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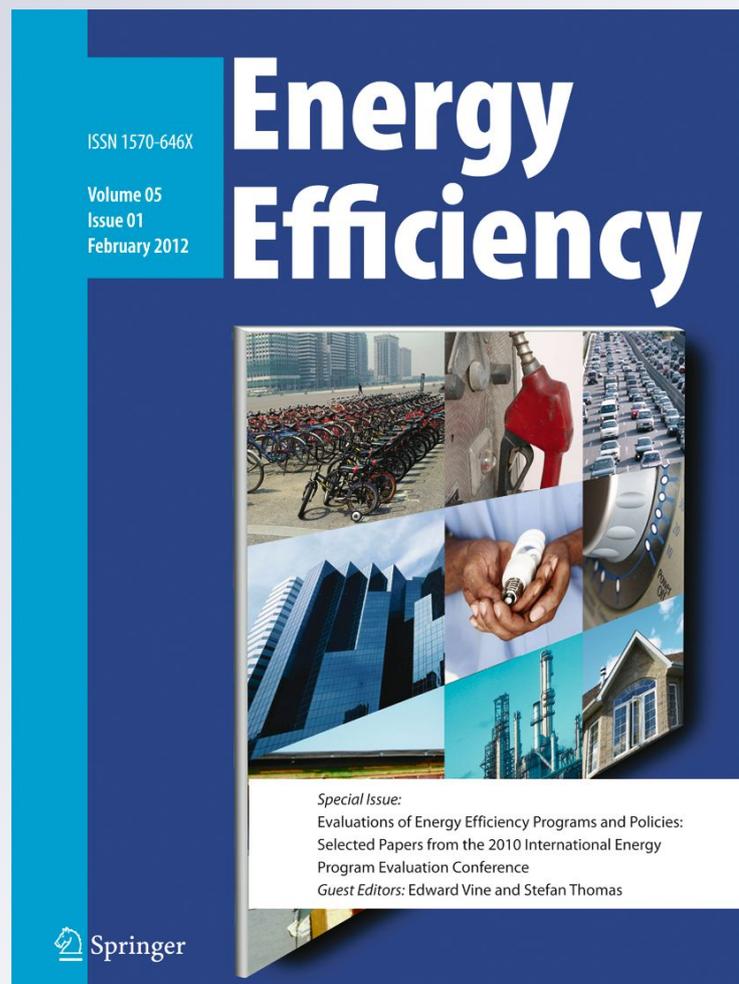
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Electricity consumption and energy savings potential of video game consoles in the United States

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Abstract Total energy consumption of video game consoles has grown rapidly in the past few decades due to rapid increases in market penetration, power consumption of the devices, and increasing usage driven by new capabilities. Unfortunately, studies investigating the energy impacts of these devices have been limited and potential responses, such as ENERGY STAR requirements, have been difficult to define and implement. We estimate that the total electricity consumption of video game consoles in the US was around 11 TWh in 2007 and 16 TWh in 2010 (approximately 1 % of US residential electricity consumption), an increase of almost 50 % in 3 years. However, any estimate of total game console energy consumption is highly uncertain, and we have determined that the key uncertainty is the unknown consumer behavior with regards to powering down the system after use. Even under this uncertainty, we demonstrate that the most effective energy-saving modification is incorporation of a default auto power down feature, which could reduce electricity consumption of game consoles by 75 % (10 TWh reduction of

electricity in 2010), saving consumers over \$1 billion annually in electricity bills. We conclude that using an auto power down feature for game consoles is at least as effective for reducing energy consumption as implementing a strict set of energy efficiency improvements for the devices, is much easier to implement given the nature of the video game console industry, and could be applied retroactively to currently deployed consoles through firmware updates.

Keywords Video game consoles · Electricity consumption · Auto power down · ENERGY STAR · Efficiency

Introduction

In the US, the residential sector accounts for 37 %¹ of national electricity consumption, 17 %² of greenhouse gas emissions, and 22 %³ of primary energy consumption. While it is widely acknowledged that the residential sector holds the potential for large energy and

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¹ Using 2008 AEO detailed tables, Table 10—Energy consumption by sector and source.

² Using EIA GHG flow from 2006. EIA reports that the residential sector is responsible for 1,234 MMT of carbon dioxide equivalent and that total greenhouse gas emissions in the United States are 7,076 MMT of carbon dioxide equivalent.

³ Using AEO 2008 detailed tables, Table 10—Energy consumption by sector and source. In 2008, the residential sector accounted for 23 EJ of primary energy consumption. The national primary energy consumption was 108 EJ.

greenhouse gas savings, designing effective policies to realize that potential is challenging because of several energy efficiency barriers and market failures (Jaffe and Stavins 1994; Golove and Eto 1996).

Residential electricity consumption has historically been dominated by four end uses: lighting, heating, cooling, and household appliances (National Research Council 2009; EIA 2011). There have been some successful efforts by policy makers and industry to decrease residential energy consumption by increasing efficiency in these four areas; however, the Energy Information Administration highlighted in its recent Annual Energy Outlook that these gains are likely to be increasingly offset by demand growth due to consumer electronics such as televisions, computers, and media playback devices (EIA 2011).

