

Land-use and Energy Practices on US Golf Courses

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KEYWORDS. best management practice, fuel, turfgrass

ABSTRACT. Golf facilities require a large area and consume energy to operate. As such, golf facilities have the potential to influence ecosystems and contribute to national and regional energy demands. The objective of this study was to document the land-use and energy practices of US golf facilities in 2021 and to determine if changes have occurred since 2005. A survey was distributed via e-mail to 13,938 US golf facilities, with 1861 responding. From 2005 to 2021, the projected acres of maintained turfgrass declined by 14.2%, whereas the median maintained turfgrass acreage declined by 3.0% indicating the decline in projected acres was likely a result of facility closures. In 2021, water features, turfgrass, and natural areas accounted for 92% of the total projected facility acres. More golf facilities used cleaner energy sources, such as natural gas and solar-electric, and fewer golf facilities used gasoline and diesel in 2021 than in 2005. The percentage of golf facilities at which behavioral changes were implemented to decrease energy use declined but design changes increased from 2005 to 2021. Golf facilities became more land and energy efficient from 2005 to 2021 by reducing the acreage of maintained turfgrass and increasing the use of clean energy sources, but room for improvement still exists in human behaviors that affect energy use.

In 2018, it was estimated that golf contributed \$84 billion to the US economy, supported 2 million jobs, and provided \$59 billion in compensation (Ozawa et al. 2016). Thus, golf is a valuable part of US culture. By nature, golf requires a large area to accommodate

the game's needs. Golf facilities often comprise a variety of areas and structures that may have anthropogenic and natural influences on the environment, economy, and society such as turfgrass, aquatic features, native/natural areas, parking lots, buildings, and so on. In addition, golf facilities require energy to operate, which includes everything from fuel for machines to electricity for office equipment. Human behavior and facility design that govern energy use

can have an environmental impact. To best evaluate golf facilities environmental impact and adoption of best management practices, it is critical that the land-use and energy practices of golf facilities are periodically measured.

The first known assessment of golf facility land use was conducted in 2006 (Lyman et al. 2007) and then reassessed in 2015 (Gelernter et al. 2017a). From 2005 to 2015, the projected total area of US golf facilities declined by 4.9%, whereas the projected area of maintained turfgrass on golf facilities declined by 8.3%. Gelernter et al. (2017a) concluded that the reduction in facility acreage was primarily due to facility closures, and the reduction in turfgrass acres was due to both facility closures (55%) and voluntary reduction in maintained turfgrass acres (45%). This conclusion was supported by the finding that the median facility acres did not change between 2005 and 2015, but the median acres of maintained turfgrass declined by 4.1%.

Energy use on US golf facilities was initially measured in 2008 (Lyman et al. 2012) and then reassessed in 2015 (Gelernter et al. 2017b). The percentage of golf facilities that used gasoline and diesel fuel was $\geq 99\%$ and did not differ from 2008 to 2015. The percentage of golf facilities that implemented behavioral or design changes to conserve energy increased from 2008 to 2015 for each parameter measured. Furthermore, the percentage of golf facilities that used a written energy plan and conducted an energy audit also

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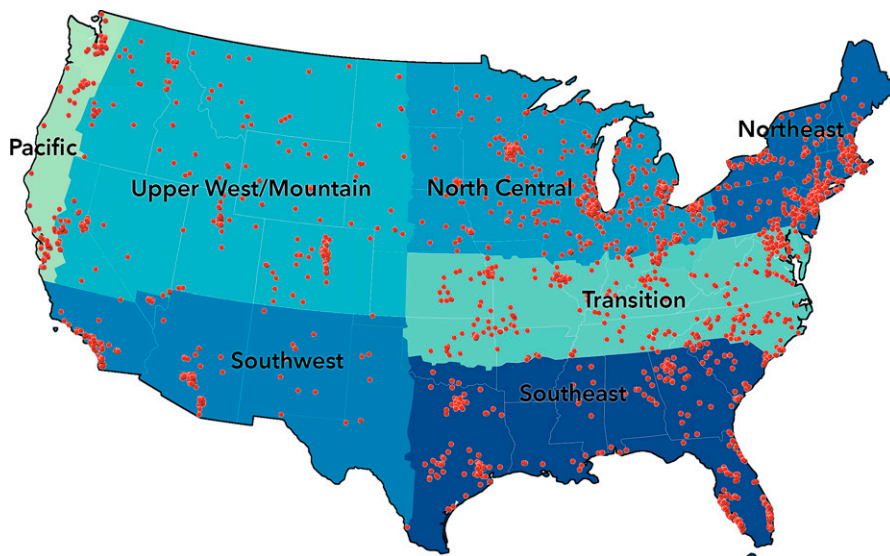


Fig. 1. Distribution of 2021 survey and the seven US agronomic regions.

increased between 2008 and 2015. Thus, prior work has documented that US golf facilities engage in practices to conserve energy.

The land-use and energy practices surveys have proven to play an integral role in education and advocacy. The 2005 and 2015 survey results indicated that the reduction in potential environmental risk occurred not only from facility closures, which is beyond the control of turfgrass managers, but from voluntary reductions in maintained turfgrass. To document changes in the golf course landscape and use of best management practices, continued measurement of land-use and energy practices is essential. Therefore, the objective of this survey was to document the land-use and energy practices of US golf facilities and to determine if changes have occurred since 2005.

Materials and methods

A survey instrument was created that contained identical questions to those used by Gelernter et al. (2017a, 2017b) during prior evaluations of land and energy use on US golf facilities. The survey was distributed in English via online software (Qualtrics, Provo, UT, USA). The electronic mailing lists of the National Golf Foundation (Jupiter, FL, USA) and the Golf Course Superintendents Association of America (Lawrence, KS, USA), which contain the largest known list of golf facilities, was used to distribute a link to the survey to 13,938 unique golf facilities. A golf facility was defined as a business where golf could be played on one or more courses. The survey was opened on 1 Sep 2022 and closed on 17 Oct 2022. Respondents were asked about their land and energy use between 1 Jan and 31 Dec 2021. Respondents' names were omitted and replaced with a unique identification number to maintain anonymity. One response was allowed per golf course. The 2021 land-use data were merged with the original raw data from 2005 and 2015, whereas the 2021 energy-use data were merged with data from 2008 and 2015 which allowed for analysis and reporting across multiple years. Responses were received from 1861 golf facilities, which was 13.3% of the known US total.

