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Video game console usage and national energy consumption: Results from a field-metering study

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1. Introduction

The share of residential electricity consumption attributable to non-appliance plug loads (often termed miscellaneous electronic loads; MELs) is rising (EIA 2013, IEA 2009). The main causes are increasing efficiency in traditional end uses such as space conditioning, lighting, and major household appliances, and the proliferation of devices in the home. Consumer electronics in particular are one of the fastest growing electricity end uses (IEA 2009). As a result, energy analysts and policymakers worldwide recently have begun to seriously and systematically attempt to understand and characterize the electricity usage of consumer electronics. It is a research area that is not yet fully mature, is lacking in energy use data, and deals with products that evolve very rapidly.

Video game consoles in particular have attracted recent attention, given that 49% of U.S. households own a console (CEA 2012). Some newest generation consoles are high-performance machines with advanced graphics processing capability that draw a considerable amount of power (*e.g.*, Microsoft Xbox 360, Sony PlayStation 3). Other consoles consume less power but appeal to a wider audience, increasing household penetration (*e.g.*, Nintendo Wii). As a result, the total national electricity consumption of game consoles is thought to be significant, potentially as high as 16 terawatt-hours per year (TWh/yr) (Neugebauer et al. 2008). Such national energy use estimates must rely on power draw and usage pattern data. The power draw of various game console models is easily tested. The precise usage pattern and its cumulative distribution, however, are largely unknown, limiting the robustness of energy use estimates. Some indications of video game console usage do exist from various sources (*e.g.*, Nielsen 2010), but these only indicate active usage of the console, and do not account for idling behavior, particularly when the television is off. Ultimately studies must rely on assumptions to complete the calculations, leading to a wide range of total national energy use estimates between 2.6-16 TWh/yr (Hittinger et al. 2012, Urban et al. 2011, Desroches & Garbesi 2011, Neugebauer et al. 2008, Roth & McKenney 2007). These more recent estimates, however, all mark a significant increase in video game console energy use as compared to early estimates from over a decade ago. Rosen et al. (2001) estimated national energy use at 0.5 TWh in 1999, and Sanchez et al. (1998) estimated national energy use at 1.5 TWh in 1995, suggesting that overall game console energy use is definitely on the rise.

One complication with modern video game consoles is that they have more functionality than simply video gaming. The latest game consoles also play removable media such as DVD or Blu-ray movies, and can access online media services (*e.g.,* Netflix, Hulu). This has the potential to vastly increase the energy use attributable to game consoles beyond that estimated from game playing time alone. Indeed, the latest trends suggest that gaming accounts for only 46-66% of console usage, depending on the specific console (Nielsen 2013). Game playing time is therefore not indicative of total usage, especially if the console is heavily utilized for its additional functionality. Additionally, many game consoles do not effectively employ power management and/or power scaling, and some games are developed with limited save options (*e.g.,* can only save a game at certain checkpoints). This leads to a phenomenon where a consumer leaves the game console on and fully powered when away from the TV, to avoid losing the current game state (first highlighted by Neugebauer et al. 2008). Energy use estimates relying on game playing time alone may not adequately account for this effect. The lack of data on the above issues potentially gives rise to the discrepancy between various energy use estimates in the literature.

The most accurate way to account for all of these issues, and to directly measure the usage of video game consoles, is to monitor the electricity usage using an electricity meter. Electricity meters, however can be expensive, and the task of installing them in many households is logistically challenging. Most studies rely on laboratory measurements with high-level estimates of usage (Hittinger et al. 2012, Desroches & Garbesi 2011, Neugebauer et al. 2008), or they rely on survey data for usage (Urban et al. 2011). Although surveys are simpler to deploy, they are less accurate and potentially suffer from social desirability and recollection biases. Studies using electricity meters have yielded only limited data with respect to game consoles thus far (Bensch et al. 2010).

In this report we present an analysis based on video game console usage data collected as part of a larger field data collection study (Greenblatt et al. 2013). This study collected data from 880 households in 2012 on a variety of MELs, including 113 video game consoles. These data will help to reduce uncertainty in national game console energy use estimates. The report includes a brief discussion of the data collection methodology in section 2, presents results in section 3, and compares results to previously published estimates of national game console energy use in section 4. Finally, the report is summarized in section 5.

2. Data and Methodology

The data analyzed in this report were collected as part of a MELs field metering study in collaboration with Rising Sun Energy Center[1], a non-profit organization providing workforce development services, residential retrofits, and education on sustainable behaviors and technologies. A total of 1176 electricity meters were deployed in 880 households by a team of Energy Specialists from Rising Sun, in conjunction with their free energy audit program. Meters were installed in fourteen cities in the San Francisco Bay Area between July 2 and August 4, 2012, and left in the field between three to ten weeks. For more details on the overall study design and deployment, see Greenblatt et al. (2013).

With respect to video game consoles, data were collected from two types of energy meters. The WattsUp?.Net meters[2] (hereafter “WattsUp”) recorded full time series electric power data, using a 2-minute time interval. The Kill-A-Watt meters[3] recorded only cumulative energy use (in kilowatt-hours) over the total elapsed time since installation, resulting in one measurement per console. These meters are less expensive and simpler to install than the WattsUp meters, and enabled us to target a greater number of game consoles as part of the study. A total of 94 WattsUp meters and 81 Kill-A-Watt meters were deployed in the field connected to game consoles. A small fraction of meters were unrecoverable, and some meters had data quality issues due primarily to multiple power outages (see Greenblatt et al. 2013 for more details). In addition, a few individual meters displayed power readings that were anomalous and highly unlikely to have originated from a game console. This was either the result of misidentified devices or a malfunctioning meter. These meters were eliminated from further analysis. Meters from unidentified game consoles were similarly not included in further analysis. After data

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[1] http://www.risingsunenergy.org
[2] https://www.wattsupmeters.com/secure/products.php?pn=0
[3] http://www.p3international.com/products/p4460.html

processing and cleaning was complete, records with less than one week of clean data were also excluded from further analysis, as we considered this sampling to be insufficient and unrepresentative. The analysis presented here includes game console data from 58 WattsUp meters and 55 Kill-A-Watt meters, as listed in Table 1.

Also shown in Table 1 are the estimated cumulative North American sales for each major game console as of March 2013 (VGChartz 2013). For the latest generation hardware (Microsoft Xbox 360, Nintendo Wii, Sony PlayStation 3), our sampling is in approximate agreement with the total stock of these devices, although this assumes the retirement rate is not any different between these devices. We are perhaps slightly undersampling Xbox 360 consoles and oversampling PlayStation 3 consoles, but as our analysis below shows, the usage and energy consumption are very similar between these two consoles. As a result, we believe our final conclusions are minimally affected by this sampling bias. For the Sony PlayStation 2, the console is quite old by industry standards, and no new game titles are being produced. We therefore expect the retirement rate to be quite high, as reflected in our sampling.

Table 1: Individual game console models metered, by meter type. Estimated cumulative North American sales from VGChartz (2013).

Console Type	WattsUp Meter	Kill-A-Watt Meter	Total	Cumulative NA Sales (millions)
Microsoft Xbox 360	17	12	29	42.5
Nintendo Wii	20	22	42	44.5
Sony PlayStation 3	16	19	35	26.2
Sony PlayStation 2	5	2	7	53.7
All	58	55	113	-

In order to perform a detailed usage analysis, the time series data were labeled as belonging to one of three mode categories: off, standby, and on. The off mode category is associated with a power reading of 0.0 W, and typically occurs when the game console is either unplugged, or with a power draw so low it registers as 0.0 W. The standby mode category (which, in reality, is a collection of individual and distinct functional modes) is when a game console is not being used to play a game, watch video content, or otherwise provide any sound or video output to a television. A game console in standby can be switched on via the controller, however, and therefore draws greater than 0 W to maintain this functionality. The Wii has an optional feature called WiiConnect24 that enables the console to maintain an Internet connection while in standby. We consider this feature as part of the standby mode category. Finally, the on mode category is when a game console is actively being used to play a game, watch video content, or otherwise provide sound and/or video output to a television. This category also includes when the console is idle, with or without a disc loaded (*e.g.*, a paused game or movie, main menu of a game, navigation menu of the console).