While many appliances and devices have experienced market saturation, both sales and power consumption of game consoles continue to increase. A 2009 study by the Entertainment Software Association found that 68 % of the 115 million American households play computer or video games and 42 % of those households have a video game console (Entertainment Software Association 2009). By the end of 2010, over 75 million current generation video game consoles (Microsoft Xbox 360, Nintendo Wii, and Sony PlayStation 3) had been sold, meaning that many homes have two or more current generation game consoles (VGChartz 2011). The NPD Group reports that the video game market in the US accounted for more than \$20 billion of retail sales in 2009 and has experienced market growth of over 250 % over the previous decade (NPD Group 2010). In addition to increased sales, game consoles are consuming more energy as they become more powerful computing machines, though their efficiency improves significantly through hardware revisions within a console generation. For example, the launch models of the Microsoft Xbox 360 and Sony PlayStation 3 both consume over 175 W when in active use, while the previous models of these consoles (Microsoft Xbox and Sony PlayStation 2) consumed less than 100 W at launch (Natural Resources Defense Council 2008).

The video game market has several unique characteristics that distinguish it from other consumer electronic products, which may call for unique regulatory strategies. The video game industry is driven primarily by profit from software sales. Video game hardware is frequently sold at a loss, especially near a console

launch, with the expectation that every console sold represents a revenue stream from future software sales (Furtado 2011; Snow 2005). Unlike most consumer electronics, game consoles do not experience continual improvements in technical capabilities (such as processing speed) because initial and later versions of the same console must perform the same tasks. Because of this need for standardized technical performance, the game console development cycle is between 4 and 8 years, after which time much more powerful consoles with new and distinct technical capabilities are released. Within a console cycle, a system will decrease significantly in price (normally a decrease of more than 50 %) and improve in energy efficiency and reliability, while maintaining the same performance capabilities as the original system. Because of these effects, console manufacturers tend to focus initially on getting a large user base of a high-performance system (frequently selling the console at a loss), with the understanding that other aspects of the product (such as power consumption and manufacturing cost) will be improved in future years (Furtado 2011). Figure 1 illustrates the sharp increase in power consumption for the current and two previous generations of game consoles from Sony (PlayStation, PlayStation 2, and PlayStation 3) and the rapidly decreasing power consumption within a console generation due to hardware improvements.

Game consoles provide an increasing array of electronic entertainment services. In addition to playing video games (historically their only function), they can usually play physical media (CDs, DVDs, and/or Blu-ray discs), stream digital media from local or Internet sources (from Netflix or Hulu, for example), and provide access to a host of media and online services. Due to the fact that games, accessories, and virtual property function only with a single game console, manufacturers are able to lock in customers, and thus exist as something of a natural monopoly. Additionally, successfully marketing a modern video game console requires long-term investments, research, advertising, and good relationships with content providers. As a result, there have never been more than three major players in the video game console market at a single time. Currently, the three major console manufacturers are Nintendo, Microsoft, and Sony; we define the “current generation” of consoles as the Nintendo Wii, Microsoft Xbox 360, and Sony PlayStation 3 (PS3).

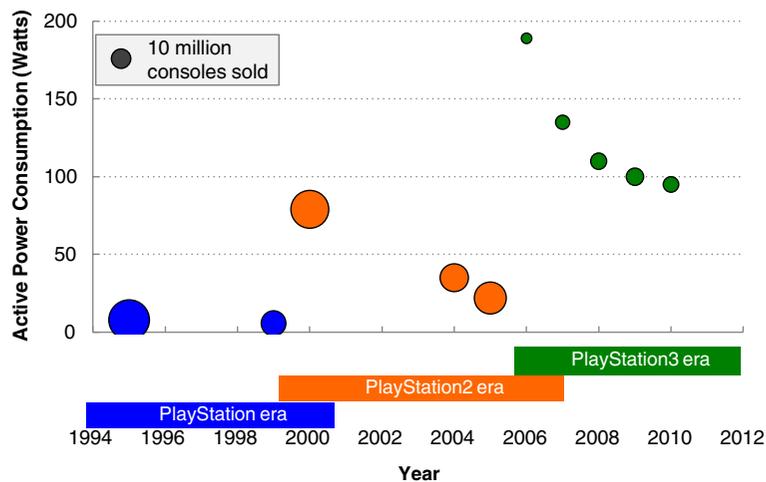


Fig. 1 Active power consumption of the three PlayStation console generations over time. The *color of the circle* corresponds to the console generation that model falls under, and *area of the circle* represents worldwide sales of the model (from redesign date forward). The figure shows both the trend of increasing power consumption between models due to increased computational capabilities and decreasing power consumption

The power consumption of game consoles differs greatly across the three current generation systems. Even within a single console, there are variations across hardware revisions, console tasks, and individual devices due to manufacturing variability. For example, an Electric Power Research Institute (EPRI) report states that the newest revision of the PS3 hardware consumes 85 W of power when in use, which is down from 180 W for the original hardware (Electric Power Research Institute 2010). A study performed by the Natural Resources Defense Council (NRDC) found that the power consumption of an Xbox 360 was 30 % lower when playing a DVD vs. a video game and that power consumption was even found to vary by 10 % across different games played in the same game console (Natural Resources Defense Council 2008). All three systems have a significant power draw when left in an idle state (see Table 2 below for details).