Responses were stratified according to their agronomic region (Fig. 1).

Table 1. Total projected and median acreage of golf facilities within the US and regions (Fig. 1) in 2005, 2015, and 2021.

Yr	US	NC ⁱ	NE	Pac	SE	SW	Trans	UWM
Area (acres) ⁱⁱ								
Projected ⁱⁱⁱ								
2005	2,421,605	629,957	394,247	90,282	508,134	198,205	447,796	152,985
2015	2,301,808	585,532	368,877	83,144	501,079	184,562	425,963	152,650
2021	2,131,838	543,227	364,231	72,999	419,552	185,937	367,032	178,861
Median ⁱⁱⁱ								
2005	149 a ^{iv}	158 a	146 a	140 a	140 a	148 a	151 a	151 a
2015	147 a	155 a	141 a	127 a	145 a	140 ab	153 a	149 a
2021	146 a	158 a	153 a	122 a	136 a	130 b	148 a	145 a

ⁱ NC = North Central; NE = Northeast; Pac = Pacific; SE = Southeast; SW = Southwest; Trans = Transition; UWM = Upper West/Mountain.

ⁱⁱ 1 acre = 0.4047 ha.

ⁱⁱⁱ Projected and median values were determined from 18-hole equivalent facilities or only 18-hole facilities, respectively. Projected and median values provide an estimate of all US golf facilities or individual facilities, respectively.

^{iv} Within columns, values followed by a common letter are not significantly different according to Tukey–Kramer test at the 10% significance level.

Table 2. Number of US golf facilities in 2005, 2015, and 2021 by region (Fig. 1) and the projected change in facility and turfgrass acreage between 2005 and 2021.

Region	Golf facilities ⁱ			Change (2005–21)		
	2005	2015	2021	Facility		Turfgrass
	n			Projected area (acres) ⁱⁱ		
US	14,969	14,289	13,167	–1,802	–291,758	–178,994
North Central	3,690	3,476	3,188	–502	–85,540	–49,901
Northeast	2,507	2,445	2,248	–259	–41,883	–27,858
Southeast	3,303	3,078	2,758	–545	–82,906	–52,015
Southwest	1,236	1,207	1,134	–102	–16,724	–8,912
Pacific	594	579	542	–52	–7,004	–5,064
Transition	2,722	2,565	2,303	–419	–66,697	–37,316
Upper West/Mountain	918	940	994	76	13,675	7,676

ⁱ 18-hole equivalents.

ⁱⁱ Projected by multiplying the change in facility numbers by the average facility or turfgrass area; 1 acre = 0.4047 ha.

To provide a valid representation of US golf facilities, data were weighted based on one of 35 categories depending on facility type (public or private), number of golf holes (9, 18, or ≥27), and public green fee (<\$55 or ≥\$55 per

Table 3. Projected and median acreage of maintained turfgrass on golf facilities within the US and regions (Fig. 1) in 2005, 2015, and 2021.

Yr	US	NC ⁱ	NE	Pac	SE	SW	Trans	UWM
Area (acres) ⁱⁱ								
Projected ⁱⁱⁱ								
2005	1,535,767	411,804	241,376	58,509	315,767	128,173	284,941	95,197
2015	1,408,412	368,977	216,187	51,826	298,702	113,168	264,887	94,664
2021	1,316,443	345,840	224,803	47,420	267,277	99,964	234,809	96,329
Median ⁱⁱⁱ								
2005	98 a ^{iv}	107 a	90 ab	94 a	92 a	100 a	100 a	99 a
2015	94 b	102 a	84 b	85 a	92 a	90 b	99 a	95 a
2021	95 b	103 a	94 a	84 a	94 a	84 b	97 a	93 a

ⁱ NC = North Central; NE = Northeast; Pac = Pacific; SE = Southeast; SW = Southwest; Trans = Transition; UWM = Upper West/Mountain.

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ⁱⁱⁱ Projected and median values were determined from 18-hole equivalent facilities or only 18-hole facilities, respectively. Projected and median values provide an estimate of all US golf facilities or individual facilities, respectively.

^{iv} Within columns, values followed by a common letter are not significantly different according to Tukey–Kramer test at the 10% significance level.

round) (Supplemental Table 1). The weights were calculated based on the proportion each group held within the total survey response.

Model residuals were analyzed for normality, both graphically and numerically, with the Shapiro–Wilk W test. Data were also checked graphically for homogeneity of variance. These tests determined data were nonnormal. As a result, data were fit to a log-logistic model, which satisfied assumptions of normality and homogeneity of variance (Gomez and Gomez 1984). Median and frequency values were determined using only

Table 4. Median maintained turfgrass acreage for 9-, 18-, and 27+-hole US golf facilities in 2005, 2015, and 2021.

Yr	9 Holes			18 Holes			27+ Holes		
	Area (acres) ⁱ								
Total									
2005	42.3 aC ⁱⁱ	97.9 aB	142.7 bA						
2015	37.8 bC	93.9 bB	177.3 aA						
2021	36.3 bC	95.0 bB	167.5 aA						
Greens									
2005	1.3 bC	3.1 bB	4.5 bA						
2015	1.4 abC	3.2 aB	5.9 aA						
2021	1.5 aC	3.3 aB	5.9 aA						
Tees									
2005	1.2 bC	3.0 aB	4.7 bA						
2015	1.2 abC	3.1 aB	5.8 aA						
2021	1.3 aC	3.1 aB	5.9 aA						
Fairways									
2005	14.4 aC	28.8 aB	41.2 bA						
2015	13.0 bC	27.7 bB	48.4 aA						
2021	11.5 cC	27.1 bB	48.0 aA						
Roughs									
2005	17.2 aC	48.6 aB	71.6 bA						
2015	15.0 bC	47.2 aB	95.5 aA						
2021	16.6 abC	49.0 aB	88.7 aA						
Practice									
2005	4.1 aC	6.5 aB	8.2 aA						
2015	3.4 bC	5.9 bB	9.1 aA						
2021	3.2 bC	5.9 bB	8.1 aA						
Nursery									
2005	0.8 abB	0.9 aA	1.0 aA						
2015	0.9 aAB	0.9 abB	1.1 aA						
2021	0.6 bB	0.8 bA	0.9 aA						
Grounds									
2005	1.3 aC	2.0 aB	2.5 abA						
2015	1.2 bC	1.7 bB	2.7 aA						
2021	1.1 bC	1.7 bB	2.1 bA						

ⁱ 1 acre = 0.4047 ha.

