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CHAPTER 11. LIFE-CYCLE COST SUBGROUP ANALYSIS

11.1 INTRODUCTION

The life-cycle cost (LCC) subgroup analysis evaluates impacts on any identifiable groups of customers who may, because of their particular socio-economic characteristics, be disproportionately affected by any national energy-efficiency standard level. This chapter of the technical support document (TSD) describes how the Department of Energy (DOE) performed its life-cycle cost consumer subgroup analysis for the distribution transformer energy-efficiency standard rulemaking.

DOE conducted this evaluation for the notice of proposed rulemaking (NOPR), in part, by analyzing the LCC and payback periods for those customers that fall into identified subgroups. For this rulemaking, DOE defined consumer subgroups in terms of retail utility ownership type and transformer installations that could incur disproportionate costs. The specific consumer subgroups that DOE chose to examine are rural electric cooperatives, municipal utilities, and utilities with space-constrained vault transformers.

11.2 ANALYSIS APPROACH

As part of the regular LCC analysis, DOE built spreadsheet analysis tools that provide a consumer economic analysis for a nationally representative sample of utilities. DOE developed a simplified approach to perform the consumer subgroup calculations: It adjusted the national data distributions for key analysis inputs by an appropriate scaling factor to produce an approximation of the input data for the consumer subgroup analysis. To estimate the economic impacts for the consumer subgroups, DOE then re-calculated the LCC with the adjusted input distributions. The subgroups examined are both subsets of the entire national electric utility sample and, hence, the analysis was limited to liquid-immersed distribution transformers, represented by design lines 1–5. DOE did not include dry-type distribution transformers, represented by design lines 9–13, in the LCC subgroup analysis since electric utilities use few, if any, dry-type transformers.

11.2.1 Adjustment Factors for Analysis Inputs

DOE selected four key data inputs that it adjusted for the consumer subgroup analysis:

1. Cost of electricity
2. Transformer loading
3. Transformer selection A and B factors
4. Space-constrained installation costs

DOE implemented the first three of these adjustment factors using an “LCC Subgroup” pull-down menu included as part of its LCC spreadsheet tool. Table 11.2.1 shows the adjustment factors for the national sample and the subgroups for rural cooperatives and municipal utilities.

Table 11.2.1 Consumer Subgroup Economic Adjustment Factors

Subgroup	Cost of Electricity	Transformer Loading	A and B Factors
National sample	1.00	1.00	1.00
Rural cooperatives	0.98	0.75	0.90
Municipal utilities	0.93	1.20	1.00

For owners of vault transformers, DOE provided a transformer vault change cost function that is described in section 7.3.5 of this TSD.

11.2.2 How DOE Estimated the Adjustment Factors

This section describes how DOE estimated the the adjustment factors for each of the selected consumer subgroups.

For the cost of electricity, DOE examined the distribution of average electricity revenues per kilowatt-hour (kWh) for all utilities using Energy Information Administration (EIA) Form 861 data for different ownership classes (privately owned, cooperatives, and municipal utilities).¹ For the purposes of this analysis, DOE assumed that the EIA ownership classification of “Political Subdivision” corresponded to a type of municipal utility. Its examination revealed that the distribution of unit revenues for different retail utility ownership classes is very similar. DOE then calculated the weighted-average unit revenues for the different ownership classes of retail utilities. It found that the average unit revenue for rural cooperatives is 98 percent of that for the national sample, and that average unit revenue for municipal utilities is 93 percent of that for the national sample.

For transformer loading estimates, the data available to DOE consisted of rough loading estimates mentioned in stakeholder comments. DOE’s estimate of average root mean square (RMS) loading for a 50 kilovolt-ampere (kVA) pad-mounted transformer for the national sample is 35 percent. Stakeholders commented that rural cooperative transformers tend to have lower loadings because of oversizing to control for voltage flicker and lack of load diversity, while municipal utility transformers tend to have more diversity and, thus, higher loadings. The typical rural cooperative transformer will serve a single customer, while the typical urban transformer will serve multiple customers. Thus, DOE estimated an adjustment factor of 0.75 for rural cooperatives, and 1.20 for municipal utilities, which results in average RMS loading estimates of 26 percent and 42 percent for 50 kVA transformers for rural cooperatives and municipal utilities, respectively.

For customer evaluation A and B factors, DOE was given factors for rural cooperatives by the National Rural Electric Cooperative Association (NRECA) in stakeholder comments; it compiled data from public sources for municipal utilities. DOE found the evaluation parameters

for rural cooperatives to be 10 percent lower than the national sample average and the parameters for municipal utilities to be approximately the same as the national sample average for the available data.

For vault transformers, DOE applied a fixed and variable cost to the installation of a transformer when the transformer exceeded a threshold size. DOE selected the median transformer size at the threshold and set the fixed component of the extra installation cost at \$XX for DL4 and \$YY for DL5. The variable portion of the vault modification cost was set at \$ZZ per cubic foot.

11.3 LIFE-CYCLE COST SUBGROUP RESULTS

This section presents the results of the LCC subgroup analysis for municipal utilities and rural electric cooperatives. The results for each subgroup and each design line are presented in tables that report the candidate standard level, the percentage of transformers that have net savings, no impact, and net LCC cost (i.e., negative savings); and the mean LCC savings.

11.3.1 Municipal Utilities Subgroup Life-Cycle Cost Results

The LCC results for the municipal utilities subgroup are a reflection of a key feature of this subgroup: Transformers purchased by municipal utilities tend to serve more diverse, urban loads than transformers that serve more rural areas. The increased load diversity increases the load factor and the transformer loading, thus increasing the potential savings from reduced load losses. Because of the increased savings from reduced load losses, the LCC savings for the municipal utilities subgroup are slightly higher than for the national sample. The extra LCC savings vary as a function of both the design line and the standard level, since the relative importance of load losses varies with both design line and transformer efficiency.

11.3.1.1 Design Line 1 Life-Cycle Cost Results

Table 11.3.1 presents the summary of the LCC subgroup analysis for municipal utilities for the representative unit from design line 1, a 50 kVA, liquid-immersed, single-phase distribution transformer. For this unit, DOE forecasts that two thirds of the transformers are not impacted by trial standard level (TSL) 1 through 3, while more than 93 percent of transformers are impacted by a TSL 4 standard level or higher. TSLs 5, 6, and A result in a majority of transformers experiencing a net cost due to a standard. With TSLs 1, 2, 3, 4, B, C, and D a majority of affected transformers experience a net savings. There is a net average LCC savings for TSLs 1 through 4 and B through D, while there is a net average LCC cost for TSLs 5, 6, and A.