Despite data on sales and stock of video game consoles and power used by such devices, there is little information on consumer behavior, particularly the amount of time that consoles are left idle when not in use. Several studies have examined the electrical load of video game consoles (Sanchez et al. 1998; Rosen et al. 2001; Roth and McKenney 2007; Natural Resources Defense Council 2008). However, with the

within a model due to improved design under fixed performance. The Sony PlayStation line is used as an example because it has a history of consistent design philosophy with regards to features and performance, though this figure represents a general trend in the game console market. (Rosen et al. 2001; Nelson 2010; VGChartz 2011; Electroschematics 2009; some data measured/verified by authors)

exception of the NRDC report, these studies look at electricity consumption of many types of consumer electronics and do not examine the electricity consumption of video games in detail.

The NRDC report “Lowering the cost of play” calculates that, in 2007, consoles used about 16.3 TWh of electricity, which we believe to be an overestimation due to their assumption that 50 % of consoles are left idle when not in use (Natural Resources Defense Council 2008). This study builds upon the work done by the NRDC by using updated values for consoles in the market as of 2010, defining idle differently,⁴ appropriately characterizing the Wii’s power consumption patterns by accounting for WiiConnect24 and including a number of what we believe to be more realistic assumptions about usage patterns. Using our method and including NRDC’s figures for last generation sales and power consumption, our base case estimate for total game console electricity consumption in 2007 is 11 TWh, with most of the difference attributable to different assumptions about usage patterns. Additionally, the NRDC did not include sensitivity analysis, so

⁴ The NRDC study defines idle as the state where the user is simply not providing input to the console via the controller. With this definition, idle and active power consumption are very similar. We define idle in “Data and Assumptions”.

there are no hypothetical scenarios with which to compare.

Internationally, the total electricity consumption of video game consoles varies significantly, due largely to differences in market penetration. In Europe, only 18 % of households had a game console in 2007, though this varied from 38 % in Iceland to almost zero in many Eastern European countries (Eurostat 2007). This was about half of the market penetration in the US (33 %) in the same time period (Entertainment Software Association 2007). In many Asian countries, PCs are the preferred platform for gaming, making consoles less common, and video game consoles have been banned in China since the year 2000 (Ashcraft 2010). Additionally, the mix of consoles varies across regions. In Europe, the PS3 holds a greater share of the market than in North America, and the Xbox 360 has a much smaller share of the market in Japan (VGChartz 2011). A 2003 study estimated that the total electricity consumption of game consoles in Germany was 0.057 TWh in 2001 and predicted that this would grow to 0.12 TWh by 2010 (CEPE and Fraunhofer 2003). The report “Innovation for sustainability in information and communication technologies (ICT)” estimates that the global electricity use from game consoles was 19 TWh in 2009 and predicts that it will more than double (to 45 TWh) by 2015 (Bronk et al. 2010).

While this paper is focused on characterizing energy consumption from video game consoles in the United States and its uncertainty and potential savings using energy efficiency measures, it is likely that data challenges will also be faced by other countries/regions. Almost no empirical longitudinal or even cross-section data exists on usage patterns and mix of consoles across countries. This is challenging for energy efficiency policy design, since total energy consumption estimates for game consoles are highly sensitive to assumptions made regarding console features and usage patterns.

The estimates listed in Table 1 vary significantly, though they are clearly increasing over time, due to increased numbers of consoles and increased power consumption of those consoles. Limited prior research on the energy implications of game consoles has overlooked critical aspects of the problem such as the sensitivity to any assumption about power down of the consoles, the importance of accurate (and console-specific) usage data, and the existence of the WiiConnect24 feature (which greatly increases the energy use of

Table 1 Estimates of total electricity consumption by video game consoles in the United States. Annual estimates show a high degree of variability but show a trend of increasing electricity consumption over time

Estimated annual electricity consumption	Applicable year of estimate	Source
1.5 TWh	1995	Sanchez et al. (1998)
0.5 TWh	1999	Rosen et al. (2001)
2.4 TWh	2006	Roth and McKenney (2007)
16 TWh	2007	Natural Resources Defense Council (2008)
11 TWh	2007	Current study
16 TWh	2010	Current study

the Wii). For example, an average user that never powers down a current model Xbox 360 will consume more than ten times electricity as a similar user who always powers down the console after use. A Wii with WiiConnect24 enabled (which happens automatically when you connect the console to the Internet) uses five times the energy as one that has not been connected (under average usage patterns). Clearly, consumer behavior is important and assumptions about that behavior can strongly affect estimates of total electricity consumption.