ⁱⁱ Within columns, values followed by a common lowercase letter are not significantly different according to Tukey–Kramer test at the 10% significance level. Within rows, values followed by a common uppercase letter are not significantly different according to Tukey–Kramer test at the 10% significance level.

Table 5. Median maintained turfgrass acreage of public and private 18-hole US golf facilities in 2021.

Facility type	Total	Greens	Tees	Fairways	Roughs	Practice	Nursery	Grounds
	Area (acres) ⁱ							
Public	93.3 b ⁱⁱ	3.2 b	3.2 a	26.8 b	48.2 a	5.9 a	0.9 a	1.5 b
Private	98.8 a	3.4 a	3.0 b	27.9 a	50.7 a	5.8 a	0.8 a	2.1 a

ⁱ 1 acre = 0.4047 ha.

ⁱⁱ Within columns, values followed by a common letter are not significantly different according to Tukey–Kramer test at the 10% significance level.

18-hole facilities except where facility types were compared by holes. Median separations were performed using Tukey–Kramer test ($\alpha = 0.1$). Golf facility frequency was analyzed using PROC SURVEYFREQ in SAS (ver. 9.4; SAS Institute Inc., Cary, NC, USA) and years were separated by using chi-square test at the 10% significance level on all pairwise comparisons. Projected values were based on 18-hole equivalents, which were calculated by assigning 9-, 18-, and 27-hole facilities an

18-hole-equivalent value of 0.5, 1.0, and 1.5, respectively. Projected values were calculated by multiplying the 18-hole facility average acres by the respective 18-hole-equivalent value. Facility acres were defined as all acres at a golf facility, whereas turfgrass acres were defined as only the acres of turfgrass. Behavioral changes were defined as an alteration in human habitats or behaviors. Design changes were defined as an alteration to facility structures, equipment, or other features.

Table 6. Median maintained turfgrass acreage of 18-hole golf facilities within the US and regions (Fig. 1) in 2005, 2015, and 2021.

Yr	US	NC ⁱ	NE	Pac	SE	SW	Trans	UWM
Greens								
2005	3.1 b ⁱⁱⁱ	3.2 b	3.2 b	2.9 b	2.9 b	3.0 a	3.1 a	3.0 a
2015	3.2 a	3.4 a	3.4 a	3.1 ab	3.0 a	3.1 a	3.2 a	3.1 a
2021	3.3 a	3.5 a	3.6 a	3.3 a	3.0 ab	3.0 a	3.2 a	3.2 a
Tees								
2005	3.0 a	2.9 b	2.6 a	3.0 a	3.4 a	3.3 a	3.2 a	3.2 a
2015	3.1 a	3.1 a	2.6 a	3.0 a	3.3 a	3.1 a	3.4 a	3.2 a
2021	3.1 a	3.1 ab	2.8a	3.2 a	3.4 a	3.1 a	3.3 a	3.0 a
Fairways								
2005	28.8 a	27.4 a	25.5 a	31.4 a	30.8 a	33.0 a	29.0 a	33.4 a
2015	27.7 b	26.6 ab	24.5 a	31.1 a	29.6 ab	30.2 a	27.9 ab	31.0 ab
2021	27.1 b	26.1 b	24.8 a	29.3 a	28.5 b	30.2 a	26.7 b	30.0 b
Roughs								
2005	48.6 a	59.5 a	46.6 ab	43.1 a	41.2 b	45.5 a	50.8 a	44.3 a
2015	47.2 a	55.6 a	42.8 b	36.3 a	43.7 ab	41.9 ab	52.4 a	44.3 a
2021	49.0 a	58.1 a	51.8 a	36.7 a	45.3 a	37.0 b	52.2 a	42.8 a
Practice areas								
2005	6.5 a	7.3 a	5.4 a	5.5 a	6.2 a	7.0 a	6.4 a	7.6 a
2015	5.9 b	6.2 b	4.9 ab	5.3 a	6.0 a	6.1 ab	6.2 a	6.3 a
2021	5.9 b	6.4 b	4.4 b	5.7 a	6.4 a	5.2 b	6.1a	6.8 a
Nursery								
2005	0.9 a	1.0 a	0.9 a	0.9 a	0.9 a	0.7 a	1.1 a	0.9 a
2015	0.9 ab	0.9 a	0.8 ab	0.8 a	0.8 a	0.9 a	1.0 a	0.8 a
2021	0.8 b	0.9 a	0.7 b	0.9 a	0.9 a	0.8 a	0.9 a	0.9 a
Grounds								
2005	2.0 a	2.1 a	2.1 a	1.5 a	2.2 a	1.7 a	1.8 a	1.6 a
2015	1.7 b	1.8 b	1.7 a	1.4 a	1.8 b	1.4 a	1.9 a	1.2 b
2021	1.7 b	1.6 b	1.8 a	1.5 a	1.8 b	1.4 a	1.9 a	1.2 b

ⁱ NC = North Central; NE = Northeast; Pac = Pacific; SE = Southeast; SW = Southwest; Trans = Transition; UWM = Upper West/Mountain.

ⁱⁱ 1 acre = 0.4047 ha.

ⁱⁱⁱ Within columns, values followed by a common letter are not significantly different according to Tukey–Kramer test at the 10% significance level.

Results and discussion

FACILITY ACRES. Facility area of US golf facilities declined by 12% from 2.4 to 2.1 million acres from 2005 to 2021 (Table 1). Except for the Upper West/Mountain region, total acres declined within each US region and ranged from 6% in the Southwest to 19% in the Pacific. Median facility size did not change between 2005 and 2021 nationally or within regions except within the Southwest region which reported a 12% reduction. The projected US total facility acres declined, but the US median facility acres did not. Therefore, the reduction in projected total acres was likely a result of facility closures. Between 2005 and 2021, operational golf facilities were reduced by 1802 facilities, or 12%, resulting in a reduction of 291,758 acres (Table 2). The Upper West/Mountain region was the only region that reported an increase in facilities. Only in the Southwest region did the reduction of facility acres appear to be influenced by both fewer operational facilities and a reduction in median size. The Southwest region was also the only region that reported a reduction in median acres of turfgrass, which declined from 100 to 84 acres between 2005 and 2021 (Table 3).