Figure 1 displays the distribution of WattsUp measurements for all four major game consoles metered in our study. The separation between standby and on was chosen to be 8 W for all consoles. This clearly separates clusters of data for the Xbox 360, PlayStation 3, and PlayStation 2. The Wii has a much more complex set of standby modes, given the WiiConnect24 feature. In addition, the Wii draws relatively low power when on, making the distinction between on and standby non-trivial. Although there are some suggestions that WiiConnect24 can consume upwards of 9 W (Hittinger 2012), our own spot testing with a Wii suggests that the power consumption is 7-8 W (and this may ultimately depend on the manufacturing run of a given Wii console). Furthermore, the power measurement distribution shows a distinct cluster between 6-7.5 W and a clear gap between 7.5 and 8 W, above which there is a continuous distribution of measurements. We associate that distinct cluster with the WiiConnect24 feature, whereas the next cluster peaking around 10 W we associate with active use of the console (most likely when the console is idling).

Due to the differing production runs in our sample, the distinction between idle and active usage is not immediately apparent in the power distributions, except for perhaps the Wii. As stated above, we elect to treat both idle and active usage as occurring in the on mode category. Although the power draw may differ, the console is providing sound and/or video output to a television in both cases.

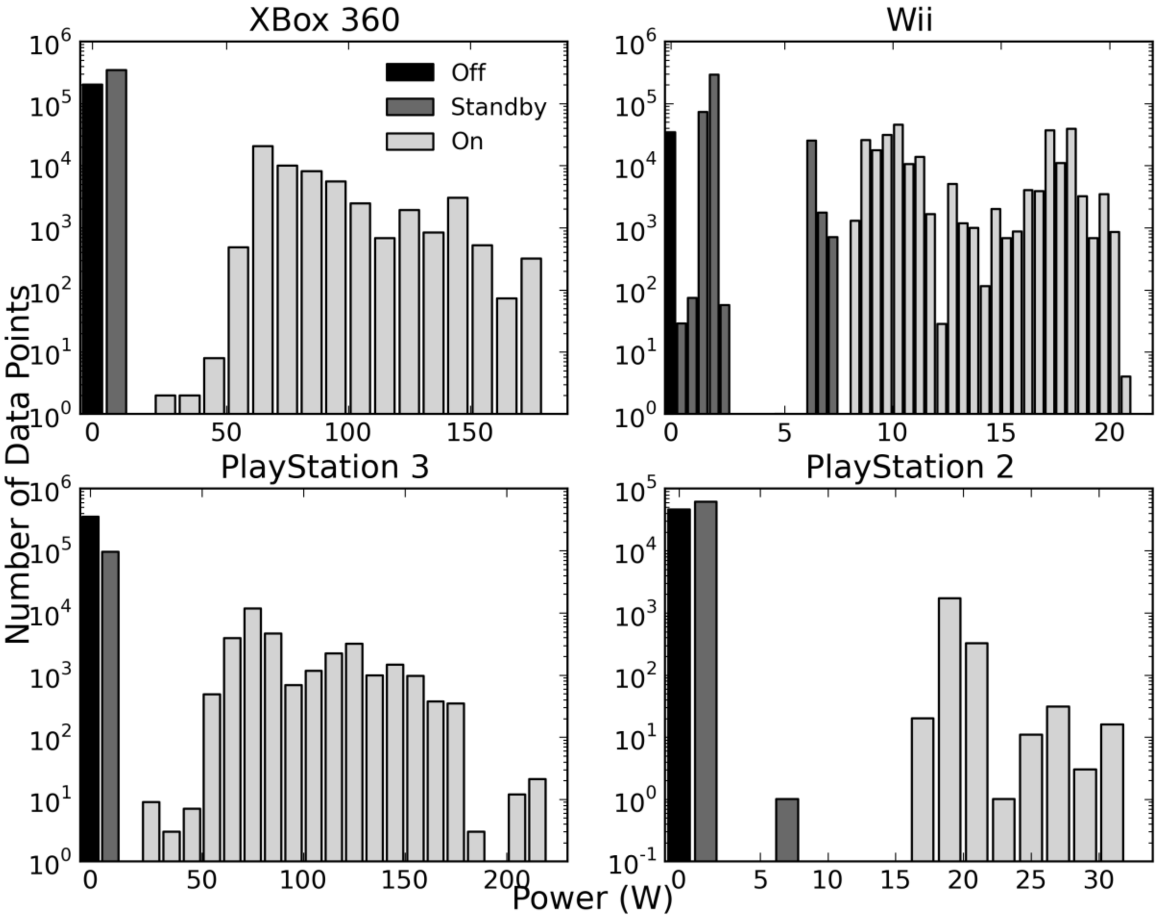

Figure 1: Full distributions of power measurements for all four major game console models (WattsUp data only). The vertical axis is on a logarithmic scale. Measurements are labeled as belonging to one of three mode categories: off, standby, or on. Off mode is for measurements of 0.0 W. Standby mode includes all measures greater than 0 W but less than 8 W for all consoles. On mode includes measurements greater than 8 W for all consoles.

3. Results

Table 2 lists the average and median power measurements in standby and on for all major game consoles. Although the console manufacturing date was recorded for some households, it was not systematically recorded for all households. As a result, we cannot separate the data according to production year. All the major consoles undergo minor design and hardware improvements over time, so that the power draw of a console at initial launch is different (typically higher) than the current production. This effect has been well documented (Hittinger et al. 2012, Neugebauer et al. 2008). Our results are therefore an average over all production runs, and we include the range of literature values for separate production runs in Table 2. Our results are consistent with literature power values, although they are systematically on the low end of published power ranges. Either we sampled mostly newer production consoles, or idle usage is a much higher fraction of overall on mode usage than previously assumed (or both). Note that the Wii and PlayStation 2 have much lower average power levels due primarily to their lower graphics processing capabilities.

Table 2: Average and median power in standby and on modes for all major game console models (WattsUp data only). Literature values from Hittinger et al. (2012) and Neugebauer et al. (2008). Errors represent the 95% confidence interval.

Console Type	Standby Power (W)			On Power (W)		
	Average	Median	Literature	Average	Median	Literature
Microsoft Xbox 360	1.447 ± 0.003	0.7	1-3	85.1 ± 0.2	76.1	75-162 (I) 94-172 (A)
Nintendo Wii	1.926 ± 0.004	1.6	2-9	13.12 ± 0.01	10.9	11 (I) 16(A)
Sony PlayStation 3	1.343 ± 0.004	1.1	1	93.8 ± 0.3	79.8	75-181 (I) 100-189 (A)
Sony PlayStation 2	0.653 ± 0.002	0.6	2	19.59 ± 0.06	19.5	24 (I) 24(A)

(I) Power when idle
(A) Power when in active use

The primary uncertainty when studying game console energy usage arises from incomplete information regarding user behavior. With detailed time series data, separated into off, standby, and on, we can begin to address some of these outstanding issues. Figure 2 shows the distribution of game consoles by the fraction of time the console is on, as opposed to in standby or off. Recall that a console left idling is considered on. The results illustrate that the majority of consoles are not used very often per day, with a median usage across all consoles of only 1.3 hours per day (this includes all console activity such as games, videos, and online content). Almost 20% of consoles were never on, close to half of all consoles are used about an hour per day or less, and nearly 80% of all consoles are used less than 5 hours per day. That being said, approximately 15% of consoles are left on nearly all day. We define this minority of "power users" as those with consoles in on mode more than 70% of the time. Power users significantly affect the average usage calculations compared to the median, as seen in Table 3. For consoles that were never or seldom on, the total metering duration varied from the minimum to the maximum in our overall sample. This suggests that we are not undersampling the usage of these low-use consoles.