The power consumption of video game consoles is increasing, the quantity of game consoles in US homes is increasing, and it is likely that the amount of time they are being used is increasing. These trends suggest that the overall electricity consumption of game consoles may be increasing rapidly and is worth investigating. We assess total energy consumption of video game consoles in 2010 while paying particular attention to key sources of uncertainty and variability, which complicate a thorough analysis of total electricity consumption from video game consoles. Sources of uncertainty include:

- Consumer behavior after use (turning off the console or leaving it idle)
- Number of hours of use for each console type and user
- Power consumption characteristics for each video game console type when active, idle, off, and connected or not to the Internet
- Entertainment activity that the console is used for (play video games, watch DVDs, etc.)

The rest of the paper is organized as follows. In “Data and assumptions” we define data sources and

assumptions. These will be used in a model that estimates, and evaluates the uncertainty of, national electricity consumption from video game consoles in “Results: estimated console energy consumption”. In “Value of design improvements and ENERGY STAR requirements”, we show the value of design improvements, in particular the value of proposed ENERGY STAR requirements for video games. “Discussion” provides policy recommendations and suggestions for future data acquisition.

Data and assumptions

Video game consoles are now in their seventh “generation,” which is composed of the Nintendo Wii, Microsoft’s Xbox 360, and Sony’s PlayStation 3 (PS3). Though consoles from previous generations have a large installed base, there are several reasons to believe that these obsolete consoles are being used infrequently and thus do not contribute in a significant way to overall electricity consumption in the US. For example, worldwide sales of PlayStation 2 games were down to 15 million units in 2010 (a decrease of more than 50 % from 2009), many of which were likely purchased to be played on a “backwards-compatible” PS3 (Sony Corporation 2011). While 15 million may seem like a large market, it is significantly smaller than the remainder of video game software sales, which were around 650 million units worldwide in 2010 (VGChartz 2011). The two other previous generation consoles, Microsoft’s Xbox and the Nintendo Gamecube, are both officially unsupported by their respective companies, meaning that new systems and games can no longer be purchased at retail. While there are a significant number of consoles from previous generations in American households, they have generally been displaced by the current generation consoles. For these reasons, we focus this study exclusively on current generation video game consoles and examine their energy use during the year 2010.

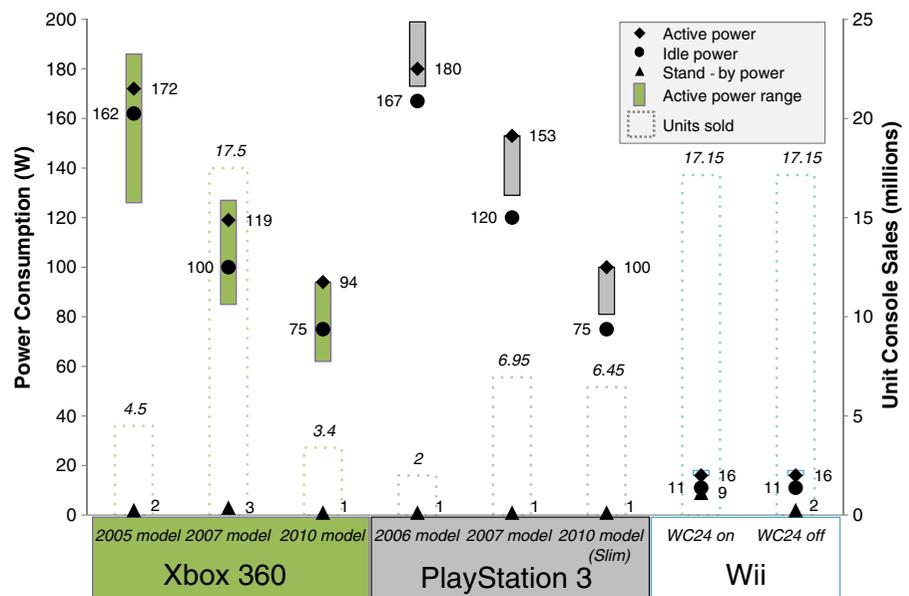
The power consumption data used in this study are shown in Fig. 2 and tabulated in Table 2. We define active mode as actual use of the console (for playing a game or watching a video), standby as the state where the console is shut down (no video output) and awaiting a signal to start up again, and idle as the state where the console is on and in the highest system menu but is not receiving any input from controllers. While it is always possible to cut power to a console

completely by unplugging the device, only the PS3 has a physical switch (located at the rear of the console). We assume that this option is not used, and this assumption has little effect on our results.

While minor hardware improvements have gradually decreased the power consumption of all three systems, the PS3 and Xbox 360 have each gone through one major hardware revision and several minor hardware revisions, with continual improvements to console energy efficiency. The newest Nintendo Wii models have an active power consumption of approximately 14 W, down from 18 W for the launch model, though standby and idle power remain approximately the same. Figure 2 and Table 2 divide the Xbox 360 and PS3 consoles into three categories, representing three different hardware revisions. Because the power consumption of the Wii has not changed significantly, we model only one Wii hardware revision, though we divide this into two groups by the use of WiiConnect24. WiiConnect24 is a feature of the Nintendo Wii which allows the console to receive messages and content updates while the system is in standby. Importantly, this feature is “on” by default for a Wii system that has been connected to the Internet and greatly increases the standby power of the device from 2 W to 9 W. Since the majority of Nintendo Wii consoles (~55 %) are connected to the Internet and WiiConnect24 is enabled by default, we assume that approximately half of all Wii consoles have this service turned on (The Diffusion Group 2010).