TURFGRASS ACRES. Median maintained turfgrass acres was greater on 27+-hole facilities than on 9- and 18-hole facilities in 2005, 2015, and 2021 for each course feature except nurseries (Table 4). Maintained turfgrass acres of nurseries were generally equivalent among 9-, 18-, and 27+-hole facilities during each year and were ~1 acre. As golf facilities increase the number of holes, the number of maintained turfgrass acres must also increase. Thus, the greater maintained turfgrass acres at larger facilities was expected. However, the increase was not concomitant to the increase in holes and varied according to course feature. For example, in 2021, maintained rough acres was 2.9- and 5.3-fold greater on 18- and 27+-hole facilities, respectively, than on nine-hole facilities.

Median total maintained turfgrass acres declined on 9- and 18-hole facilities between 2005 and 2021 (Table 4). However, median maintained turfgrass area increased on 27+-hole facilities from 142.7 to 167.5 acres between 2005 and 2021, respectively. The

Table 7. Projected and median acreage of subfeatures on golf facilities within the US and regions (Fig. 1) in 2021.

Region	Bunkers	Buildings	Parking lots	Water features	Natural areas	
						Area (acres) ⁱ
Projected ⁱⁱ						
US	44,631	46,682	42,189	141,746	549,518	
North Central	9,884	10,216	9,701	34,279	135,579	
Northeast	9,528	8,240	8,470	19,688	94,841	
Pacific	1,759	1,316	1,607	2,951	17,038	
Southeast	9,363	10,776	8,067	45,642	82,479	
Southwest	4,197	6,270	4,582	8,064	63,742	
Transition	6,668	6,669	6,563	19,920	94,606	
Upper West/Mountain	3,231	3,195	3,199	11,202	61,233	
Median ⁱⁱ						
US	2.2	2.1	2.2	5.7	23.3	
North Central	2.1 a ⁱⁱⁱ	2.0 a	2.4 a	5.4 bc	23.9 a	
Northeast	2.5 a	2.2 a	2.4 a	4.1 c	31.0 a	
Pacific	1.9 a	1.9 a	2.6 a	3.6 c	19.2 ab	
Southeast	2.4 a	2.4 a	1.9 b	10.2 a	15.2 b	
Southwest	2.3 a	1.9 a	2.2 ab	4.1 bc	24.3 a	
Transition	2.1 a	2.0 a	2.2 ab	5.9 b	25.4 a	
Upper West/Mountain	2.1 a	2.1 a	2.2 ab	5.4 bc	26.1 a	

ⁱ 1 acre = 0.4047 ha.

ⁱⁱ Projected and median values were determined from 18-hole equivalent facilities or only 18-hole facilities, respectively. Projected and median values provide an estimate of all US golf facilities or individual facilities, respectively.

ⁱⁱⁱ Within columns, values followed by a common letter are not significantly different according to Tukey–Kramer test at the 10% significance level.

increase on 27+-hole facilities occurred as a result of increased acres on greens, tees, fairways, and roughs with the largest contribution of 17.1 acres occurring in roughs. The decrease of turfgrass acres on 9-hole and 18-hole facilities

occurred on fairways, practice, nursery, and grounds sites.

In 2021, private golf facilities reported maintaining 5.5 acres more turfgrass than public golf facilities (Table 5). Private golf facilities also

Table 8. Median acreage of impervious surfaces on 18-hole golf facilities within the US and regions (Fig. 1) in 2005, 2015, and 2021.

Yr	US	NC ⁱ	NE	Pac	SE	SW	Trans	UWM
Cart paths								
2005	1.7 b ⁱⁱⁱ	1.0 b	0.9 b	2.6 a	2.4 a	2.2 a	2.9 b	1.2 a
2015	2.0 a	1.2 ab	1.0 ab	2.9 a	2.7 a	2.6 a	3.3 a	1.5 a
2021	2.1 a	1.4 a	1.2 a	2.8 a	2.8 a	2.3 a	3.5 a	1.8 a
Parking lots								
2005	3.1 a	3.1 a	3.2 a	3.2 a	3.2 a	3.1 a	3.1 a	3.0 a
2015	2.1 b	2.2 b	2.2 b	2.5 a	2.0 b	2.0 b	2.2 b	2.0 b
2021	2.0 b	2.1 b	2.1 b	2.5 a	1.8 b	2.1 b	2.0 b	1.9 b
Buildings								
2005	3.6 a	3.4 a	3.6 a	3.1 a	3.9 a	3.6 a	3.9 a	3.1 a
2015	2.2 b	2.0 b	2.2 b	2.1 b	2.4 b	1.9 b	2.2 b	2.0 b
2021	2.1 b	2.0 b	2.2 b	1.9 b	2.4 b	1.9 b	2.0 b	2.1 b
Total								
2005	9.6 a	8.8 a	8.5 a	10.0 a	10.4 a	9.4 a	10.9 a	8.5 a
2015	7.3 b	6.3 b	6.6 b	8.1 a	7.9 b	7.0 b	8.5 b	6.6 b
2021	7.1 b	6.5 b	6.4 b	7.9 a	7.3 b	7.2 b	8.2 b	6.1 b

ⁱ NC = North Central; NE = Northeast; Pac = Pacific; SE = Southeast; SW = Southwest; Trans = Transition; UWM = Upper West/Mountain.

ⁱⁱ 1 acre = 0.4047 ha.

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reported maintaining greater acres of greens, fairways, and grounds than public facilities. Conversely, public golf facilities maintained 6.6% greater acres of tees than private facilities. Private golf facilities operate with greater budgets than public facilities (Golf Course Superintendents Association of America 2021) and we postulate that facilities with larger budgets are capable of maintaining greater acres of turfgrass than facilities with smaller budgets.