Table 3: Average and median usage for all major game console models, in both daily percentage and hours per day (WattsUp data only). Errors represent the 95% confidence interval estimated using the bootstrap resampling method.

Console Type	Average Usage		Median Usage	
	(% time on)	(hr/day)	(% time on)	(hr/day)
Microsoft Xbox 360	11^{+17}_{-6}	$2.6^{+4.0}_{-1.4}$	4	1.0
Nintendo Wii	40^{+20}_{-17}	$9.5^{+4.7}_{-4.2}$	11	2.6
Sony PlayStation 3	9^{+5}_{-3}	$2.1^{+1.3}_{-0.8}$	6	1.3
Sony Playstation 2	2^{+7}_{-2}	$0.5^{+1.6}_{-0.5}$	0.08	0.02
All	19^{+9}_{-7}	$4.7^{+2.3}_{-1.7}$	6	1.3

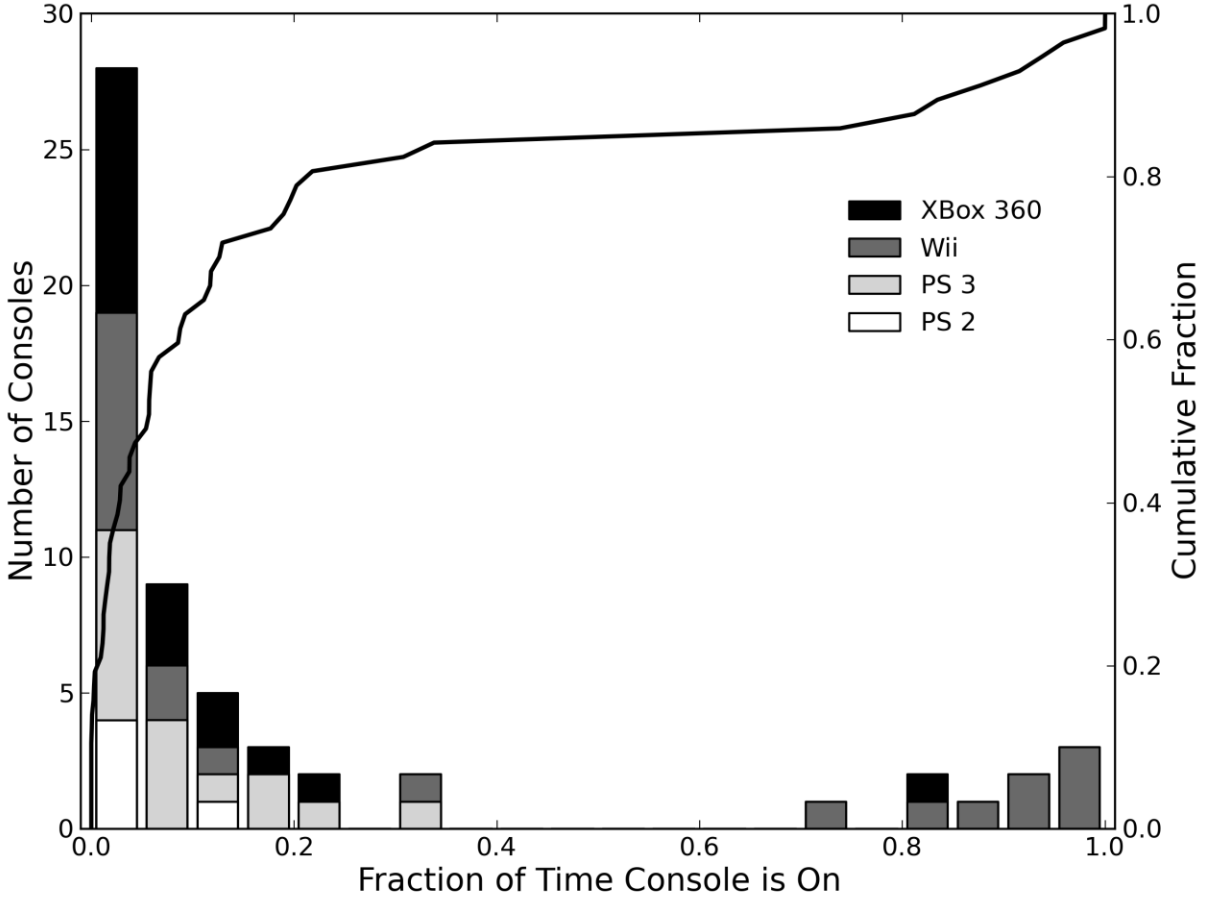

Figure 2: Distribution of individual game consoles by the fraction of time the console is on (WattsUp data only). Results are shown separately for each major game console model (left vertical axis). The histogram bins are evenly distributed between a fraction of 0 to 1, and are 0.05 wide. The first histogram bin includes values of 0. Also shown is the continuous cumulative distribution of all game consoles together (solid line, right vertical axis).

The average fraction of time spent in either off, standby, or on modes is also shown in Figure 3. Note that there are very large variations about these averages for individual consoles, given that a few consoles are on nearly 24 hours per day. Our sample of power users consisted mostly of Wii owners, which is why the Wii has a significantly higher average fraction in on mode. Surprisingly, consoles are in off mode far more than expected, suggesting that some users are conscious about disconnecting their consoles when not in use (or using a smart power strip).

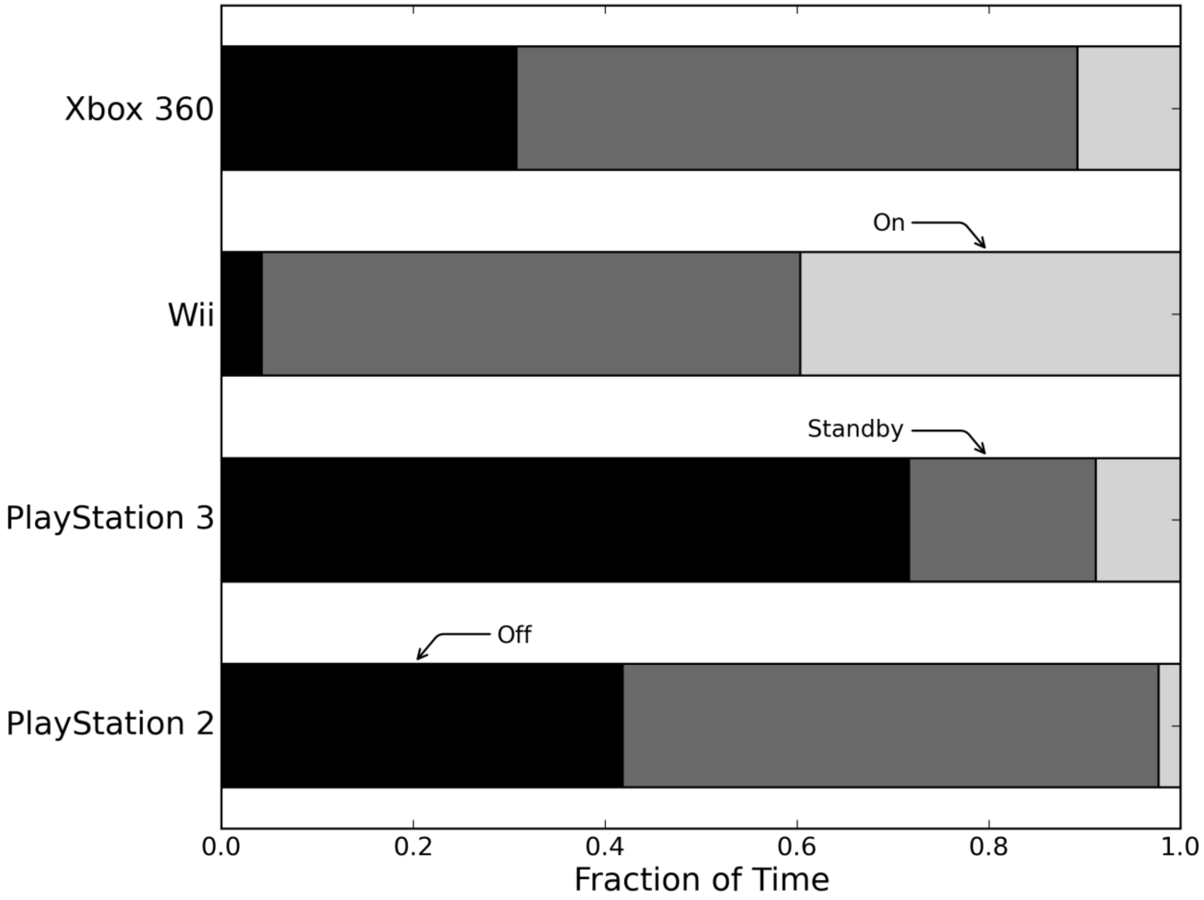

Figure 3: Average fraction of time spent in either off, standby, or on modes, for each major game console model (WattsUp data only).