Console power consumption varies across tasks and due to manufacturing variability, and the data provided should not be interpreted as point values; ranges are included in Fig. 2 and Table 2. The greatest variability is seen in the active power, due to different consumptions for different tasks. Generally, media playback requires the least power and actively playing a game from physical media requires the most power. For active power, we assume that a game is being played, which is normally near the high end of the reported range. There are other variables that affect the power consumption of a console, such as online/offline play or the processing requirements of the particular game being played, but these have little effect (on the order of 10 %) on power consumption (Natural Resources Defense Council 2008). Importantly, changes in the active power consumption do not significantly change the overall power consumption due to the effects of consumer behavior, as discussed below.

Fig. 2 Power consumption and sales figures of current generation video game consoles. Ranges are provided for the active power. Note that total Wii sales are 34.3 million, distributed based on the assumption of 50 % of consoles having WiiConnect24 (WC24) enabled. (Natural Resources Defense Council 2008; Hollister 2010; Miller 2009; Nelson 2007; VGChartz 2011; some data measured/verified by authors)



Data for console sales are available on a yearly basis, but the console revisions were released midyear. We assume that if a revision came out midyear, reported sales were split evenly between pre- and postrevision console specifications. In sensitivity analysis, adjusting this assumption away from 50 % did not substantially change the total power consumption and has no effect on our recommendations.

Video game consoles have a low failure rate (1–5 % per year), with the notable exception of the high failure rate (more than 10 % per year) of early Xbox 360 consoles (Sands and Tseng 2009). This class of failures was characterized by a red ring of lights around the console’s on/off indicator and is known in the industry as the “red ring of death” or “RRoD”.

Microsoft has a policy of replacing any RRoD Xbox 360 console within 3 years of purchase (Microsoft 2007). The Xbox 360 hardware failures were within acceptable levels (5 % per year) by 2009 (Sands and Tseng 2009), and RRoD Xbox 360 units were replaced with more reliable units. Because of the low failure rates and short time periods involved, we assume that all consoles sold are in active use. Furthermore, even though the failure rate is known, many failed consoles are replaced under warranty or repaired by the manufacturer (which is cheaper than purchasing a replacement) and thus do not decrease the quantity of active consoles.

The three current generation video game consoles do not offer exactly equivalent services. Each system

Table 2 Power consumption and sales figures of current generation video game consoles. Ranges are provided for the active power. (Natural Resources Defense Council 2008; Hollister

2010; Miller 2009; Nelson 2007; VGChartz 2011; some data measured/verified by authors)

Console and year released	Standby power (W)	Idle power (W)	Active power (range) (W)	US sales through 2010 (million units)
Microsoft Xbox 360 (Current, 2010)	1	75	94 (62–94)	3.5
Microsoft Xbox 360 (2007)	3	100	119 (85–127)	17.5
Microsoft Xbox 360 (Launch, 2005)	2	162	172 (126–186)	4.5
Sony PlayStation 3 (Current, 2010)	1	75	100 (81–100)	6.5
Sony PlayStation 3 (2007)	1	120	153 (129–153)	7
Sony PlayStation 3 (Launch, 2006)	1	167	180 (173–199)	2
Nintendo Wii with WC24 enabled (2006)	9	11	16 (14–18)	17
Nintendo Wii with WC24 disabled (2006)	2	11	16 (14–18)	17

offers different performance capabilities for games and media. The PS3 and Xbox 360 have similar technical performance, and many multiplatform games offer essentially the same experience on these platforms. The Wii has a notably lower processing capability, hence the much lower active power consumption, and games designed to run on the other two systems must be modified for its more limited capabilities. In addition to games, each of the systems has multimedia capabilities such as playing DVDs (Xbox 360 and PS3), playing Blu-ray movies (PS3), and streaming Netflix video (all three systems). The Nintendo Wii has included motion controls since its launch in 2007 (all three systems now have a form of motion control available), though it does not support high definition video output.

A recent Nielsen Company study of game console usage highlights the effect that differences in the functionality of the three different video game consoles have on consumer behavior (Nielsen Company 2010). The study states that more than 50 % of PS3 active use time is dedicated to nongaming tasks, most prominently media playback. It also shows that the average Nintendo Wii console is used about one-third as much as a PS3 or Xbox 360. The user hours per week and the fraction of that time dedicated to media playback (rather than gaming) reported in the Nielsen study can be found in Table 3. Nielsen has extensive experience in measuring consumer behavior as it relates to entertainment media and states that these results are metered, suggesting that they are likely to be more accurate than self-reported data. Nielsen reports their usage per console user, not per console,

Table 3 Usage data for the three current generation video game consoles, which includes all console usage (games, media playback, streaming media, web browsing, etc.). The Nintendo Wii is used significantly less than the Xbox 360 or PS3. (Nielsen Company 2010)

Console	Usage (h/week) ^a	Media playback use (percent of active use)
PlayStation3	8.2	51 %
Xbox 360	9.8	38 %
Wii	2.8	31 %

^aNielsen reports usage in weekly hours per user but does not state the number of users per console. Nielsen defines a user as someone who uses the console in the reporting period. We assume an average of two users per console

and we assume an average of two users per console. Sensitivity analysis (discussed below) finds this parameter to have little effect on the overall results.