Table 11.3.1 Municipal Utilities Subgroup Life-Cycle Cost Results: Design Line 1

	Trial Standard Level									
	1 (TP 1)	2	3	4	5	6	A	B	C	D
Efficiency (%)	98.90	98.90	98.90	99.04	99.19	99.59	99.19	99.08	99.08	99.04
Transformers with Net LCC Cost (%)	1.9	1.9	1.9	15.1	60.8	94.8	60.8	23.3	23.3	15.1
Transformers with No Change in LCC (%)	66.1	66.1	66.1	50.0	7.0	0.0	7.0	38.8	38.8	50.0
Transformers with Net LCC Benefit (%)	32.0	32.0	32.0	35.0	32.2	5.2	32.2	38.0	38.0	35.0
Mean LCC Savings (\$)	118	118	118	116	-23	-1003	-23	109	109	116
Mean LCC Savings for those effected	347	347	347	233	-25	-1003	-25	177	177	233

11.3.1.2 Design Line 2 Life-Cycle Cost Results

Table 11.3.2 presents the summary of the LCC subgroup analysis for municipal utilities for the representative unit from design line 2, a 25 kVA, liquid-immersed, single-phase distribution transformer. For this unit, DOE forecasts that 42 percent of the transformers are not impacted by TSL 1, while 83 percent or more of transformers are impacted by a TSL 5 standard level or higher. TSLs C, B, 5, A and 6 result in a majority of transformers experiencing a net cost due to a standard. With TSLs 1 through 4 and D, the majority of affected transformers experience a net savings. There is a net average LCC savings for TSLs 1 through 5, D, C, and B, while there is a net average LCC cost for TSLs 5, 6 and A.

Table 11.3.2 Municipal Utilities Subgroup Life-Cycle Cost Results: Design Line 2

	Trial Standard Level									
	1 (TP 1)	2	3	4	5	6	A	B	C	D
Efficiency (%)	98.70	98.73	98.76	98.79	98.96	99.46	99.04	98.91	98.91	98.79
Transformers with Net LCC Cost (%)	12.2	10.7	9.2	11.9	57.1	99.1	78.9	42.9	42.9	11.9
Transformers with No Change in LCC (%)	42.0	38.4	36.3	34.1	10.0	0.0	0.1	16.5	16.5	34.1
Transformers with Net LCC Benefit (%)	45.8	50.9	54.5	54.0	32.9	0.9	21.0	40.6	40.6	54.0
Mean LCC Savings (\$)	55	59	74	75	-19	-1073	-106	21	21	75
Mean LCC Savings for those effected	95	97	116	113	-21	-1073	-106	25	25	113

11.3.1.3 Design Line 3 Life-Cycle Cost Results

Table 11.3.3 presents the summary of the LCC subgroup analysis for municipal utilities for the representative unit from design line 3, a 500 kVA, liquid-immersed, single-phase distribution transformer. For this unit, DOE forecasts that two thirds of the transformers are not impacted by TSL 1, while 97 percent or more of transformers are impacted by a TSL 4 standard level or higher. TSLs 5 and 6 result in a majority of transformers experiencing a net cost due to a standard. With TSLs 1 through 4 and A through D, a majority of affected transformers experience a net savings. There is a net average LCC savings for all levels except TSLs 5 and 6.

Table 11.3.3 Municipal Utilities Subgroup Life-Cycle Cost Results: Design Line 3

	Trial Standard Level									
	1 (TP 1)	2	3	4	5	6	A	B	C	D
Efficiency (%)	99.30	99.38	99.46	99.54	99.74	99.75	99.54	99.47	99.42	99.38
Transformers with Net LCC Cost (%)	1.6	1.7	6.8	45.5	80.5	83.9	45.5	7.3	2.5	1.7
Transformers with No Change in LCC (%)	66.6	59.0	49.1	2.1	0.2	0.0	2.1	47.1	56.5	59.0
Transformers with Net LCC Benefit (%)	31.8	39.4	44.2	52.4	19.4	16.1	52.4	45.6	41.0	39.4
Mean LCC Savings (\$)	1357	1691	1885	1674	-1779	-2837	1674	1920	1798	1690
Mean LCC Savings for those effected	4064	4118	3701	1710	-1782	-2837	1710	3630	4135	4118

11.3.1.4 Design Line 4 Life-Cycle Cost Results

Table 11.3.4 presents the summary of the LCC subgroup analysis for municipal utilities for the representative unit from design line 4, a 150 kVA, liquid-immersed, three-phase distribution transformer. For this unit, DOE forecasts that more than 54 percent of the transformers are not impacted by TSL 1, while more than 87 percent of transformers are impacted by a TSL 3 standard level or higher. TSL 4 and lower has a majority of affected transformers experiencing a net savings, while TSLs 5 and 6 result in a majority of transformers experiencing a net cost due to a standard. With all TSLs except 5 and 6, there is a net average LCC savings.

Table 11.3.4 Municipal Utilities Subgroup Life-Cycle Cost Results: Design Line 4

	Trial Standard Level									
	1 (TP 1)	2	3	4	5	6	A	B	C	D
Efficiency (%)	98.90	99.08	99.26	99.26	99.58	99.61	99.19	99.08	99.08	99.08
Transformers with Net LCC Cost (%)	7.9	19.2	22.5	22.5	74.7	83.4	33.5	19.2	19.2	19.2
Transformers with No Change in LCC (%)	54.4	20.6	13.0	13.0	0.1	0.0	13.0	20.6	20.6	20.6
Transformers with Net LCC Benefit (%)	37.7	60.2	64.5	64.5	25.2	16.6	53.5	60.2	60.2	60.2
Mean LCC Savings (\$)	435	577	661	661	-563	-1338	442	577	577	577
Mean LCC Savings for those effected	955	727	760	760	-563	-1338	508	727	727	727

11.3.1.5 Design Line 5 Life-Cycle Cost Results

Table 11.3.5 presents the summary of the LCC subgroup analysis for municipal utilities for the representative unit from design line 5, a 1500 kVA, liquid-immersed, three-phase distribution transformer. For this unit, DOE forecasts that two thirds of the transformers are not impacted by TSL 1, while more than two thirds of transformers are impacted by a TSL 4 standard level or higher. TSL A has similar proportions of transformers incurring a net cost and a net savings as a result of a standard, and TSLs 1 through 4 and B through D result in the majority of affected transformers obtaining a net savings from a standard. There is a net average LCC savings for all TSLs except 5 and 6.