We calculate the estimated annual energy consumption (AEC) of all individual consoles, assuming that the usage observed during the metering period is representative of the yearly average. (See "Nielsen Data" section below for data that help justify this assumption.) Therefore, we can simply extend the aggregate energy measured over the metering period to 365 days. For this exercise, we combine the WattsUp and Kill-A-Watt data. The separate AEC distributions for the WattsUp and Kill-A-Watt meters show no obvious systematic differences with each other (beyond sampling), and there is no reason to suspect any such differences should occur between the two types of meters. Figure 4 shows the distributions of AEC from the combined data, and also includes the cumulative distributions of WattsUp and Kill-A-Watt data separately for comparison. Table 4 lists the average and median AEC for each game console model, as well as for all game consoles together (from combined WattsUp and Kill-A-Watt data). A weighted average using the North American shipments in Table 1 (and assuming only 10% of PlayStation 2 consoles are still in use) gives nearly the same result as the unweighted average over our sample. Approximately 70% of all consoles metered have an estimated AEC less than 100 kilowatt-hours per year (kWh/yr), and only 10% of consoles have an estimated AEC greater than 200 kWh/yr. In general, the Wii consumes the least amount of energy, which is not surprising given its technical specifications, whereas the Xbox 360 and PlayStation 3 consume the most. The highest AEC in our sample was 484 kWh/yr, for a console that was on over 80% of the time. By contrast, the highest AEC for a Wii console was only 159 kWh/yr, for a console that was on virtually 100% of the time.

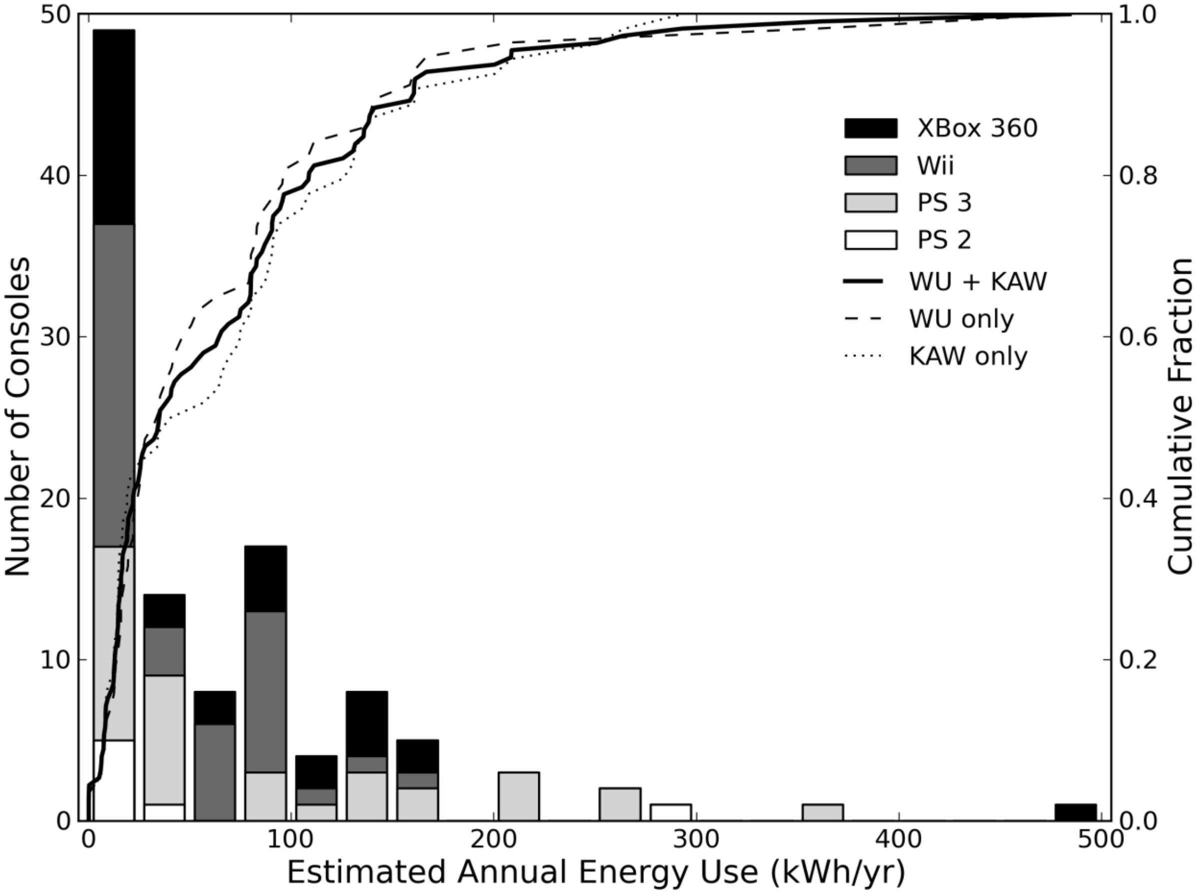

Figure 4: Distribution of individual game consoles by the estimated annual energy consumption. WattsUp and Kill-A-Watt data are combined together. Results are shown separately for each major game console model (left vertical axis). The histogram bins are evenly distributed between 0 and 500 kWh/yr, and are 25 kWh/yr wide. The first histogram bin includes values of 0 kWh/yr. Also shown are the continuous cumulative distributions of all game consoles together (right vertical axis). Results are shown for WattsUp and Kill-A-Watt data combined (solid line), WattsUp data only (dashed lined), and Kill-A-Watt data only (dotted line).

Table 4: Average and median estimated annual energy use for all major game console models (WattsUp and Kill-A-Watt data). Errors represent the 95% confidence interval estimated using the bootstrap resampling method.

Console Type	Average AEC (kWh/yr)	Median AEC (kWh/yr)
Microsoft Xbox 360	78^{+53}_{-24}	63
Nintendo Wii	47^{+13}_{-11}	27
Sony PlayStation 3	86^{+34}_{-27}	40
Sony Playstation 2	52^{+124}_{-44}	8
All	68^{+17}_{-12}	35

Figure 5 shows the contribution of on mode energy consumption to the total AEC. For most consoles, the vast majority of the estimated AEC is attributable to on mode power. For the Xbox 360, PlayStation 3, and PlayStation 2, the average standby power is low compared to on mode power. The Wii, however, has much lower on mode power. As a result, the standby energy consumption can be a sizable fraction of the total estimated AEC, especially if the WiiConnect24 feature is enabled. Standby energy consumption is clearly dominant for several Wii consoles in our sample. Collectively, about half of the total energy consumption from Wii consoles occurred in standby. The same is also true of the PlayStation 2 with its low on mode power, but the effect is likely pronounced due to the age of the console and lack of any new game titles, resulting in low usage for some console owners.