Unfortunately, neither Nielsen nor any other available source measures how often console users leave their system in idle mode when they are not actively used. As this information is necessary to calculate total energy consumption, we assume that 30 % of users leave their console idle when not in use, with the remainder putting their console into standby mode. Given the importance of this assumption, we perform a thorough sensitivity analysis, discussed at length in “Results: estimated console energy consumption”. The PS3 and Xbox 360 have both added an “auto power down” capability through firmware updates, but this feature is not enabled by default and is difficult to find in system menus. We believe that this feature is not frequently utilized by consumers, and we neglect its effects on overall power consumption. The value of auto power down is discussed in detail in “Value of design improvements and ENERGY STAR requirements”.

Results: estimated console energy consumption

Using the data for power consumption, number of consoles in American homes, and time the consoles are operational in each of the three modes (active, idle, and standby) as well as several key assumptions detailed in “Data and assumptions”, we estimate that total console electricity consumption in the US was 16 TWh in 2010 (Table 4). This is roughly 1 % of annual US residential electricity consumption and is about double the annual electricity consumption of the state of Rhode Island (US Department of Energy 2008). Sixteen terawatt hours is approximately 330 kWh/year for each game console, though actual

Table 4 Base case total US console electricity use by operational mode and by console type. Energy units are in gigawatt hour in 2010

	Xbox 360	PS3	Wii	All
Standby	370	90	1,100	1,600
Active	1,600	890	80	2,600
Idle	6,800	4,100	1,000	11,800
Total	8,700	5,100	2,200	16,000

consumption depends strongly on which console is being discussed and how it is used. For both the Xbox 360 and the PS3, the energy consumed while in idle mode is about 75 % of the total. For the Wii, more than half of the energy is used while in standby mode because of the high standby energy consumption when the WiiConnect24 service is enabled.

These results are highly sensitive to the amount of time played and to the behavior of the user with regards to how long the console is left idle vs. powered down to standby. The greatest energy consumption occurs if the consoles are constantly in active use and the lowest if they are constantly in standby mode. While each of these scenarios is unlikely, they provide bounds on the energy consumption and context for the following sensitivity discussion. In an 'all active' scenario, electricity consumption would be roughly 51 TWh for the 2010 fleet of current generation consoles. In an 'all standby' scenario, electricity consumption would be roughly 2 TWh. If the consoles' active use time is doubled from the base case scenario, the total electricity consumption increases by only 12 %, from 16 to 18 TWh. If the consoles' idle time is doubled, the total electricity consumption increases by 70 % to 27 TWh.

The estimated total electricity usage is strongly dependent on the assumption regarding consoles left idle, as illustrated in Fig. 3. It is important to note that this figure accounts for both the quantity of consoles in US homes and the hours of use per week. The Xbox 360 and PS3 have similar power consumption and usage, but Xbox 360 consoles consume more

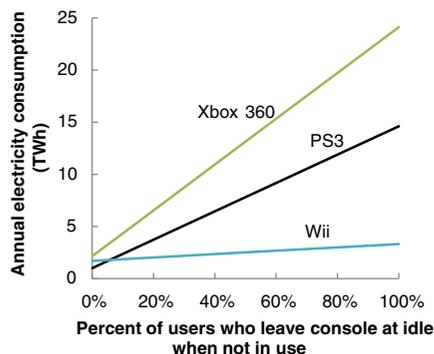


Fig. 3 Estimated total annual electricity consumption of US video game consoles vs. percentage of users that leave console in idle when not in use. The total electricity consumption varies greatly depending on consumer behavior regarding power down. Our base case assumption is that 30 % of users leave their console idle when not in use

electricity than PS3 consoles as a whole due to the greater number of these consoles in American homes. Despite having the largest number of systems sold, Wii consoles use the least electricity over most of the range because they are used one-third as much as the other consoles and have very low power consumption in active mode. Interestingly, for a low idle percentage (i.e., almost all users put their console to standby mode when not in active use), total energy from the Wii consoles is greater than that of PS3 consoles due to the high power consumption of the WiiConnect24 service during standby.

Sensitivity analysis of the total annual electricity consumption calculation shows that the uncertainty regarding how long the console is left in idle drives the overall uncertainty regarding total electricity consumption (Fig. 4). In this figure, fraction of time left idle is varied between 10 % and 80 % (base value is 30 %) due to great uncertainty in this parameter, which has the largest effect on the total electricity consumption. The number of users per console relates to the hours of active use (see Table 3) and is varied between 1 and 4 (base value is 2). Percent of Wiis with WiiConnect24 enabled is varied between 10 % and 80 % (base value is 50 %) and has little effect on overall electricity consumption (though it strongly affects the consumption of Wii consoles). The total number of active consoles refers to the quantity of active consoles and is varied between 80 % and 120 % of reported sale figures (base value is 100 %). While the number of active consoles has the most direct influence on total electricity consumption, its value can be established with greater certainty than the other parameters, due to careful tracking of sales data by the video game industry.

