For our calculations, we will use the average installation cost of $700/kW, as specified above.

Operation and maintenance (O&M) costs for installed commercial-grade wind turbines must also be factored into an estimate of the economic feasibility of a wind turbine facility. O&M costs have decreased significantly from 1980 and now average $10/MWh for newer projects (IRENA 2012). Another method of estimating O&M costs utilizes a percentage of the capital cost of the turbine: "For modern machines the estimated maintenance costs are in the range of 1.5% to 2% of the original investment per annum" (WMI

Table 1.—Estimated energy production per year by each of the five selected commercial wind turbines using wind data from the Cooper Farm site.

No.	Wind turbine type	Energy/year (MWh/yr)
1	GE 2.5 MW, 139 m tower	7190
2	Vestas 126 - 3.3 MW, 137 m tower	7920
3	Nordex N117/2400, 91 m tower	5830
4	Repower 3.2 MW – 114, 143 m tower	7370
5	GAMESA - G52 - 850 kW, 65 m tower	1070

2016). For the estimated O&M costs presented in Table 2, a value of 2% of the capital cost per year is used. Projections of O&M costs suggest a declining trend over the next couple of decades, with approximately 7% lower costs in 2020 compared to 2011, according to a study of wind turbines in the United Kingdom (IRENA 2012).

A summary of the economic feasibility of the five sample wind turbines used in this study is given in Tables 2a & 2b. While the capital, installation, and maintenance costs scale directly with the rated output power of the various turbines, the energy produced per year does not, being dependent upon how each turbine responds to the spectrum of wind speeds at the chosen site. In general, turbines with higher hub heights produce more energy for a given output rating, since average wind speeds increase with height above the ground.

The calculated results of Table 2b indicate that of the five commercial wind turbines included in the study, the GE 2.5 MW turbine (#1 in the table) with a 139 m hub height is projected to yield the best estimated performance, based on the measured wind speed data at the Cooper Farm site. The installed cost of this turbine could be paid off in just under 11 years, and factoring in O&M costs for 20 years yields a payoff time of 13.5 years. Each year the wind turbine is used after payoff results in savings of approximately $400,000, based on the current cost of electricity paid by Ball State (Lowe, Associate Vice President for Facilities Planning and Management at Ball State University, Pers. Comm. 2016). The total savings for a 20-year lifetime is projected to yield $2.6 million in avoided costs, and for a 25-year lifetime the savings is projected to yield nearly $4.4 million in avoided costs. The mathematical formulae used to obtain these results are spelled out in the Appendix. Obviously, the magnitude of the estimated savings depends strongly upon the actual lifetime of the turbines. A recent comprehensive study in the UK has indicated a positive trend in wind turbine lifetimes, stating that newly installed turbines should operate effectively for up to 25 years (Myers 2014). Allowing for a modest decrease in turbine output power with age could reduce the estimated lifetime savings by approximately 20–25%.

An additional consideration affecting the economic viability of a renewable energy source such as a wind turbine is the possibility of selling renewable energy certificates (RECs). Each REC validates an amount of renewable or "green" energy equivalent to 1 MWh (Lau & Aga 2008). The green energy market is growing, with the sale of RECs allowing customers to purchase green energy even if local sources of green energy are not actually available. The price of RECs varies with location and time, and commercial vendors are often used to establish specific transaction pricing. Nationally-sourced RECs sold at approximately $0.50/MWh in September 2015 (U.S. DOE 2016). With an average turbine output of 7200 MWh/yr.

Table 2a.—For the 5 wind turbines listed in Table 1, estimates of the capital and installation costs, the lifetime maintenance costs, and the overall 20-year lifetime cost for each turbine are given. In addition, the estimated energy produced by each turbine for the Cooper Farm site is shown (referenced from Table 1). Calculations used in obtaining the numerical values presented in Tables 2a & 2b are detailed in the Appendix.

Turbine	MW rating of turbine	Cost of turbine (2020)	Installation cost	Maintenance cost of 20-yr life-time	Total 20-yr lifetime cost of turbine	Energy produced by turbine in a year (kWh/yr)
1	2.5	$2,635,000	$1,750,000	$1,054,000	$5,439,000	7,192,548
2	3.3	$3,478,200	$2,310,000	$1,391,280	$7,179,480	7,917,526
3	2.4	$2,529,600	$1,680,000	$1,011,840	$5,221,440	5,827,897
4	3.2	$3,372,800	$2,240,000	$1,349,120	$6,961,920	7,374,531
5	0.85	$895,900	$595,000	$358,360	$1,849,260	1,074,734

Table 2b.—Total Cost of Ownership (TCO). Continuing from Table 2a, estimates of the number of years for each turbine to achieve payoff of installed costs and total lifetime costs are shown (including O&M costs for 20 years and 25 years). The financial savings to the University per year after payoff are also estimated for both 20 year and 25 year turbine lifetimes.