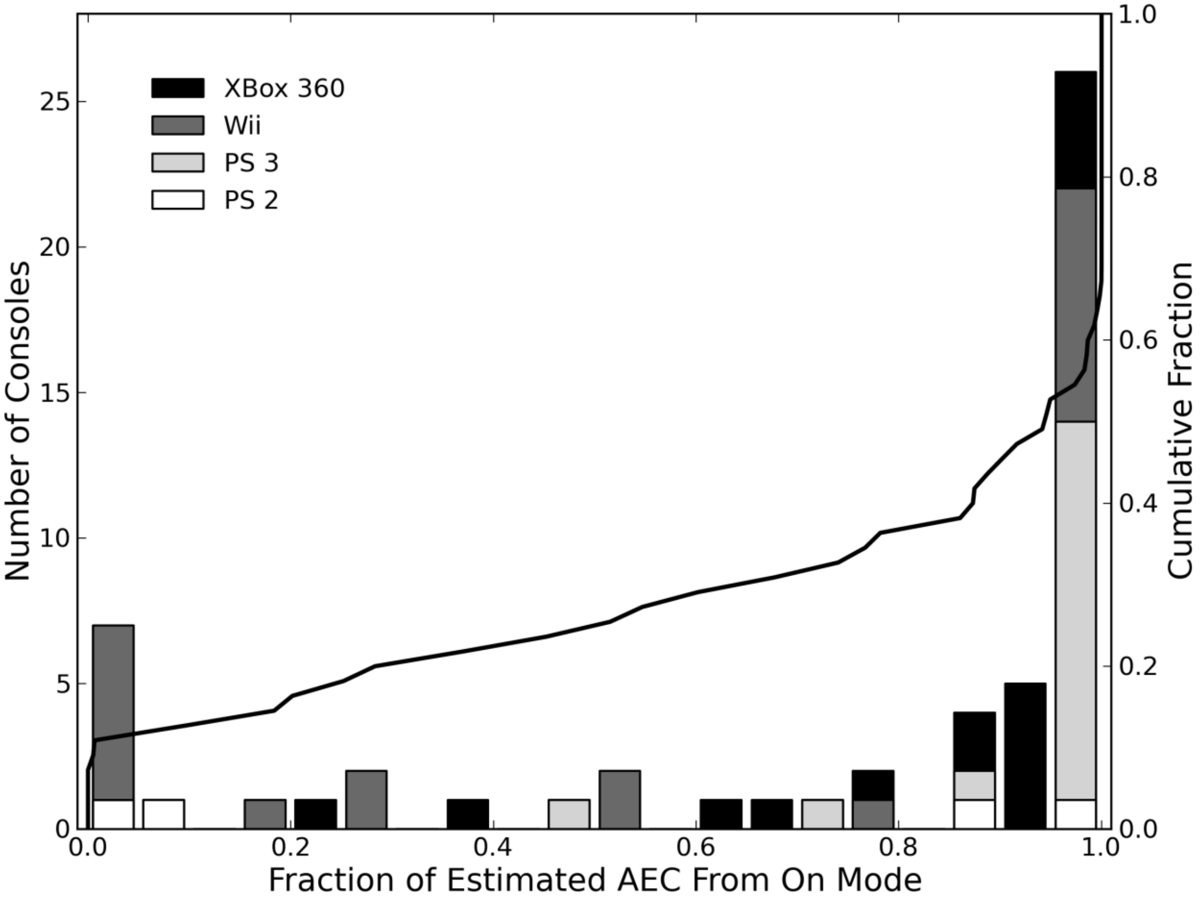

Figure 5: Distribution of individual game consoles by the fraction of estimated AEC attributable to on mode energy consumption (WattsUp data only). Results are shown separately for each major game console model (left vertical axis). The histogram bins are evenly distributed between a fraction of 0 to 1, and are 0.05 wide. The first histogram bin includes values of 0. Also shown is the continuous cumulative distribution of all game consoles together (solid line, right vertical axis).

4. Discussion

National Energy Consumption

Under the assumption that our metering results are indicative of usage nationwide, we can estimate total national energy consumption due to video game consoles. Using both the WattsUp and Kill-A-Watt data, the average AEC over all consoles is 68 kWh/yr, albeit with a significant scatter. The installed base of video game consoles (excluding portable units) in the U.S. is estimated to be 105 million units (CEA 2012). Assuming that none of these consoles are lost, broken, or otherwise unusable, our estimated national energy consumption is 7.1 TWh in 2012 (see Table 5). To put this value in context, the U.S. residential sector consumed an estimated 1383 TWh of electricity in 2012, 94 TWh of which was in a category combining televisions, set-top boxes, and video game consoles (EIA 2013).

There have been several prior studies that estimated either per unit annual energy use, national energy use, or both. The results from these studies are summarized in Table 5. Overall there is a very wide range of estimates, due primarily to uncertainty regarding user behavior. The more comprehensive studies assume average active usage ranging from 964-2890 hours per year (2.6-7.9 hours per day), though one limited field metering effort suggests far lower usage. Our results suggest an average usage of 1704 hours per year (4.7 hours per day), which is heavily influenced by power users (console is on more than 70% of the time). Excluding power users, we find an average usage of only 574 hours per year (1.6 hours per day). For power users only, we find an average usage of 7857 hours per year (21.5 hours per day). Any study, including ours, is therefore sensitive to the number of power users sampled or considered. We identified 9 consoles out of 58 (the WattsUp data set) as belonging to power users.

Our average usage of 1704 hours per year is lower than that assumed by Hittinger et al. (2012) but higher than that reported by Urban et al. (2011). Urban et al. rely on a phone survey to estimate game console usage, finding an average value of approximately 4 hours per day (including idle usage). There are, however, several important potential biases associated with survey data in general that may result in under-reporting of game console usage (especially idle usage), similar to biases that exist when reporting television viewing (Pettee et al. 2008). These include a social desirability bias, potential calculation errors in estimating average or total usage on the part of survey respondents, and a recollection bias for lower intensity activities. Nevertheless, our average usage is not all that dissimilar from Urban et al., suggesting that such biases are likely to be present but small in survey data.

Our results, however, have a much greater discrepancy with the usage assumption from Hittinger et al., who assume an average usage of 2890 hours per year (including both active and idle usage). This value is derived from usage reported on a per user basis (Nielsen 2010) as well as an assumption that 30% of users leave their consoles idle when not in use. Only approximately 15% of consoles in our sample were on nearly 24 hours per day, reducing our average usage substantially. Hittinger et al. are therefore potentially overestimating total average usage, and the authors acknowledge that their national energy consumption estimates are sensitive to the percentage of consoles that are assumed to be left in idle when not in use. Looking at only active usage, Hittinger et al. find a weighted average of 0.9 hours per day, whereas we find 1.6 hours per day with power users excluded (although this includes some idle usage as well as active usage). These results are in much closer agreement with each other, confirming that the main difference lies with the power user fraction.

Table 5: Recent energy use estimates for video game consoles.

Study	National Energy Use (TWh/yr)	Average Unit Energy Use (kWh/yr)	Average Usage[a] (h/yr)	Average Standby Usage (h/yr)	Units in Stock (millions)	Applicable Year
This study	$7.1^{+1.8}_{-1.3}$	68^{+17}_{-12}	1704^{+844}_{-597} [b]	4089^{+991}_{-988} [b]	105	2012
Hittinger et al. (2012)	11	213[c]	2890[d]	5870[d]	52	2007
	16	213[c]	2890[d]	5870[d]	75	2010
Desroches & Garbesi (2011)	3.5	55[e]	-	-	63[f]	2006
	6[f]	55[e]	-	-	109[f]	2010
Urban et al. (2011)	14.6	135	1450	7310	109	2010
Bensch et al. (2010)	-	1 – 45[g]	183 – 438[g]	8322 – 8577[g]	-	2009
Neugebauer et al. (2008)	16[h]	-	-	-	52	2007
Roth & McKenney (2007)	2.4	36	964	7796	64	2006

[a] Includes active gaming, viewing video, menu navigation, idle, and other media functionality.

[b] Active plus standby usage does not equal 8760 hours, due to time in off mode.

[c] Extrapolated from national energy use and units in stock.

[d] Assumes a weighted average of 6.3 hours per week per user spent actively using console, and two users per console. Further assumes that 30% of consoles are left in idle when not in use.