Value of design improvements and ENERGY STAR requirements

There are several technical options for reducing the overall electricity consumption of video game consoles. Overall consumption can be decreased by reducing the power consumption in any or all of the modes of operation (standby, idle, or active use). Electricity consumption can also be decreased by increasing hardware flexibility so that less computationally intensive tasks can be performed with some of the processing resources disabled. For example, many standalone Blu-ray players

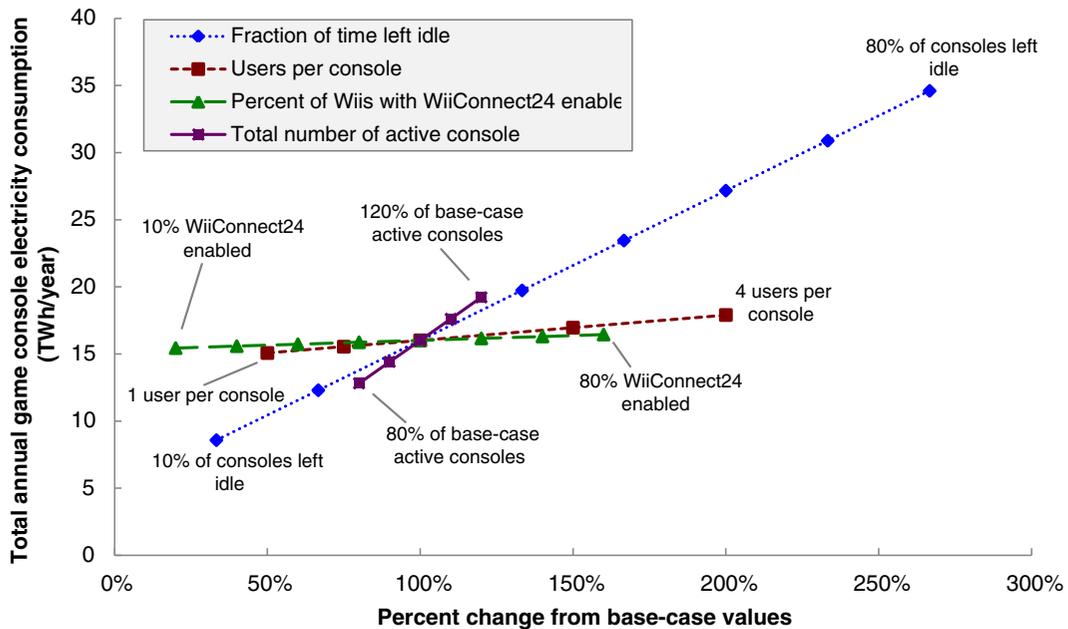


Fig. 4 Sensitivity plot showing effect of changes in inputs to total annual electricity use of consoles. Each input is varied over a range representative of the uncertainty inherent in the parameter

consume 20–30 W during playback, while an early model PS3 consumes around 150 W when performing the same task (Natural Resources Defense Council 2008), suggesting that the system is maintaining processing resources that are not required for playback. Electricity use can be controlled by reducing the duration and frequency of auto-wake events such as WiiConnect24. Currently, WiiConnect24 maintains a Wi-Fi data link when in standby mode, but this continuous connection could be replaced by an intermittent connection to save energy.

Electricity consumption can also be decreased by implementing an auto power down function on the console, which allows the console to automatically put itself into a low power state (normally to standby) if there is no user input for a predefined period. Currently, the PS3 offers users the opportunity to set an auto power down after 1, 2, 3, or 6 h of inactivity, while the Xbox 360 has 1- or 6-h options. These settings are disabled by default and are only changed through a system sub-menu, suggesting that most console owners have not enabled this feature or even known of its existence. The Wii currently has no auto power down feature. If the best currently available auto power down option was enabled for all consoles (i.e., PS3 at 1 h, Xbox 360 at 1 h, and no change from the base case for the Wii) and assuming that 30 % of consoles are left idle, the total energy use in

2010 would have been roughly 6.7 TWh. This represents savings of 9.3 TWh (a 60 % reduction from base case) or total savings to consumers of \$1.1 billion at average US residential electricity prices (Energy Information Administration 2010a, b).

The US Environmental Protection Agency's (EPA) ENERGY STAR program, a voluntary product labeling system for consumer end-use products that helps consumers identify energy efficient appliances, is currently working on ENERGY STAR requirements for video game consoles (ENERGY STAR 2011). At this time, the EPA does not have ENERGY STAR requirements for video game systems, currently making consoles ineligible for ENERGY STAR certification. This may be partly due to the historically lower power consumption and sales numbers of consoles, but is primarily because of the difficulty of setting standards for an industry that consists of only three products at a time, with each product offering a different set of services. EPA has recently (August 2011) released game console energy use test methods and drafted eligibility requirements for stakeholder review (ENERGY STAR 2011). EPA will work with stakeholders over the coming months to refine the test metrics and eligibility criteria (Kaplan 2011). Currently, this draft describes requirements for auto power down, display sleep, and power supply efficiency but does not state

particular energy efficiency requirements, which will be included in future versions of the document.