Turbine	Years to payoff installed cost	Average maintenance cost per year	Years to pay off 20-yr lifetime cost	Money saved/yr by using turbine (after payoff)	Money saved over 20-yr lifetime	Years to pay off 25-yr lifetime cost	Money saved over 25-yr lifetime
1	10.9	$52,700	13.5	$402,783	$2,616,654	14.2	$4,367,067
2	13.1	$69,564	16.2	$443,381	$1,688,149	17.0	$3,557,236
3	12.9	$50,592	16.0	$326,362	$1,305,805	16.8	$2,684,656
4	13.6	$67,456	16.9	$412,974	$1,297,555	17.7	$3,025,144
5	24.8	$17,918	30.7	$60,185	-$645,558	32.2	-$434,223

(referring to Table 2a), this could provide annual income from the sale of RECs averaging $3600/yr.

With climate change and the prospect of global warming due to increasing atmospheric CO_2 concentrations being a continuing concern, the possibility of future carbon taxes may also enhance the economic viability of investing in wind power as a sustainable alternative energy source. "Economists and international organizations have long advocated carbon taxes, because they can achieve the same emissions reduction target at lower costs than conventional command-and-control regulations" (Zhang & Baranzini 2003). Experts also suggest that once instituted, the carbon tax rate would increase over time, further increasing the desirability of investing in a viable alternative energy source, such as wind power.

Ball State University is a member of the Association for the Advancement of Sustainability in Higher Education (AASHE) and is a charter and ongoing participant in the Sustainability Tracking, Assessment & Rating System (STARS). In 2012, Ball State's campus sustainability efforts earned the University a STARS Gold rating, and it has continued to be awarded this high ranking for sustainability performance (BSU 2012; STARS 2016). A major BSU initiative towards sustainability is its comprehensive geothermal energy system (BSU 2015). An investment in wind energy would help to further reduce BSU's carbon footprint and enhance its reputation as a global leader in sustainability efforts in higher education.

Based on the offset in the cost of purchased electricity, the cumulative savings from the installation of a commercial wind turbine at the Cooper Farm site are expected to range from $2 million to $4 million for a 25-year lifetime. Natural variability in wind speeds from one year to the next is a potential source of uncertainty in the results of this study. Other factors that may affect the estimated economic savings of an installed wind turbine relate to actual costs for turbines at the time of purchase, as established by the manufacturer. This study focused on estimating the expected wind power produced from commercially available turbines, and provided an estimate of economic viability using the payback method. A more comprehensive economic viability analysis would need to incorporate adjustments for expected increases in the utility rate for electrical energy, future inflation, and a net present value calculation of the proposed project with appropriate effective annual discount rates. Installing two or more turbines at the site may result in favorable economies of scale related to the capital and installment costs of the turbines. In addition to the economic and environmental benefits of a wind turbine installation, the facility would provide significant educational opportunities for multiple students to become involved in longitudinal research studies of the turbine's energy performance and economic impact over its operational lifetime. In summary, based on the predicted monetary savings from energy produced by a turbine over its expected lifetime, coupled with trends of decreasing costs and increasing turbine performance, the option of installing a wind turbine to supplement the electrical energy needs of Ball State University appears economically feasible.

APPENDIX

The mathematical formulae used to obtain the numerical values in Tables 2a & 2b are presented below.

$$\textbf{Cost of turbine (2020)} = (\text{MW of turbine}) \times (1000\ \text{MW/kW}) \times (\$1054/\text{kW})$$

$$\textbf{Installation cost} = (\text{MW of turbine}) \times (1000\ \text{MW/kW}) \times (\$700/\text{kW})$$

Note: "Installed cost" = (Cost of turbine) + (Installation cost)

$$\textbf{Operation \& Maintenance cost for 20 years} = (\text{Cost of turbine}) \times (2.0\%/\text{yr}) \times (20\ \text{yr})$$

$$\textbf{Total 20-year cost of turbine} = (\text{Cost of turbine}) + (\text{Installation cost}) + (\text{O \& M cost for 20 yr})$$

$$\textbf{Years to pay off installed cost} = \frac{(\text{Installed cost})}{(\$0.056/\text{kWh})(\text{kWh/yr produced by turbine})}$$

Note: The current utility price that Ball State pays for electricity is \$0.056/kWh.

$$\textbf{Average maintenance cost per year} = (\text{Cost of turbine}) \times (2\%/\text{yr})$$

$$\textbf{Years to pay off 20-year lifetime cost} = \frac{(\text{Total 20-yr cost of turbine})}{(\$0.056/\text{kWh})(\text{kWh/yr produced by turbine})}$$

$$\textbf{Money saved per year after payoff} = (\text{kWh/yr produced by turbine}) \times (\$0.056/\text{kwh})$$

$$\textbf{Money saved after 20-year lifetime} = (20\ \text{yr} - \text{years to payoff 20-yr lifetime}) \times (\text{Money saved per yr after payoff})$$

The last two columns of Table 2b (for a 25-year lifetime) are calculated in the same manner as for the corresponding columns for a 20-year lifetime.

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