[e] Assumes 20% of consoles are left in idle when not in use, but only for 2000 hours per year.

[f] The original national energy use estimate relied on an older stock estimate, and thus the applicable year is 2006. Using an updated stock estimate for 2010 yields a national energy use estimate that would have been more representative at the time of publication.

[g] This study only measured the energy consumption of 13 game consoles for 1 month each, and is likely not representative of average national usage.

[h] Assumes that 50% of consoles are left in idle when not in use.

Our study has also revealed that consoles spend a significant time in off mode. Several meters exhibit a time series that suggests the console is either repeatedly disconnected and reconnected, or disconnected for long periods of time, as shown in Figure 6. Other consoles exhibited what appears to be a 0 W standby mode all the time. Their active power levels were indicative of the newest version of the Xbox 360. It is possible that the standby mode for this model is so low that it registers as 0 W on the power meter, which would be characterized as off mode in our analysis. In addition, nearly 20% of consoles in our sample were never in on mode. These factors bring down the average AEC in our analysis, and may be under-reported or underestimated in prior studies.

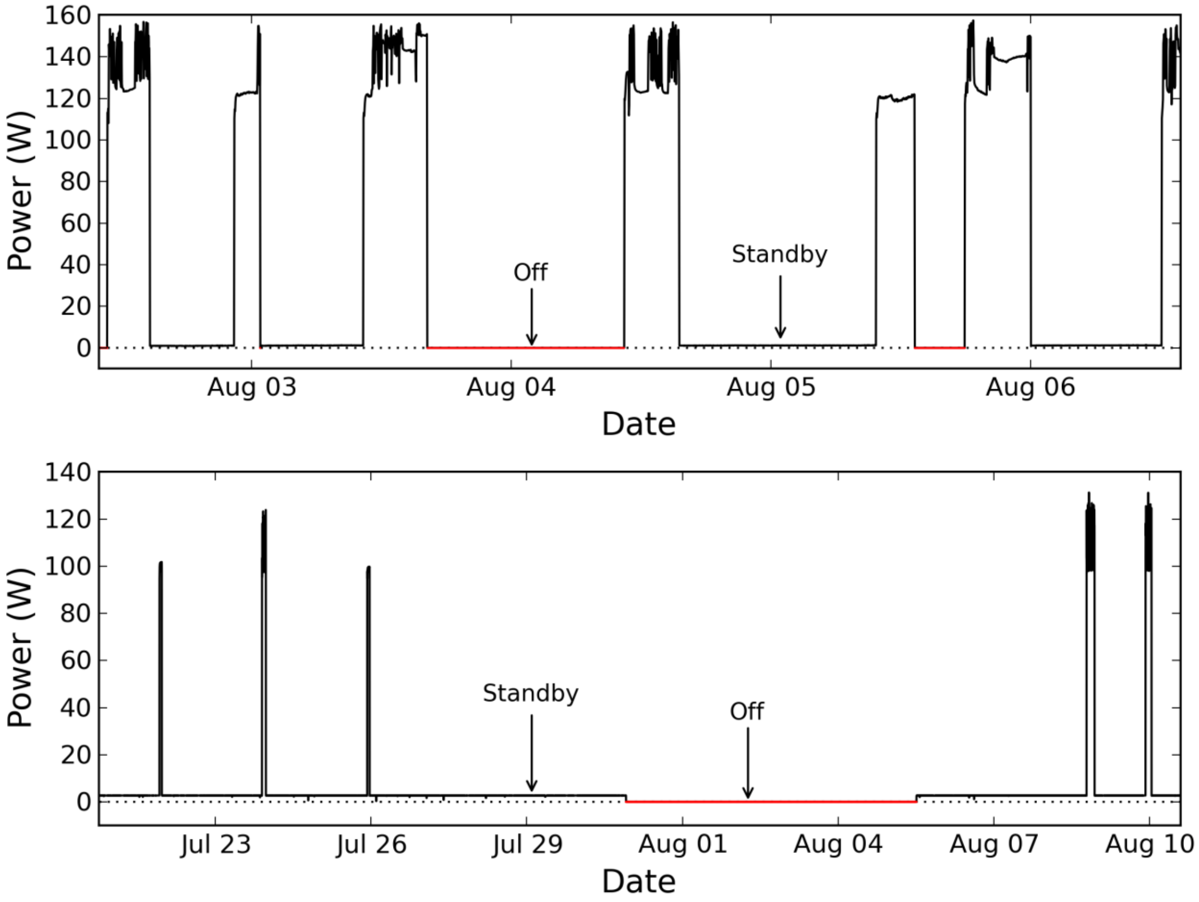

Figure 6: Example time series data from WattsUp meters, for two individual game consoles. Only a narrow portion of the full data series is shown, and a dotted line indicating 0 W is shown for clarity. Measurements of 0 W are indicated by a red line. These time series show a typical usage pattern for moderately used game consoles. The top panel illustrates an example of a game console oscillating between off mode (0 W) and standby mode (greater than 0 W but less than 8 W) when not in use, suggesting the console is repeatedly disconnected and reconnected to mains power. The bottom panel illustrates an example where a game console is disconnected for a long period of time, presumably when the user knows the console will not be used (*e.g.*, during vacation).

With respect to the Wii console, Hittinger et al. assume half of all Wii consoles have the WiiConnect24 feature enabled, drastically increasing average standby power and increasing the average AEC for Wii consoles. In our sample, however, only 2 out of 20 consoles with WattsUp meters exhibited power readings indicative of the WiiConnect24 feature. It is possible idle peak power was misidentified in many meters and is in fact the WiiConnect24 feature, though we consider misidentification unlikely given the clear gap in the histogram of the data (Figure 1). In addition, the WiiConnect24 feature is disabled by default, and we expect only a small percentage of users are likely to significantly modify console settings.

The various recent studies have found a wide range in estimated average per unit annual energy use. Of the more recent studies, the range spans 55 to 213 kWh/yr. Our average result of 68 kWh/yr is on the lower end of this range, likely due to the issues identified above. In addition, it is possible that our sample may also be somewhat biased toward newer console versions, which have improved power consumption compared to initially released console versions (Hittinger et al. 2012, Neugebauer et al. 2008). Our power user sample consists mostly of Wii consoles (from the WattsUp data), which may also bias our average unit annual energy use to lower values. However, the Kill-A-Watt data are also included in the average unit annual energy use calculation so this additional bias is mitigated by a larger sample. Finally, there is a potential for a social desirability bias, given that these meters were installed as part of an energy audit program. Users may be overly conscious about their energy use, biasing our results downward. However, we expect this bias to be very small, if it exists at all. The data collection is automated, as opposed to via a face-to-face (or on the phone) interview, and any bias that may exist initially is unlikely to persist over the long metering period.

Nielsen Data

We compare our results to data obtained from Nielsen, as part of their Television Audience Measurement[4] research. Nielsen has been metering television usage for many decades as part of their research related to television show ratings and advertising. With a representative household sample of over 10,000 households every month, this represents a rich data source. Peripheral devices such as game consoles and DVD players are also connected to the meter, so that television usage can be attributed to various types of input. It is worth emphasizing, however, that the meter is measuring television usage, not peripheral usage (or power) directly. This is particularly important to bear in mind, as a portion of game console usage occurs while idling, potentially with the television off (Hittinger et al. 2012, Urban et al. 2011, Desroches & Garbesi 2011, Neugebauer et al. 2008). If the game console is idling, but the television is off, Nielsen would not include this usage. If a game console is idling with the television on, this usage would be captured by Nielsen. Comparing our total game console usage results to the Nielsen usage results allows us to determine what fraction of total usage occurs with the television off.