Table 11.3.5 Municipal Utilities Subgroup Life-Cycle Cost Results: Design Line 5

	Trial Standard Level									
	1 (TP 1)	2	3	4	5	6	A	B	C	D
Efficiency (%)	99.30	99.36	99.42	99.47	99.71	99.71	99.54	99.47	99.42	99.42
Transformers with Net LCC Cost (%)	3.8	3.4	9.7	17.0	77.4	77.4	51.3	17.0	9.7	9.7
Transformers with No Change in LCC (%)	66.7	61.7	45.5	33.0	0.0	0.0	4.7	33.0	45.5	45.5
Transformers with Net LCC Benefit (%)	29.6	34.9	44.9	50.0	22.6	22.6	44.1	50.0	44.9	44.9
Mean LCC Savings (\$)	2370	3154	3708	4094	-3192	-3192	2096	4094	3708	3708
Mean LCC Savings for those effected	7105	8230	6799	6114	-3193	-3193	2199	6114	6799	6799

11.3.2 Rural Cooperatives Subgroup Life-Cycle Cost Results

The LCC results for the rural cooperatives subgroup are a reflection of a key feature of this subgroup: Distribution transformers purchased by rural cooperatives tend to serve smaller loads than transformers that serve urban areas. The lower loading decreases the potential savings from reduced load losses and, thus, the benefits from efficiency improvements. Because of the reduced savings from reduced load losses, the LCC savings for the rural cooperatives subgroup are slightly less than for the national sample. The diminished LCC savings vary as a function of both the design line and the standard level, since the relative importance of load losses varies with both design line and transformer efficiency. The LCC savings for rural cooperatives are also, on average, less than for the municipal utility case per affected transformer.

11.3.2.1 Design Line 1 Life-Cycle Cost Results

Table 11.3.6 presents the summary of the LCC subgroup analysis for rural cooperatives for the representative unit from design line 1, a 50 kVA, liquid-immersed, single-phase distribution transformer. For this unit, DOE forecasts that 65 percent of transformers are impacted by a TSL 1 standard level while 95 percent of transformers or more are impacted by standards at TSL5 or higher. There is a net average LCC savings for TSLs 1, through 4 and B through D, while there is a net average LCC cost for TSLs 5, 6 and A.

Table 11.3.6 Rural Cooperatives Subgroup Life-Cycle Cost Results: Design Line 1

	Trial Standard Level									
	1 (TP 1)	2	3	4	5	6	A	B	C	D
Efficiency (%)	98.90	98.90	98.90	99.04	99.19	99.59	99.19	99.08	99.08	99.04
Transformers with Net LCC Cost (%)	2.4	2.4	2.4	20.2	70.8	98.7	70.8	29.5	29.5	20.2
Transformers with No Change in LCC (%)	65.2	65.2	65.2	49.7	4.6	0.0	4.6	36.8	36.8	49.7
Transformers with Net LCC Benefit (%)	32.4	32.4	32.4	30.1	24.5	1.3	24.5	33.8	33.8	30.1
Mean LCC Savings (\$)	120	120	120	61	-131	-1218	-131	49	49	61
Mean LCC Savings for those effected	343	343	343	122	-137	-1218	-137	78	78	122

11.3.2.2 Design Line 2 Life-Cycle Cost Results

Table 11.3.7 presents the summary of the LCC subgroup analysis for rural cooperatives for the representative unit from design line 2, a 25 kVA, liquid-immersed, single-phase distribution transformer. For this unit, DOE forecasts that 36 percent of rural cooperative transformers are not impacted by a TSL 1 standard level while more than 88 percent of transformers are impacted by a TSL C standard level or higher. Transformers that incur a net LCC cost resulting from a standard dominate the affected transformers for TSLs 5, 6 and A through C, while TSLs 1 through 4 and D have more affected transformers with net savings. There are net average LCC savings for TSLs 1 through 4 and B through D, while there is a net average LCC cost for TSLs 5, 6 and A.

Table 11.3.7 Rural Cooperatives Subgroup Life-Cycle Cost Results: Design Line 2

	Trial Standard Level									
	1 (TP 1)	2	3	4	5	6	A	B	C	D
Efficiency (%)	98.70	98.73	98.76	98.79	98.96	99.46	99.04	98.91	98.91	98.79
Transformers with Net LCC Cost (%)	15.6	13.5	13.1	16.5	66.7	99.7	84.7	50.0	50.0	16.5
Transformers with No Change in LCC (%)	35.8	32.1	30.1	28.0	6.1	0.0	0.1	11.5	11.5	28.0
Transformers with Net LCC Benefit (%)	48.6	54.3	56.8	55.5	27.2	0.3	15.2	38.5	38.5	55.5
Mean LCC Savings (\$)	54	61	71	67	-51	-1174	-148	4	4	67
Mean LCC Savings for those effected	85	90	102	94	-55	-1174	-148	5	5	94

11.3.2.3 Design Line 3 Life-Cycle Cost Results

Table 11.3.8 presents the summary of the LCC subgroup analysis for rural cooperatives for the representative unit from design line 3, a 500 kVA, liquid-immersed, single-phase distribution transformer. For this unit, DOE forecasts that 63 percent of transformers are not impacted by TSL 1, while more than 99 percent of transformers are impacted by a TSL 4 standard level or higher. TSLs 5 and 6 result in a majority of transformers with a net cost as a result of a standard, and TSLs 1 through 3 and B through D have the majority of affected transformers incurring a net savings. TSL 4 and A have similar numbers of affected transformers with net costs and net savings. There are net average LCC savings for TSLs 1 through 4 and A through D, while there is a net average LCC cost for TSLs 5 and 6.