Nationally, median area of greens increased from 2005 to 2021 from 3.1 to 3.3 acres (Table 6). Median area of greens also increased by 0.3, 0.4, and 0.4 acres in the North Central, Northeast, and Pacific regions, respectively. Although putting greens commonly account for less than 4% of the total maintained turfgrass acres on US golf facilities, putting green management is typically more intensive and requires greater resources per acre than areas such as fairways and roughs. To this end, the increase in putting green acres may disproportionately influence a golf facility's energy requirements. Median acres of tees did not change nationally or within any region between 2005 and 2021. In 2021, median area of fairways was 27.1 acres, which was a decline of 5.9% nationally from 2005 to 2021. Median fairway acres also declined within each region except the Northeast, Pacific, and Southwest, which reported no change between 2005 and 2021. The change in median acres of roughs between 2005 and 2021 varied according to regions with no change reported nationally. The Southeast reported a 10.0% increase in median rough acres between 2005 and 2021, whereas the Southwest reported an 18.7% decrease. The decline in maintained turfgrass acres in the Southwest may be a result of increased cost or reduced access to irrigation water. Shaddox et al. (2022) reported water use in the Southwest exceeded that reported in other US regions in large part due to the high heat and low precipitation common to the region. Thus, golf facilities faced with increased cost of water and/or reduced access to water may be electing to remove turfgrass acres to remain operational and within budget. More research in this area would

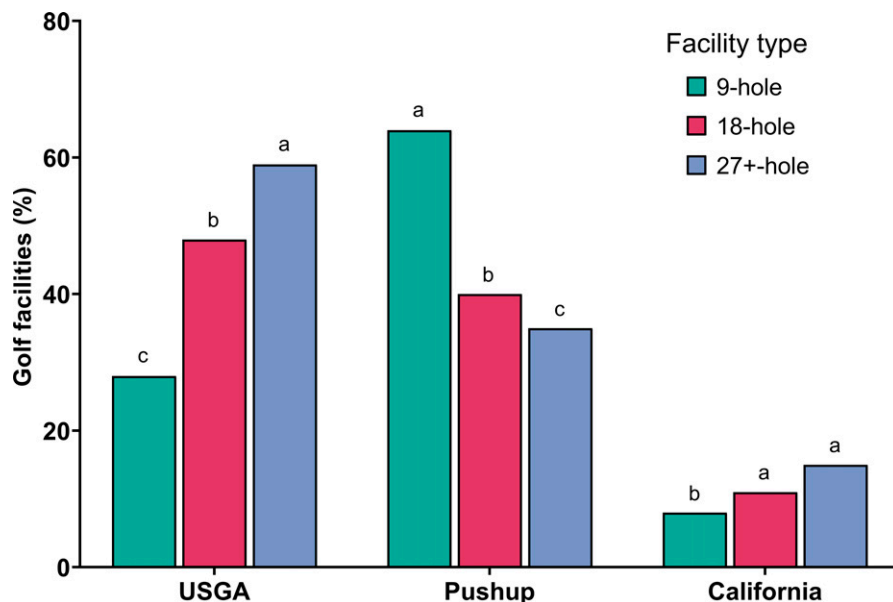


Fig. 2. Frequency of 9-, 18-, and 27+-hole US golf facilities that reported having putting greens constructed according to US Golf Association (USGA) specifications (85% sand and 15% amendment root zone), pushup (existing soil root zone), or California-style (100% sand root zone). Bars with a common letter are not significantly different according to chi-square test at the 10% significance level.

provide greater confidence in this postulate.

IMPERVIOUS SURFACES. The median acres of bunkers and buildings were similar across regions (Table 7). The Southeast reported the fewest acres of parking lots and the greatest median acres of water features, which

was 1.8-fold greater than the national median. The Pacific, Southwest, and Northeast reported the least median area of water features at 3.6, 4.1, and 4.1 acres, respectively. The Southeast reported the fewest median area of natural areas at 15.2 acres, which was less than all other regions except the

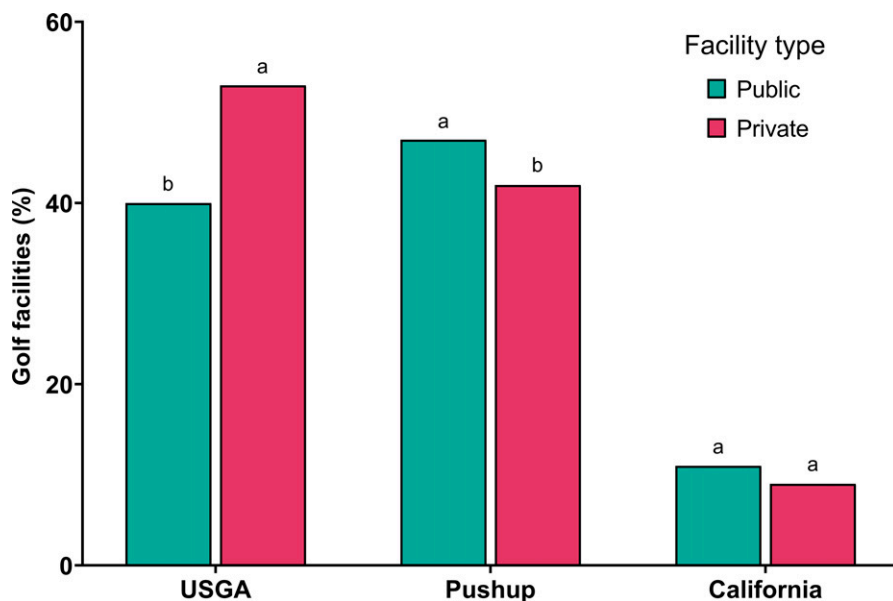


Fig. 3. Frequency of public and private US golf facilities that reported having putting greens constructed according to US Golf Association (USGA) specifications (85% sand and 15% amendment root zone), pushup (existing soil root zone), or California-style (100% sand root zone). Bars with a common letter are not significantly different according to chi-square test at the 10% significance level.

Table 9. Frequency of 18-hole US golf facilities that made an addition or improvement to the listed feature during the 5 years preceding 2005, 2015, and 2021.

Added or improved feature	2005	2015	2021
	Golf facilities (%)		
Irrigation system	66 a ⁱ	62 b	56 c
Recycling	39 b	55 a	42 b
Native plantings	51 a	42 b	38 c
Wildlife habitat	48 a	42 b	32 c
Chemical storage	51 a	38 b	30 c
Erosion control	43 a	36 b	29 c
Buffer strips	33 a	33 a	24 b
Waste reduction	26 b	30 a	22 c
Wild pollinator habitat (not including beehives/apiaries)	– ⁱⁱ	10 b	20 a
Equipment washing stations	32 a	19 b	18 b
Chemical mix and load pads	27 a	20 b	17 c
Stream bank restoration	20 a	19 ab	17 b
Composting	24 a	18 b	17 b
Stormwater retention	23 a	17 b	13 c
Petroleum storage tank	39 a	16 b	12 c
Wetland construction/restorations	17 a	13 b	10 c
Alternate water source	13 a	12 a	9 b
Beehives/apiaries	–	5 b	8 a
Capped/closed water wells	14 a	9 b	4 c
Rain garden	–	2 a	2 a

ⁱ Within rows, values followed by a common letter are not significantly different according to chi-square test at the 10% significance level.