Using monthly data from May 2007 to April 2012, we calculated the average hours per day in which the game console was actively used (this includes both gaming and media playback) or idling with the television turned on. We included only non-zero usage values in our analysis, since it is impossible to determine from the Nielsen data whether a given television with zero game console usage in a month actually has a game console attached to it or not. This biases the usage estimate upward when using Nielsen data, assuming that about 20% of consoles are not used very frequently or at all (as shown in Figure 2). In our discussion below, however, we compare to non-zero usage results in our sample to account for this bias. Figure 7 displays the results obtained with Nielsen data, including a linear regression to the data. There are three main observations from these data.

First, game console usage is highly variable during the calendar year. Usage peaks during winter holiday months (December-January) and summer holiday months (June-August). This obviously correlates with school holidays (including post-secondary), allowing more time for children and young adults to play video games. The winter holiday peak is larger than the summer holiday peak, and is likely a result of gifts received during the holidays (both new games and new consoles). The cumulative distribution of game console usage for four individual months is shown in Figure 8, including January and July where

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[4] http://www.nielsen.com/us/en/measurement/television-measurement.html

usage is highest and where the cumulative distribution clearly shifts compared to lower usage months. The cumulative distributions illustrate that the averages are influenced by a small minority of users who actively use game consoles for several hours per day. The median usage is less than 0.5 hours per day, which is significantly lower than the average usage shown in Figure 7. Our metering results were obtained between July and mid-October, which according to Figure 7 spans the summer peak to autumn trough. For this reason, we consider our metering results to be, on average, representative of the annual average, and do not perform any seasonal adjustments.

Second, overall game console usage is steadily trending upward. The trend has been consistent from 2007-2012. There are market analysts who discuss the possible death of console gaming, in favor of mobile app gaming (Snow 2012), but this does not appear to lead to a decline in game console usage. Even though the latest generation of consoles (*e.g.*, Sony Playstation 3, Microsoft Xbox 360, Nintendo Wii) is approaching the end of its lifecycle, usage remains high and is increasing. Since the Nielsen data include both gaming and media playback usage, this suggests that any potential decrease in gaming usage is easily compensated for by increasing usage for media playback. The latest trends are that total gaming time is increasing by 7 percent per year, although that is shared among mobile, handheld, tablet, and console gaming (Nielsen 2012).

Finally, the overall television usage attributed to game consoles is less than the usage of game consoles themselves, as measured directly from our field metering. According to the Nielsen data, only about 0.9 hours per day per console on average is spent actively gaming, viewing video content, or idling with the television on (in 2012). Nielsen (2010) states that average usage varies between 1.4 hours and 4.9 hours *per week per user*, depending on the specific console. Under the assumption that there are multiple users per console (with some usage overlap), that is consistent with an upper limit of 0.9 hours per day per console. This result underscores the concern, initially raised by Neugebauer et al. (2008), that consoles are being left on while users walk away from the television (and turn the television off). If the television is off, the Nielsen meter will not assign any usage to the game console. We believe that this is the primary reason for the discrepancy between our average result of 4.7 hours per day and the Nielsen data. Excluding power users (whose usage is mostly idle, presumably with the television off) and consoles with non-zero usage (in order to properly compare to Nielsen data), we find an average usage of 1.8 hours per day in our data. This is in closer agreement with the Nielsen data. Our non-zero, non-power-user data still likely include some idle usage with the television off, explaining why we find an average of 1.8 as compared to 0.9 hours per day. Considering all these factors, it appears that the Nielsen data and our data are consistent with each other, reinforcing the conclusions we draw from our sample. Ultimately, a significant fraction of average game console usage occurs with the television off.

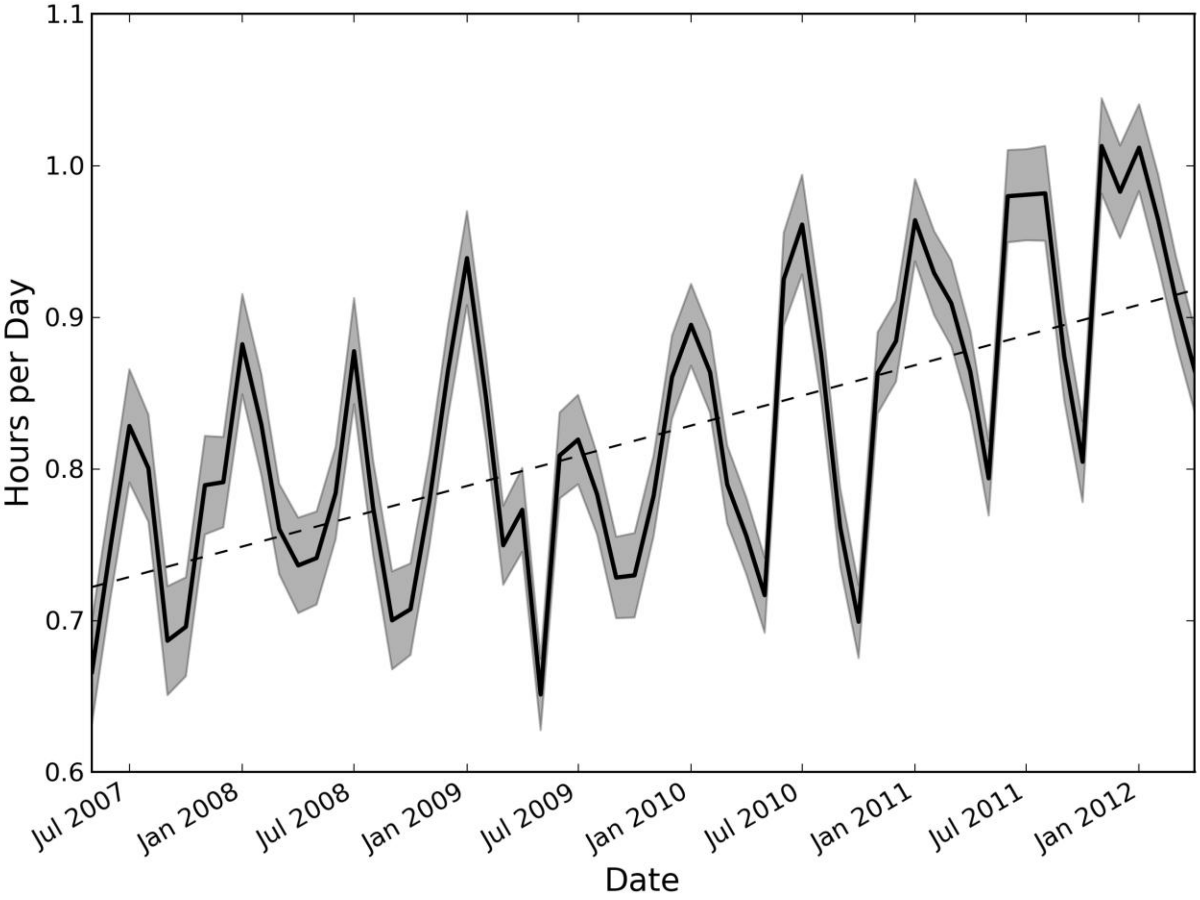

Figure 7: Monthly average television usage attributed to game consoles, using data from Nielsen's Television Audience Measurement in the U.S. Monthly averages (bold line) are in hours per day per console, and only include televisions with non-zero game console usage in any given month. A 95% confidence interval on the monthly average is indicated by the shaded region. A linear regression (dashed line) on the monthly average is also shown.