Table 11.3.8 Rural Cooperatives Subgroup Life-Cycle Cost Results: Design Line 3

	Trial Standard Level									
	1 (TP 1)	2	3	4	5	6	A	B	C	D
Efficiency (%)	99.30	99.38	99.46	99.54	99.74	99.75	99.54	99.47	99.42	99.38
Transformers with Net LCC Cost (%)	2.5	2.1	9.4	44.1	90.0	93.1	44.1	10.0	3.2	2.1
Transformers with No Change in LCC (%)	63.1	55.2	46.0	0.8	0.0	0.0	0.8	43.2	53.1	55.2
Transformers with Net LCC Benefit (%)	34.4	42.8	44.6	55.1	10.0	6.9	55.1	46.8	43.7	42.8
Mean LCC Savings (\$)	835	1151	1114	786	-3324	-4518	786	1155	1215	1151
Mean LCC Savings for those effected	2264	2566	2061	793	-3324	-4518	793	2034	2591	2566

11.3.2.4 Design Line 4 Life-Cycle Cost Results

Table 11.3.9 presents the summary of the LCC subgroup analysis for rural cooperatives for the representative unit from design line 4, a 150 kVA, liquid-immersed, three-phase distribution transformer. For this unit, DOE forecasts that 53 percent of the transformers are not impacted by TSL 1, while more than 92 percent of transformers are impacted by a TSL 3 standard level or higher. TSLs 5, and 6 result in a majority of transformers experiencing a net cost as a result of a standard. TSLs 1, through 4 and B through D have the majority of affected transformers obtaining a net savings from a standard. There is a net average LCC savings for TSLs 1 through 4 and A through D, while there is a net average LCC cost for TSLs 5 and 6.

Table 11.3.9 Rural Cooperatives Subgroup Life-Cycle Cost Results: Design Line 4

	Trial Standard Level									
	1 (TP 1)	2	3	4	5	6	A	B	C	D
Efficiency (%)	98.90	99.08	99.26	99.26	99.58	99.61	99.19	99.08	99.08	99.08
Transformers with Net LCC Cost (%)	13.5	26.7	23.2	23.2	87.3	93.8	43.4	26.7	26.7	26.7
Transformers with No Change in LCC (%)	52.9	14.8	7.8	7.8	0.1	0.0	7.8	14.8	14.8	14.8
Transformers with Net LCC Benefit (%)	33.7	58.5	69.1	69.1	12.6	6.2	48.7	58.5	58.5	58.5
Mean LCC Savings (\$)	247	353	653	653	-1216	-2064	173	353	353	353
Mean LCC Savings for those effected	523	414	708	708	-1218	-2064	188	414	414	414

11.3.2.5 Design Line 5 Life-Cycle Cost Results

Table 11.3.10 presents the summary of the LCC subgroup analysis for rural cooperatives for the representative unit from design line 5, a 1500 kVA, liquid-immersed, three-phase distribution transformer. For this unit, DOE forecasts that more than 65 percent of the transformers are not impacted by TSL 1, while more than 70 percent or more of transformers are impacted by a TSL 4 standard level or higher. TSLs 5, 6 and A result in a majority of transformers incurring a net cost, and all other TSLs have the majority of affected transformers incurring a net savings from a standard. There are net average LCC savings for all TSLs except 5 and 6.

Table 11.3.10 Rural Cooperatives Subgroup Life-Cycle Cost Results: Design Line 5

	Trial Standard Level									
	1 (TP 1)	2	3	4	5	6	A	B	C	D
Efficiency (%)	99.30	99.36	99.42	99.47	99.71	99.71	99.54	99.47	99.42	99.42
Transformers with Net LCC Cost (%)	8.0	7.9	16.5	26.1	91.1	91.1	55.2	26.1	16.5	16.5
Transformers with No Change in LCC (%)	65.5	59.9	42.0	30.1	0.0	0.0	2.0	30.1	42.0	42.0
Transformers with Net LCC Benefit (%)	26.5	32.2	41.5	43.8	8.8	8.8	42.9	43.8	41.5	41.5
Mean LCC Savings (\$)	945	1371	1537	1505	-8122	-8122	292	1505	1537	1537
Mean LCC Savings for those effected	2739	3419	2652	2152	-8125	-8125	298	2152	2652	2652

11.3.3 Vault Transformer Subgroup Life-Cycle Cost Results

The LCC results for the vault transformer subgroup are a reflection of a key feature of this subgroup: Distribution transformers at the higher efficiency levels have larger volumes and higher installation costs from vault modifications. This can dramatically decrease the economic benefits from the highest standard levels of TSLs 5 and 6.

11.3.3.1 Design Line 5 Life-Cycle Cost Results, Medium Vault Cost Case

Table 11.3.11 presents the summary of the LCC subgroup analysis for the vault transformers subgroup for the representative unit from design line 5, a 1500 kVA, liquid-immersed, three-phase distribution transformer for the medium vault cost case. This is the design line that is most likely to be used in vault transformer applications. For this subgroup, owners tend to purchase smaller, less efficient designs in order to avoid higher installation costs. For the lowest standard levels, the majority of transformers are unaffected by a standard. There are net average LCC savings for all TSLs except 5 and 6.

Table 11.3.11 Vault Transformer Subgroup Life-Cycle Cost Results, Medium Vault Cost Case: Design Line 5

	Trial Standard Level									
	1 (TP 1)	2	3	4	5	6	A	B	C	D
Efficiency (%)	99.30	99.36	99.42	99.47	99.71	99.71	99.54	99.47	99.42	99.42
Transformers with Net LCC Cost (%)	2.3	5.7	16.5	47.3	91.6	91.6	61.9	57.3	16.5	16.5
Transformers with No Change in LCC (%)	66.6	49.0	40.4	4.8	0.0	0.0	0.8	4.8	40.4	40.4
Transformers with Net LCC Benefit (%)	31.1	45.3	43.1	37.9	8.4	8.4	38.1	37.9	43.1	43.1
Mean LCC Savings (\$)	1707	2334	2523	1157	-13327	-13327	404	1157	2523	2523
Mean LCC Savings for those effected	5107	4576	4232	1216	-13327	-13327	404	1216	4232	4232

11.3.3.2 Design Line 5 Life-Cycle Cost Results, Very High Vault Cost Case

Table 11.3.12 presents the summary of the LCC subgroup analysis for the vault transformers subgroup for the representative unit from design line 5, a 1500 kVA, liquid-immersed, three-phase distribution transformer. This is the design line that is most likely to be used in vault transformer applications. For this subgroup, owners tend to purchase smaller, less efficient designs in order to avoid higher installation costs. For the lowest standard levels, the majority of transformers are unaffected by a standard. There are net average LCC savings for all TSLs except 5 and 6. In this case, DOE assumes that the replacement cost for a transformer vault is very high. The result is that whenever possible customers will avoid making a purchase that requires a vault replacement. For TSLs 5 and 6 this may not be possible and the incremental cost of a standard can be very high as a result.