ⁱⁱ Question not asked in 2005.

Pacific. Nationally, water features, turf-grass, and natural areas accounted for 92% of the total projected facility acres in 2021 (Tables 1, 3, and 7).

The median of total impervious surfaces on US golf facilities decreased by 26% between 2005 and 2021 (Table 8).

Similarly, impervious surfaces of parking lots and buildings decreased between 2005 and 2021 by 35% and 42%, respectively. In contrast, impervious acres of cart paths increased 24% to 2.1 acres from 2005 to 2021. Generally, decreases were observed within each region for

impervious parking lots and buildings except for parking lots in the Pacific where no change was measured between years. Changes in the impervious acres of cart paths between 2005 and 2021 varied depending on regions with increases measured in the North Central, Northeast, and Transition and no changes measured in all remaining regions. Impervious surfaces have been identified as a contributor to stormwater runoff and, to that end, may result in detrimental effects on aquatic ecosystems [US Environmental Protection Agency (USEPA) 2023]. Thus, the overall reduction in the median impervious surfaces on US golf facilities may be viewed as beneficial. The median increase of impervious cart paths may be minimized, or potentially reduced, if golf facilities incorporate permeable pavement technologies (USEPA 2021).

PUTTING GREEN CONSTRUCTION. Golf course putting greens are constructed according to one of three specifications. The US Golf Association (USGA) specification requires the root zone be constructed of 85% sand and 15% amendment, such as peat. California-style putting greens consist of a 100% sand root zone, and “push-up” putting greens are created by “pushing up” the existing soil. Putting greens constructed according to USGA recommendations were reported on 59% of 27+-hole facilities (Fig. 2). Inversely, 64% of nine-hole

Table 10. Frequency of fuel source on 18-hole US golf facilities in 2008, 2015, and 2021.

Energy source	2008	2015	2021
	Golf facilities (%)		
Gasoline	98.3 a ⁱ	98.4 a	94.7 b
Diesel	94.7 a	95.5 a	89.0 b
Natural gas	21.1 b	22.7 b	44.0 a
Propane	35.7 ab	32.8 b	39.0 a
Heating oil	7.4 a	8.3 a	8.1 a
Solar electric	1.3 b	4.4 a	5.2 a
Biodiesel	3.7 a	4.2 a	3.3 a
Geothermal	0.1 b	0.1 b	1.4 a
Hydroelectric	0.2 b	0.0 ⁱⁱ	1.1 a
Solar heat	0.3 a	0.0	0.7 a
Wind	0.5 a	0.0	0.6 a
Waste biomass	0.0	0.0	0.6
Methane	0.1 b	0.0	0.3 a
Hydrogen	0.0	0.0	0.0

ⁱ Within rows, values followed by a common letter are not significantly different according to chi-square test at the 10% significance level.

ⁱⁱ Values without variability were not analyzed.

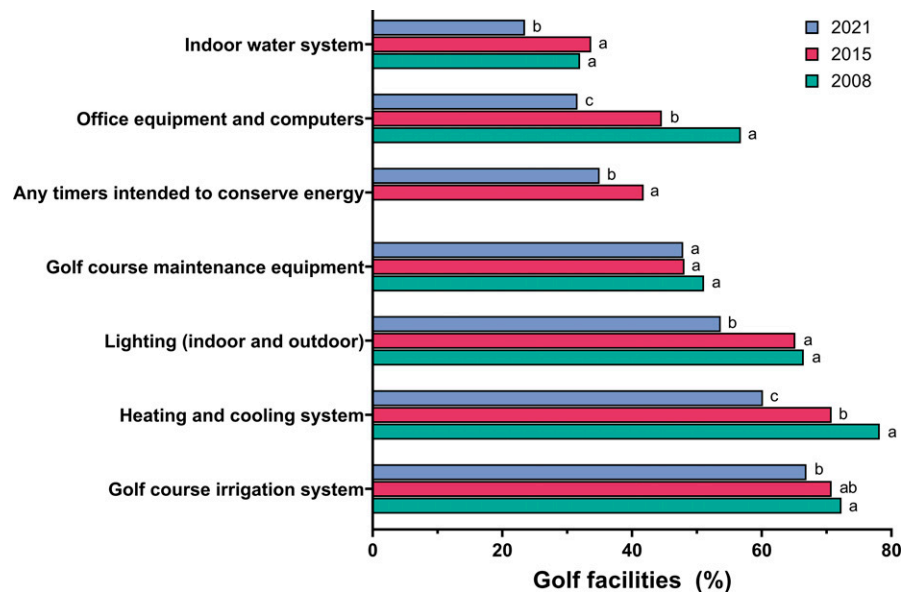


Fig. 4. Frequency of US golf facilities that reported incorporating behavioral, procedural, or practice changes that may conserve energy in 2008, 2015, and 2021. Bars with a common letter are not significantly different according to chi-square test at the 10% significance level.

facilities reported having pushup-greens, which was greater than both 18- and 27+-hole facilities. California-style putting greens were the least common of the three putting green styles with 15% of 27+-hole facilities reporting having them. This was equivalent to 18-hole facilities but greater than nine-hole facilities. Pushup greens are commonly the least expensive construction method because the green is constructed from existing soil. As a result, no additional resources such as sand and peat are required, and they typically lack internal drainage systems. In addition, the budget of a golf facility increases as the number of holes increases. We postulate that USGA-recommended and California-style greens are more common on 27+-hole facilities than nine-hole facilities because they operate with larger budgets. This postulate appears to be supported by results of public and private facilities (Fig. 3). A greater percentage of private golf facilities reported having USGA-recommended greens and a lower percentage reported having pushup greens compared with public facilities. No differences between public and private facilities were measured with California-style greens.

FACILITY ADDITIONS AND IMPROVEMENTS. Within the 5 years preceding each survey, facilities implementing changes either by adding or improving existing facility features waned in 2021. Each facility addition or improvement to features that may reduce environmental impact declined from 2005 to 2021 except recycling, which did not change from 2005 to 2021 (Table 9). Despite the reduction, a large percentage of golf facilities use these features. Irrigation systems, recycling, and native plantings were improved or added by 56%, 42%, and 38% of golf facilities in 2021. Additions or improvements to wild pollinator habitats and apiaries, which were added in the 2015 survey, increased from 2015 to 2021 to 20% and 8% of golf facilities, respectively.