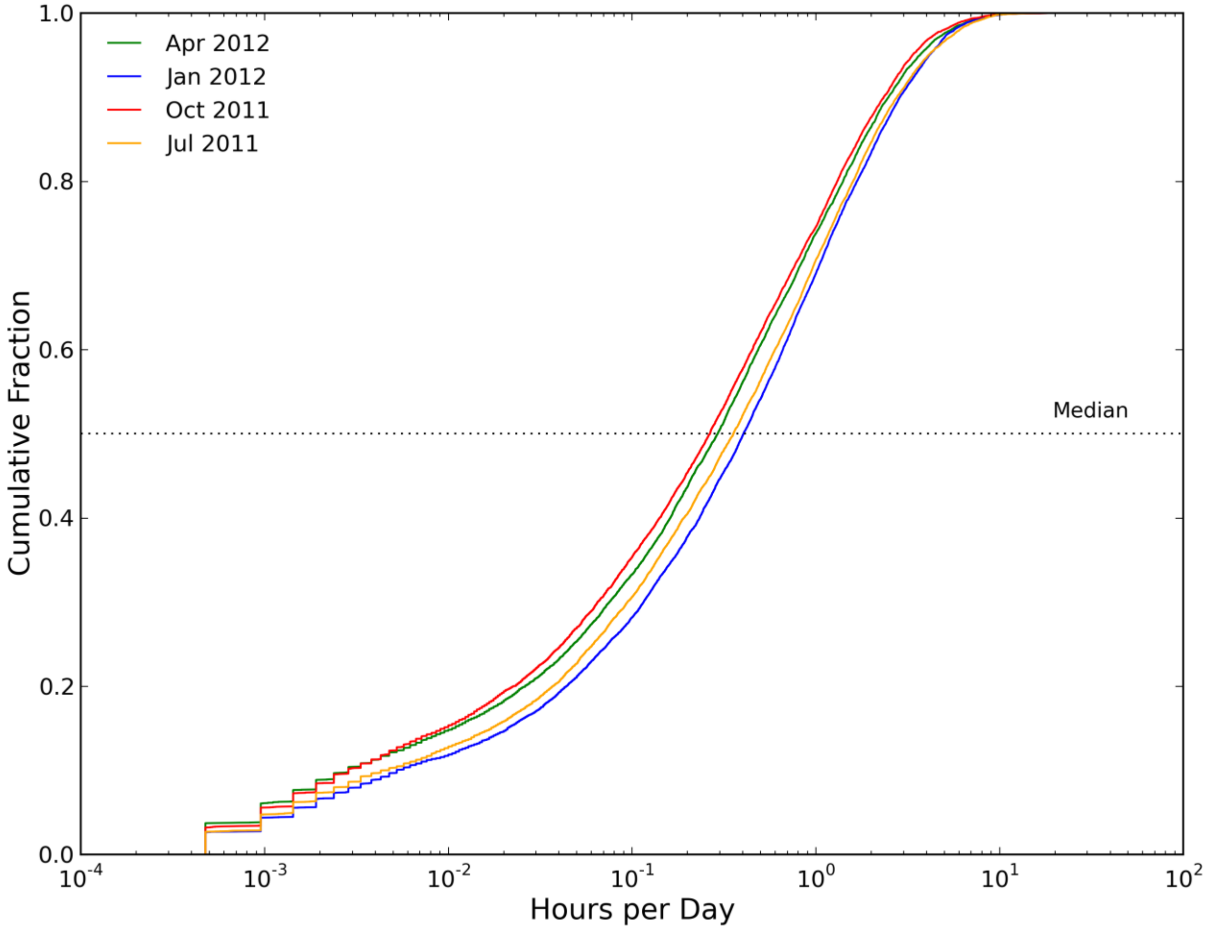

Figure 8: Cumulative distributions of television usage attributed to game consoles, using data from Nielsen's Television Audience Measurement in the U.S. Distributions of average hours per day include non-zero usage only. Shown from left to right are October 2011 (*red*), April 2012 (*green*), July 2011 (*orange*), and January 2012 (*blue*). This represents the order of increasing average usage, with usage peaks in January and July. A line representing the median (cumulative fraction of 0.5) is shown for clarity.

Energy Savings Opportunities

As discussed in previous studies, the primary energy savings opportunities with respect to game consoles is in reducing the on mode power when not actively playing games or viewing video content (Hittinger et al. 2012, Desroches & Garbesi 2011, Neugebauer et al. 2008). This occurs when the consoles are left idling (*e.g.*, the game is paused, or the console is left on in a menu navigation screen). There is no user input during such times, and the television may not even be on most of the time a console is idling, as suggested by the Nielsen data. An auto power down feature enabled by default would be very effective in reducing this energy use, although this requires the cooperation of game developers to ensure that in-game progression is not lost when auto power down is engaged, reverting to an earlier saved game state. If game saving is not properly addressed, users will quickly disable an auto power down feature. The Xbox 360 and PlayStation 3 currently both offer an auto power down feature with adjustable settings, but the feature is not enabled by default. We suspect that the vast majority of users do not turn this feature on.

The energy savings strongly depend on the fraction of users who are power users, leaving their consoles idling or paused nearly 24 hours per day. Our results suggest that this fraction of power users is smaller than many have assumed, and likely represents only about 15% of consoles at most. This limits the total energy savings available, but it is substantial nonetheless. If excess idling from power users were eliminated, overall average usage would drop from 4.7 hours per day to a value closer to 1.6 hours per day.

Another potential for improved energy efficiency involves power scaling. Game consoles contain powerful central and graphics processing units, consuming a lot of power. When they are used for non-gaming functionality, such as watching DVD/Blu-ray movies or streaming online video content, power consumption remains nearly as high even though this functionality is not computationally intensive (Neugebauer et al. 2008). Given that such non-gaming usage is significant and on the rise (Nielsen 2013), allowing the console to scale power to the required functionality represents a large energy savings opportunity.

Finally, the initial launch versions of the major game consoles are fairly inefficient compared to subsequent versions released only a few years later. Hittinger et al. (2012) highlight this effect very clearly, with the Xbox 360 improving from 172 W to 94 W in average active power, and the PlayStation 3 improving from 180 to 100 W in average active power. These dramatic efficiency improvements occur over only 4-5 years. If manufacturers invested more effort into designing consoles with efficiency in mind from the beginning, the initial launch versions could easily consume less power.

5. Summary

Estimating national energy use of video game consoles has been challenging due to uncertainties regarding user behavior. In particular, game consoles are no longer used for just video gaming, and some users leave their consoles idling when not using them. For a minority of users, consoles can be left idling for nearly 24 hours per day. Different assumptions regarding the fraction of consoles left idling all day have resulted in a wide range of national energy use estimates in the literature, from 2.4 to 16 TWh per year according to recent studies.

As part of a larger residential study, we obtained field-metered data from 113 individual game consoles from households in the San Francisco Bay Area. Of those 113 game consoles, 58 have full time series power data. From our data, we conclude the following:

1. Approximately 20% of consoles were never turned on (and some unplugged) during the 3-10 week metering period. If the results are representative of the annual average, this suggests that many consoles sold do not contribute significantly to the total national energy use.
2. Approximately 15% of consoles were left on nearly 24 hours per day, dominating the total combined energy use.
3. Average usage over all consoles was 4.7 hours per day. The median usage is only 1.3 hours per day. Excluding those consoles left on nearly all day reduces this average to 1.6 hours per day.

4. National energy use is estimated to be 7.1 TWh annually in 2012. This is lower than some recent estimates in the literature. The main difference lies with the percentage of consoles that are assumed to be left on all day. Assumptions of 20-50% in the literature are higher than what we observe in the field-metered data.
5. The average per console energy use is estimated to be only 68 kWh/yr, with a median of 35 kWh/yr. Our sample may be biased toward newer console versions, however, which have improved power consumption. The maximum annual energy use was estimated to be nearly 500 kWh/yr, similar to a standard-size refrigerator.
6. Game consoles are increasingly used for watching video content (DVD/Blu-ray discs and streamed online) in addition to video gaming. The power consumption of game consoles does not scale with such computationally less demanding functionality. Therefore a clear energy savings opportunity is to design consoles assuming mixed usage, and allow the power to scale with required processing functionality.
7. According to Nielsen data, consoles with non-zero usage are actively used (for video gaming and video content) only about 0.9 hours per day on average. This value is largely driven by a very small minority of users who actively use consoles for several hours a day. Given that this estimate of active usage is far lower than our estimates of total game console usage, this suggests that an appreciable fraction of console energy use is due to idling when the television isn't even turned on. This is true even if we exclude consoles left idling all day. Proper console power management when not in active use therefore presents the best energy savings opportunity.

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