Table 11.3.12 Vault Transformer Subgroup Life-Cycle Cost Results, Very High Vault Cost Case: Design Line 5

	Trial Standard Level									
	1 (TP 1)	2	3	4	5	6	A	B	C	D
Efficiency (%)	99.30	99.36	99.42	99.47	99.71	99.71	99.54	99.47	99.42	99.42
Transformers with Net LCC Cost (%)	2.3	5.7	16.5	57.3	100.0	100.0	61.4	57.3	16.5	16.5
Transformers with No Change in LCC (%)	66.6	49.0	40.4	4.8	0.0	0.0	0.0	4.8	40.4	40.4
Transformers with Net LCC Benefit (%)	31.1	45.3	43.1	37.9	0.3	0.3	38.6	37.9	43.1	43.1
Mean LCC Savings (\$)	1707	2334	2523	1157	-197936	-197936	474	1157	2523	2523
Mean LCC Savings for those effected	5107	4576	4232	1216	-197936	-197936	474	1216	4232	4232

11.4 PAYBACK PERIOD RESULTS

As described in more detail in section 8.6, a common technique for evaluating investment decisions is to perform a payback period (PBP) analysis. A more energy-efficient device will usually cost more to purchase than a device of standard energy efficiency, while the more efficient device will usually cost less to operate. Operating expenses decrease due to a reduction in energy use. The payback period is the time (usually expressed in years) it takes to recover the additional first cost of the efficiency device with its energy cost savings. Because DOE analyzed the economics of a nationally representative distribution of transformers, DOE provides results in terms of a distribution of payback periods.

There are several potential complications to performing an analysis of a distribution of PBP estimates (see section 8.6). Specifically, a payback period is a ratio of increased first cost and decreased operating expenses. When there is a distribution of changes for both first cost and operating expense reductions, the average of the ratio does not equal the ratio of the averages. Therefore, in the tables below, DOE reports all quantities of interest: the mean PBP, the mean incremental first cost, and the average decrease in annual operating expenses (in the first year of operation). These quantities allow stakeholders to compare the average PBP to a ratio of the mean incremental first cost increase and the mean operating cost savings. These two values are comparable, but not equal, because not all transformer purchase decision computations have well-defined PBPs.

11.4.1 Municipal Utilities Subgroup Payback Period Results

The PBP results for the municipal utilities subgroup are a reflection of a key feature of this subgroup. This key feature is that distribution transformers purchased by municipal utilities tend to serve more diverse, urban loads than transformers that serve more rural areas. The increased load diversity increases the load factor and the transformer loading, thus increasing the potential savings from reduced load losses. While the mean PBP for the municipal utilities subgroup is generally shorter than the PBP for the national sample, it is often within a year of the national sample mean PBP. Compared to the rural cooperatives subgroup, the benefits from efficiency improvements are on average greater for municipal utilities, and the PBP tends to be slightly smaller than that for rural cooperatives.

11.4.1.1 Design Line 1 Payback Period Results

Table 11.4.1 presents the summary of the PBP subgroup analysis for municipal utilities for the representative unit from design line 1, a 50 kVA, liquid-immersed, single-phase distribution transformer. For this unit, DOE forecasts that nearly 66 percent of the transformers are not impacted by TSL 1, while nearly 93 percent or more of transformers are impacted by a

TSL 5 standard level or higher. Undefined^a PBPs remain below ten percent for all TSLs. Mean distribution PBPs for this design line range from 5.7 to 43 years; TSL 1 has the minimum distribution PBP. PBP for the average transformer varies from 2.5 to 35 years depending on the TSL.

Table 11.4.1 Municipal Utilities Subgroup Payback Period Results: Design Line 1

	Trial Standard Level									
	1 (TP 1)	2	3	4	5	6	A	B	C	D
Mean Payback (Years)	5.7	5.7	5.7	16.4	32.0	43.4	32.0	19.6	19.6	16.4
Transformers Unaffected by the TSL (%)	66.1	66.1	66.1	50.0	7.0	0.0	7.0	38.8	38.8	50.0
Transformers having Well Defined Payback (%)	25.0	25.0	25.0	48.8	89.5	99.8	89.5	58.9	58.9	48.8
Transformers having Undefined Payback (%)	8.9	8.9	8.9	1.3	3.5	0.2	3.5	2.3	2.3	1.3
Mean Incremental First Cost (\$)	59	59	59	262	481	2087	481	286	286	262
Mean Operating Cost Savings (\$)	24	24	24	29	26	59	26	27	27	29
Payback of Average Transformer	2.5	2.5	2.5	9.0	18.5	35.4	18.5	10.6	10.6	9.0

11.4.1.2 Design Line 2 Payback Period Results

Table 11.4.2 presents the summary of the PBP subgroup analysis for municipal utilities for the representative unit from design line 2, a 25 kVA, liquid-immersed, single-phase distribution transformer. For this unit, DOE forecasts that 54 percent of transformers are not impacted by TSL 1, while 83 percent or more of transformers are impacted by a TSL C standard level or higher. Undefined PBPs are five percent or less for all TSLs. Mean PBPs for this design line range from 10 to 58 years. The PBP for the average transformer varies from approximately 8 to 50 years.