ENERGY USE AND MANAGEMENT. The frequency of golf facilities using gasoline and diesel fuel declined between 2005 and 2021 to 94.7% and 89.0%, respectively (Table 10). Whereas the use of natural gas more than doubled from 2005 to 2021 to 44% of golf facilities. The use of solar-electric, geothermal, and hydro-electric energy

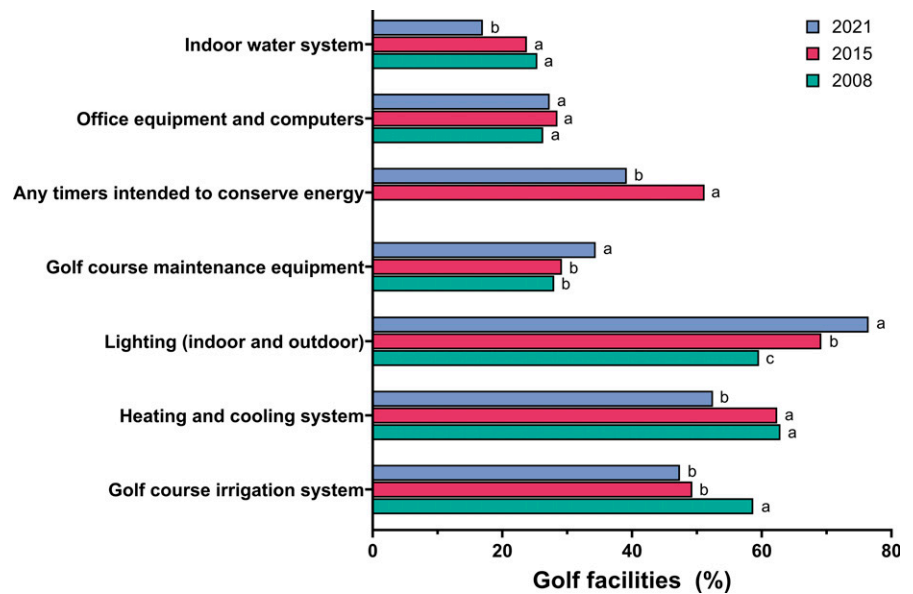


Fig. 5. Frequency of US golf facilities that reported incorporating physical, mechanical, or design changes to equipment that may conserve energy in 2008, 2015, and 2021. Bars with a common letter are not significantly different according to chi-square test at the 10% significance level.

sources increased more than 4-fold from 2005 to 2021 to 5.2%, 1.4%, and 1.1%, respectively. Although the percentage of facilities using cleaner energy sources remains low, an increase from 2005 to 2021, coupled with a decrease in gasoline and diesel, may indicate that golf facilities are exploring alternatives to gasoline and diesel. These findings may be a result of voluntary or compulsory change via governmental regulations. In

some locations, such as California, regulations have been implemented since 2005 that prohibit engine exhaust and evaporative emissions from small off-road engines, which includes some turfgrass maintenance equipment (California Senate 2021). Such regulations have been identified as potential sources of behavioral change on golf facilities (Shaddox et al. 2023). The survey instrument was not designed

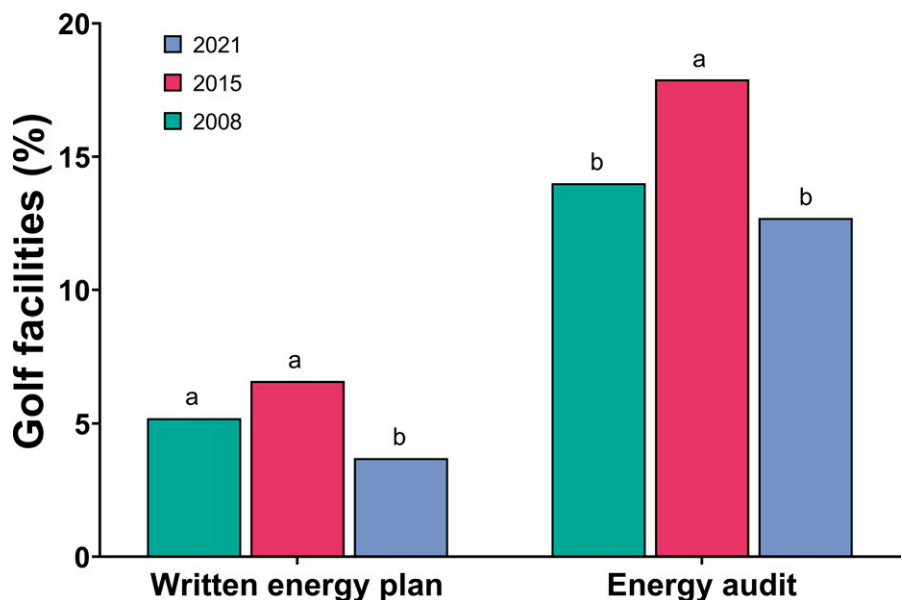


Fig. 6. Frequency of US golf facilities that reported having a written energy plan in 2008, 2015, and 2021 or conducting an energy audit in the 5 years preceding 2008, 2015, and 2021. Bars with a common letter are not significantly different according to chi-square test at the 10% significance level.