Table 11.4.2 Municipal Utilities Subgroup Payback Period Results: Design Line 2

	Trial Standard Level									
	1 (TP 1)	2	3	4	5	6	A	B	C	D
Mean Payback (Years)	12.7	11.9	10.5	11.8	26.5	57.8	33.2	22.2	22.2	11.8
Transformers Unaffected by the TSL (%)	42.0	38.4	36.3	34.1	10.0	0.0	0.1	16.5	16.5	34.1
Transformers having Well Defined Payback (%)	54.1	57.0	58.6	61.1	88.6	100.0	98.0	81.9	81.9	61.1
Transformers having Undefined Payback (%)	3.9	4.6	5.1	4.8	1.4	0.0	1.9	1.6	1.6	4.8
Mean Incremental First Cost (\$)	84	94	85	96	295	1721	409	234	234	96
Mean Operating Cost Savings (\$)	10	11	12	12	16	34	17	15	15	12
Payback of Average Transformer	8.4	8.6	7.1	8.0	18.5	50.6	24.0	15.6	15.6	8.0

^a Undefined refers to all invalid PBP computations. See section 8.6 for a full discussion.

11.4.1.3 Design Line 3 Payback Period Results

Table 11.4.3 presents the summary of the PBP subgroup analysis for municipal utilities for the representative unit from design line 3, a 500 kVA, liquid-immersed, single-phase distribution transformer. For this unit, DOE forecasts that two thirds of the transformers are not impacted by TSL 1, while 98 percent of transformers are impacted by a TSL 4 standard level or higher. Undefined PBPs remain below 3 percent for all TSLs. For this design line, PBPs increase monotonically from 4 to 30 years with increasing TSL stringency.

Table 11.4.3 Municipal Utilities Subgroup Payback Period Results: Design Line 3

	Trial Standard Level									
	1 (TP 1)	2	3	4	5	6	A	B	C	D
Mean Payback (Years)	3.7	5.2	9.7	19.6	29.5	32.8	19.6	9.8	6.3	5.2
Transformers Unaffected by the TSL (%)	66.6	59.0	49.1	2.1	0.2	0.0	2.1	47.1	56.5	59.0
Transformers having Well Defined Payback (%)	31.3	40.2	50.4	92.9	99.8	100.0	92.9	52.1	43.1	40.2
Transformers having Undefined Payback (%)	2.1	0.8	0.5	5.0	0.0	0.0	5.0	0.8	0.5	0.8
Mean Incremental First Cost (\$)	532	991	1784	2226	9294	10629	2226	1722	1237	991
Mean Operating Cost Savings (\$)	272	302	323	229	426	439	229	315	317	302
Payback of Average Transformer	2.0	3.3	5.5	9.7	21.8	24.2	9.7	5.5	3.9	3.3

11.4.1.4 Design Line 4 Payback Period Results

Table 11.4.4 presents the summary of the PBP subgroup analysis for municipal utilities for the representative unit from design line 4, a 150 kVA, liquid-immersed, three-phase distribution transformer. For this unit, DOE forecasts that more than 54 percent of the transformers are not impacted by TSL 1, while 87 percent or more of transformers are impacted by a TSL 3 standard level or higher. For this design line, transformers with undefined PBPs are 2 percent or fewer of all transformers. Mean distribution PBP ranges from 11 to 33 years, with a dip in mean PBP. The PBP of the average transformer ranges from 7 to 24 years.

Table 11.4.4 Municipal Utilities Subgroup Payback Period Results: Design Line 4

	Trial Standard Level									
	1 (TP 1)	2	3	4	5	6	A	B	C	D
Mean Payback (Years)	11.2	13.7	13.9	13.9	28.8	33.5	16.7	13.7	13.7	13.7
Transformers Unaffected by the TSL (%)	54.4	20.6	13.0	13.0	0.1	0.0	13.0	20.6	20.6	20.6
Transformers having Well Defined Payback (%)	43.8	77.2	86.9	86.9	99.7	100.0	86.9	77.2	77.2	77.2
Transformers having Undefined Payback (%)	1.8	2.2	0.1	0.1	0.2	0.0	0.1	2.2	2.2	2.2
Mean Incremental First Cost (\$)	669	947	1622	1622	4086	5054	1650	947	947	947
Mean Operating Cost Savings (\$)	95	97	138	138	199	209	124	97	97	97
Payback of Average Transformer	7.0	9.8	11.8	11.8	20.5	24.2	13.3	9.8	9.8	9.8

11.4.1.5 Design Line 5 Payback Period Results

Table 11.4.5 presents the summary of the PBP subgroup analysis for municipal utilities for the representative unit from design line 5, a 1500 kVA, liquid-immersed, three-phase distribution transformer. For this unit, DOE forecasts that two thirds of the transformers are not impacted by TSL 1, while 55 percent or more of transformers are impacted by a TSL A standard level or higher. Undefined PBPs remain below 2 percent of transformers for all TSLs. Mean distribution PBP ranges from 8 to 28 years and increases monotonically with increasing TSL stringency. The PBP of the average transformer ranges from 4 to 20 years.

Table 11.4.5 Municipal Utilities Subgroup Payback Period Results: Design Line 5

	Trial Standard Level									
	1 (TP 1)	2	3	4	5	6	A	B	C	D
Mean Payback (Years)	7.7	8.0	11.6	13.3	28.0	28.0	21.3	13.3	11.6	11.6
Transformers Unaffected by the TSL (%)	66.7	61.7	45.5	33.0	0.0	0.0	4.7	33.0	45.5	45.5
Transformers having Well Defined Payback (%)	32.3	37.9	53.7	66.4	99.9	99.9	95.0	66.4	53.7	53.7
Transformers having Undefined Payback (%)	1.1	0.4	0.8	0.6	0.0	0.0	0.3	0.6	0.8	0.8
Mean Incremental First Cost (\$)	2409	3693	4265	5391	22624	22624	9794	5391	4265	4265
Mean Operating Cost Savings (\$)	561	700	649	673	1106	1106	693	673	649	649
Payback of Average Transformer	4.3	5.3	6.6	8.0	20.5	20.5	14.1	8.0	6.6	6.6

11.4.2 Rural Cooperatives Subgroup Payback Period Results

The PBP results for the rural cooperatives subgroup are a reflection of a key feature of this subgroup: Distribution transformers purchased by rural cooperatives tend to serve smaller loads than transformers that serve urban areas. The lower loading decreases the potential savings from reduced load losses, and thus the benefits from efficiency improvements are on average less than the national average case per affected transformer, and payback times will be longer than the national average.

11.4.2.1 Design Line 1 Payback Period Results

Table 11.4.6 presents the summary of the LCC subgroup analysis for rural cooperatives for the representative unit from design line 1, a 50 kVA, liquid-immersed, single-phase distribution transformer. For this unit, DOE forecasts that 65 percent of transformers are not impacted by a TSL 1 standard level, while about 50 percent of transformers are impacted by a TSL 4 standard level. Undefined paybacks remain below ten percent for all TSLs. Mean distribution PBPs for this design line range from 6.6 to 52 years; TSL 1 has the minimum distribution PBP. PBP for the average transformer varies from 2.5 to 45 years depending on the TSL.

Table 11.4.6 Rural Cooperatives Subgroup Payback Period Results: Design Line 1

	Trial Standard Level									
	1 (TP 1)	2	3	4	5	6	A	B	C	D
Mean Payback (Years)	6.6	6.6	6.6	21.1	40.9	51.6	40.9	25.0	25.0	21.1
Transformers Unaffected by the TSL (%)	65.2	65.2	65.2	49.7	4.6	0.0	4.6	36.8	36.8	49.7
Transformers having Well Defined Payback (%)	25.5	25.5	25.5	46.7	89.2	99.8	89.2	58.4	58.4	46.7
Transformers having Undefined Payback (%)	9.3	9.3	9.3	3.6	6.2	0.2	6.2	4.8	4.8	3.6
Mean Incremental First Cost (\$)	60	60	60	261	472	2094	472	282	282	261
Mean Operating Cost Savings (\$)	24	24	24	22	19	47	19	21	21	22
Payback of Average Transformer	2.5	2.5	2.5	11.9	24.8	44.6	24.8	13.4	13.4	11.9

11.4.2.2 Design Line 2 Payback Period Results

Table 11.4.7 presents the summary of the LCC subgroup analysis for rural cooperatives for the representative unit from design line 2, a 25 kVA, liquid-immersed, single-phase distribution transformer. For this unit, DOE forecasts that 36 percent of rural cooperative transformers are not impacted by a TSL 1 standard level, while over 88 percent of transformers are impacted by a TSL C standard level or higher. Undefined PBPs remain below six percent for all TSLs. Mean PBPs for this design line range from 14 to 65 years, with a monotonic increase in mean PBP with increasing TSL stringency.

Table 11.4.7 Rural Cooperatives Subgroup Payback Period Results: Design Line 2

	Trial Standard Level									
	1 (TP 1)	2	3	4	5	6	A	B	C	D
Mean Payback (Years)	13.9	12.8	12.0	13.9	29.5	65.0	36.1	24.2	24.2	13.9
Transformers Unaffected by the TSL (%)	35.8	32.1	30.1	28.0	6.1	0.0	0.0	11.5	11.5	28.0
Transformers having Well Defined Payback (%)	59.4	63.0	64.1	66.5	92.1	100.0	98.2	86.4	86.4	66.5
Transformers having Undefined Payback (%)	4.8	4.9	5.8	5.5	1.8	0.0	1.8	2.1	2.1	5.5
Mean Incremental First Cost (\$)	84	94	85	96	301	1744	427	237	237	96
Mean Operating Cost Savings (\$)	10	11	11	11	14	30	16	14	14	11
Payback of Average Transformer	8.4	8.6	7.8	8.8	21.5	58.1	26.7	16.9	16.9	8.8

11.4.2.3 Design Line 3 Payback Period Results

Table 11.4.8 presents the summary of the LCC subgroup analysis for rural cooperatives for the representative unit from design line 3, a 500 kVA, liquid-immersed, single-phase distribution transformer. For this unit, DOE forecasts that 63 percent of the transformers are not impacted by TSL 1, while more than 99 percent of transformers are impacted by a TSL 4 standard level or higher. Undefined PBPs remain below four percent for all TSLs. For this design line, PBPs increase monotonically from 5.5 to 38 years with increasing TSL stringency. PBPs for the average transformer range from 3.3 to 31 years.

Table 11.4.8 Rural Cooperatives Subgroup Payback Period Results: Design Line 3

	Trial Standard Level									
	1 (TP 1)	2	3	4	5	6	A	B	C	D
Mean Payback (Years)	5.5	6.0	11.6	19.7	33.2	37.5	19.7	11.8	7.2	6.0
Transformers Unaffected by the TSL (%)	63.1	55.2	46.0	0.8	0.0	0.0	0.8	43.2	53.1	55.2
Transformers having Well Defined Payback (%)	34.0	44.3	52.8	95.4	100.0	100.0	95.4	55.1	46.6	44.2
Transformers having Undefined Payback (%)	2.9	0.6	1.2	3.8	0.0	0.0	3.8	1.7	0.3	0.6
Mean Incremental First Cost (\$)	546	999	1782	2251	9365	10710	2251	1705	1247	999
Mean Operating Cost Savings (\$)	166	211	226	177	339	345	177	220	227	211
Payback of Average Transformer	3.3	4.7	7.9	12.7	27.6	31.0	12.7	7.8	5.5	4.7

11.4.2.4 Design Line 4 Payback Period Results

Table 11.4.9 presents the summary of the LCC subgroup analysis for rural cooperatives for the representative unit from design line 4, a 150 kVA, liquid-immersed, three-phase distribution transformer. For this unit, DOE forecasts that 53 percent of the transformers are not impacted by TSL 1, while more than 92 percent of transformers are impacted by a TSL 3 standard level or higher. Undefined PBPs remain below four percent of transformers for all TSLs. Mean distribution PBP ranges from 14 to 38 years. PBPs for the average transformer range from 10 to 30 years.