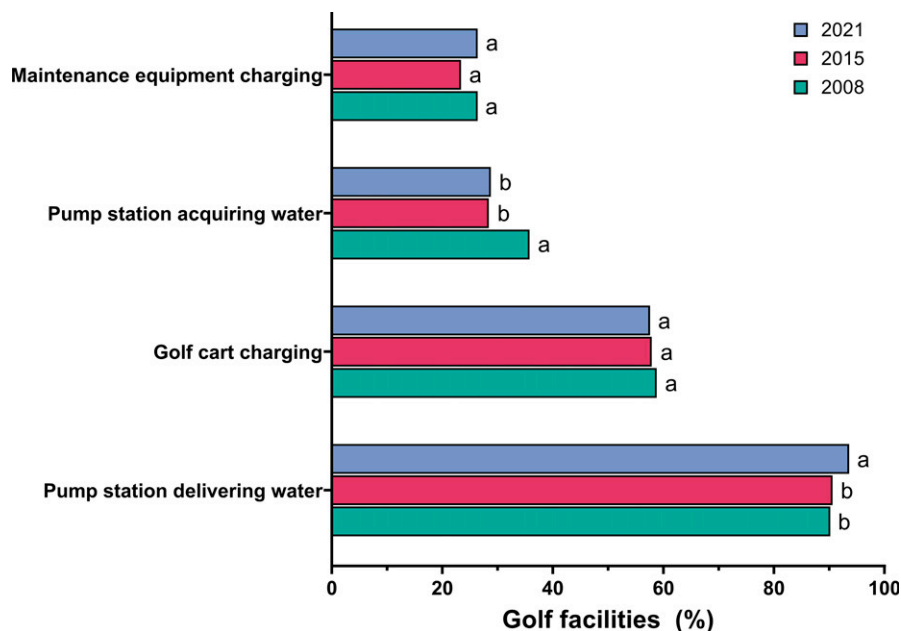


Fig. 7. Frequency of US golf facilities that reported conducting the listed practice during nonpeak energy hours in 2008, 2015, and 2021. Bars with a common letter are not significantly different according to chi-square test at the 10% significance level.

to determine the cause of behavioral changes. Thus, more research in this area would be necessary to determine whether voluntary and/or compulsory actions contributed to these changes.

The percentage of golf facilities that implemented behavioral, procedural, or practice changes that may conserve energy decreased from 2008 to 2021 for each category except golf course maintenance equipment, which did not change from 2008 to 2021 (Fig. 4). A similar result was measured for golf facilities that implemented physical, mechanical, or design changes except for the categories of lighting and golf course maintenance equipment in which more golf facilities implemented changes to equipment that may conserve energy in 2021 than in 2008 (Fig. 5). Why nearly all behavioral changes declined, whereas some physical changes increased is unknown. However, golf facilities may perceive behavioral changes as more challenging than physical changes. For example, implementing a policy to use lights made from light-emitting diodes instead of incandescent or florescent lights may be viewed as easier to adopt than implementing a policy that requires a person to turn off the lights when the light is not in use. Regardless, determining the cause of these results was beyond the scope of this study and

would require a more robust survey to provide any confidence in this postulate.

The percentage of golf facilities that use a written energy plan remained below 5% and was less than that reported in 2008 (Fig. 6). The percentage of facilities that conducted an energy audit was 13% in 2021 and was equivalent to 2008. The percentage of golf facilities that charged maintenance equipment and golf carts during non-peak hours was 26% and 58%, respectively, and were equivalent to 2008 (Fig. 7). The percentage of golf facilities that delivered water to the pump station during non-peak hours increased to 94% from 2008 to 2021, whereas the percentage of golf facilities that acquired water for the pump station during non-peak hours declined to 29% from 2008 to 2021.

Conclusions

Since 2005, golf facilities have not reduced the median facility area but have reduced the median area of maintained turfgrass while simultaneously reducing the area of impervious surfaces. This indicates that golf facilities, whether compulsory or voluntary, have made changes that align with best management practices of land-use intended to reduce environmental impact. However, many best

management practices were less frequently implemented in 2021 than 2008 and 2015. While this report does not provide the overall frequency of these specific practices, golf facilities are encouraged to revisit land-use best management practices and determine which can be implemented and to what degree.

Golf facilities appear to be incorporating cleaner energy sources into their operations as evidenced by the reduction in facilities using gasoline and diesel and the increase in facilities using natural gas and solar-electric energy sources. The increase in facilities implementing design changes and decrease in facilities implementing behavior changes to reduce energy use may highlight the challenges of changing human behavior.

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Supplemental Table 1. 2021 land and energy survey responses and weighting factors categorized by region (Fig. 1), facility type, number of holes, and green fee.

Region	Facility type	Holes (no.)	Green fee (\$)	Golf facilities		Survey responses		Wt
				(no.)	(%)	(no.)	(%)	
Northeast	All	9	All	629	4.5	47	2.5	1.787
Northeast	Public	18	<55	458	3.3	26	1.4	2.352
Northeast	Public	18	≥55	590	4.2	88	4.7	0.895
Northeast	Private	18	All	576	4.1	124	6.7	0.620
Northeast	All	27+	All	178	1.3	22	1.2	1.080
North Central	All	9	All	1125	8.1	48	2.6	3.129
North Central	Public	18	<55	1085	7.8	90	4.8	1.610
North Central	Public	18	≥55	563	4.0	96	5.2	0.783
North Central	Private	18	All	451	3.2	115	6.2	0.524
North Central	All	27+	All	296	2.1	58	3.1	0.681
Transition	All	9	All	625	4.5	31	1.7	2.692
Transition	Public	18	<55	761	5.5	85	4.6	1.195
Transition	Public	18	≥55	394	2.8	60	3.2	0.877
Transition	Private	18	All	517	3.7	116	6.2	0.595
Transition	All	27+	All	174	1.2	41	2.2	0.567
Southeast	All	9	All	442	3.2	10	0.5	5.902
Southeast	Public	18	<55	679	4.9	55	3.0	1.648
Southeast	Public	18	≥55	529	3.8	76	4.1	0.929
Southeast	Private	18	All	676	4.9	153	8.2	0.590
Southeast	All	27+	All	342	2.5	78	4.2	0.585
Southwest	All	9	All	235	1.7	8	0.4	3.922
Southwest	Public	18	<55	142	1.0	19	1.0	0.998
Southwest	Public	18	≥55	353	2.5	37	2.0	1.274
Southwest	Private	18	All	217	1.6	39	2.1	0.743
Southwest	All	27+	All	169	1.2	34	1.8	0.664
Upper West/Mountain	All	9	All	416	3.0	25	1.3	2.222
Upper West/Mountain	Public	18	<55	167	1.2	34	1.8	0.656
Upper West/Mountain	Public	18	≥55	328	2.4	83	4.5	0.528
Upper West/Mountain	Private	18	All	159	1.1	45	2.4	0.472
Upper West/Mountain	All	27+	All	79	0.6	22	1.2	0.479
Pacific	All	9	All	166	1.2	9	0.5	2.463
Pacific	Public	18	<55	44	0.3	4	0.2	1.469
Pacific	Public	18	≥55	202	1.4	42	2.3	0.642
Pacific	Private	18	All	116	0.8	27	1.5	0.574
Pacific	All	27+	All	55	0.4	14	0.8	0.525