Table 11.4.9 Rural Cooperatives Subgroup Payback Period Results: Design Line 4

	Trial Standard Level									
	1 (TP 1)	2	3	4	5	6	A	B	C	D
Mean Payback (Years)	15.2	16.2	13.7	13.7	31.8	37.5	19.1	16.2	16.2	16.2
Transformers Unaffected by the TSL (%)	52.9	14.8	7.8	7.8	0.1	0.0	7.8	14.8	14.8	14.8
Transformers having Well Defined Payback (%)	43.5	82.4	92.2	92.2	99.0	99.7	92.0	82.4	82.4	82.4
Transformers having Undefined Payback (%)	3.7	2.8	0.0	0.0	0.9	0.3	0.2	2.8	2.8	2.8
Mean Incremental First Cost (\$)	656	910	1631	1631	4167	5136	1638	910	910	910
Mean Operating Cost Savings (\$)	68	77	136	136	166	171	105	77	77	77
Payback of Average Transformer	9.6	11.8	12.0	12.0	25.1	30.0	15.6	11.8	11.8	11.8

11.4.2.5 Design Line 5 Payback Period Results

Table 11.4.10 presents the summary of the LCC subgroup analysis for rural cooperatives for the representative unit from design line 5, a 1500 kVA, liquid-immersed, three-phase distribution transformer. For this unit, DOE forecasts that nearly 66 percent of the transformers are not impacted by TSL 1, while 70 percent of transformers are impacted by a TSL 4 standard level or higher. Undefined PBPs remain two percent or less of transformers for all TSLs. Mean distribution PBP ranges from 13 to 33 years, while the PBPs for the average transformer range from 8 to 28 years.

Table 11.4.10 Rural Cooperatives Subgroup Payback Period Results: Design Line 5

	Trial Standard Level									
	1 (TP 1)	2	3	4	5	6	A	B	C	D
Mean Payback (Years)	13.4	12.4	15.5	17.7	32.7	32.7	25.5	17.7	15.5	15.5
Transformers Unaffected by the TSL (%)	65.5	59.9	42.0	30.1	0.0	0.0	2.0	30.1	42.0	42.0
Transformers having Well Defined Payback (%)	32.6	39.4	57.0	69.2	99.7	99.7	98.0	69.2	57.0	57.0
Transformers having Undefined Payback (%)	1.9	0.7	1.0	0.7	0.2	0.2	0.0	0.7	1.0	1.0
Mean Incremental First Cost (\$)	2377	3618	4161	5330	22930	22930	9830	5330	4161	4161
Mean Operating Cost Savings (\$)	300	412	398	435	830	830	582	435	398	398
Payback of Average Transformer	7.9	8.8	10.5	12.2	27.6	27.6	16.9	12.2	10.5	10.5

11.4.3 Vault Transformer Subgroup Payback Period Results

The LCC results for the vault transformer subgroup are a reflection of a key feature of this subgroup: Distribution transformers at the higher efficiency levels have larger volumes and higher installation costs from vault modifications. This can dramatically decrease the economic benefits from the highest standard levels of TSLs 5 and 6.

11.4.3.1 Design Line 5 Payback Period Results, Medium Vault Cost Case

Table 11.4.11 presents the summary of the LCC subgroup analysis for rural cooperatives for the representative unit from design line 5, a 1500 kVA, liquid-immersed, three-phase distribution transformer for the medium vault cost case. For this unit, DOE forecasts that the results are similar to the results for the general population of transformers. Undefined PBPs remain two percent or less of transformers for all TSLs. Mean distribution PBP ranges from 7 to 28 years, while the PBPs for the average transformer range from 5 to 23 years.

Table 11.4.11 Vault Transformer Subgroup Payback Period Results, Medium Vault Cost Case: Design Line 5

	Trial Standard Level									
	1 (TP 1)	2	3	4	5	6	A	B	C	D
Mean Payback (Years)	7.1	8.2	12.6	23.7	34.3	34.3	20.2	23.7	12.6	12.6
Transformers Unaffected by the TSL (%)	66.6	49.0	40.4	4.8	0.0	0.0	0.0	4.8	40.4	40.4
Transformers having Well Defined Payback (%)	33.4	49.8	59.5	93.0	100.0	100.0	98.5	93.0	59.5	59.5
Transformers having Undefined Payback (%)	0.0	1.2	0.1	2.2	0.0	0.0	1.5	2.2	0.1	0.1
Mean Incremental First Cost (\$)	2857	2985	5101	7002	32453	32453	10358	7002	5101	5101
Mean Operating Cost Savings (\$)	525	498	609	528	1176	1176	690	528	609	609
Payback of Average Transformer	5.4	6.0	8.4	13.3	27.6	27.6	15.0	13.3	8.4	8.4

11.4.3.2 Design Line 5 Payback Period Results, Very High Vault Cost Case

Table 11.4.12 presents the summary of the LCC subgroup analysis for rural cooperatives for the representative unit from design line 5, a 1500 kVA, liquid-immersed, three-phase distribution transformer for the very high vault cost case. For this unit, DOE forecasts that the results are similar to the results for the general population of transformers, except for the highest standard levels of TSLs 5 and 6. Undefined PBPs remain two percent or less of transformers for all TSLs. Mean distribution PBP ranges from 7 to 71 years, while the PBPs for the average transformer range from 5 to 61 years.

Table 11.4.12 Vault Transformer Subgroup Payback Period Results, Very High Vault Cost Case: Design Line 5

	Trial Standard Level									
	1 (TP 1)	2	3	4	5	6	A	B	C	D
Mean Payback (Years)	7.0	8.2	12.6	23.7	98.7	98.7	20.1	23.7	12.6	12.6
Transformers Unaffected by the TSL (%)	66.6	49.0	40.4	4.8	0.0	0.0	0.0	4.8	40.4	40.4
Transformers having Well Defined Payback (%)	33.4	49.8	59.5	93.0	100.0	100.0	98.2	93.0	59.5	59.5
Transformers having Undefined Payback (%)	0.0	1.2	0.1	2.2	0.0	0.0	1.8	2.2	0.1	0.1
Mean Incremental First Cost (\$)	2857	2985	5101	7002	226540	226540	10224	7002	5101	5101
Mean Operating Cost Savings (\$)	525	498	609	528	1154	1154	687	528	609	609
Payback of Average Transformer	5.4	6.0	8.4	13.3	196.3	196.3	14.9	13.3	8.4	8.4

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1. U.S. Department of Energy - Energy Information Administration. *Form EIA-861: Annual Electric Utility Data*. 2003. (Last accessed September, 2005.) This material is available in Docket #86. Contact Ms. Brenda Edwards-Jones, U.S. Department of Energy, Building Technologies Program, Mailstop EE-2J, 1000 Independence Avenue, SW, Washington, DC, 20585-0121, telephone (202) 586-2945 for more information. <<http://www.eia.doe.gov/cneaf/electricity/page/eia861.html>>