In 2009, EPA released an earlier draft of game console requirements for ENERGY STAR that included power consumption limits for game consoles (ENERGY STAR 2009). Though this version is not the official working draft, it is similar to the current proposal thus far and gives an example of the level of energy efficiency EPA would like to achieve. This earlier draft addresses maximum power allowed for different console functions and auto power down specifications (ENERGY STAR 2009a, b). Using a tiered approach, the program would become more aggressive with power targets over time. The power management requirements from the 2009 draft are summarized in Table 5. Interestingly, these requirements do not limit the active power consumption of the consoles, which is likely an acknowledgment of the vastly different services from each company's offering.

This set of ENERGY STAR requirements targets energy use in two distinct ways. The first specifies limits on how much power the console can use while operating in each state. The second specifies how long the console can be left in various states, increasing the likelihood that the console will be in its lowest power state. This two-pronged approach addresses both technical and behavioral aspects of energy use.

In 2010, no existing console met Tier One requirements because of their power management settings:

none shipped with appropriate power management settings enabled by default. If the ENERGY STAR performance requirement of 1-h auto power down had been enforced for all three current generation consoles, the existing fleet of consoles would have used only 5.2 TWh in 2010. This represents a 10.8-TWh reduction (a 68 % decrease) or a savings of \$1.24 billion to consumers and a missed opportunity for a cost-effective energy efficiency policy.

Most current generation console users keep their systems connected to the Internet (The Diffusion Group 2010), and adding or enabling the auto power down feature could easily be accomplished in one of the frequent automatic system updates. Though not all users would keep this setting enabled, studies have shown that people are far more likely to remain in a program than to opt out, so much of this potential energy savings could be realized with this simple step from console manufacturers (Madrian and Shea 2001). The most difficult aspect of this deployment may be pushback from consumers. While most modern games automatically save a player's progress every few minutes, some games do not (normally for gameplay rather than technical reasons) and consumers that leave games in an idle state for more than an hour could lose their progress, depending on how idle is defined by the console manufacturers. Linking an informative message to the firmware update that describes the potential electricity and dollar savings

Table 5 ENERGY STAR Game Console Requirement (version 5.1) power summary. These figures are from an earlier effort to define ENERGY STAR game console requirements and are

used as an example of a reasonable set of power requirements since the current ENERGY STAR requirements document has not yet added specific figures

	Program phase		
	Tier one	Tier two	Tier three
Operational mode power requirements			
Sleep	2 W	1 W	1 W
System idle	–	45 W	25 W
Media playback	–	–	35 W
Power management requirements			
Sleep mode engaged after 1 h inactivity	✓	✓	✓
Console must power down immediately after auto-wake event ^a	✓	✓	✓
Power management settings enabled by default	✓	✓	✓

^a The guidelines define this type of automatic wake event more specifically as the console exiting sleep mode without input from the user. This situation happens when the console is set to automatically update or perform system maintenance

of auto power down for the user could encourage compliance while alerting users to the change in their console's operation.

While the costs of including this in a future firmware update are nonzero, the marginal development and distribution costs for such a minor change would be trivial relative to the potential savings to consumers. Each of the three consoles has gone through dozens of firmware updates that have improved and expanded hundreds of capabilities. For example, previous firmware updates for consoles have added read/write capability for SD cards (Wii), enabled support for USB keyboards (Wii), added 3D video output (PS3), and added the ability to output in 1080p video format (Xbox 360) (Nintendo 2010; Sony 2011; Klepek 2006). Adding or changing auto power down settings through firmware updates is a realistic option.

The potential savings per household depends on electricity price, usage habits (particularly power down habits), and what version of game console is owned. The average Xbox 360 or PS3 owner could save around \$30/year with 1-h auto power down enabled, though users that never power down their console manually stand to save more than \$100/year. An average Wii owner would save only \$2/year (\$5 if they never powered down their system) due to the low active power consumption of the Wii. While the Wii does not currently have an auto power down feature, this feature could be added through automatic firmware updates.

The operational power mode requirements cannot be implemented on the existing console base, as these require changes to hardware, not firmware. While the ENERGY STAR requirements for game consoles target the next generation of video game consoles, it is illuminating to see what effect the requirements would have had if applied to the three current generation consoles. We examine a counterfactual scenario where the ENERGY STAR benchmarks were in place before the current generation of consoles were released and further assume that all three consoles meet the ENERGY STAR requirements. In this scenario, in any aspect where the consoles fail to meet the ENERGY STAR requirements, we improve them to the relevant requirement. For modes where the current consoles exceed the requirements, we use the actual consumption numbers. While this is a theoretical experiment, it provides insight into how the ENERGY STAR requirements might affect the design of the next

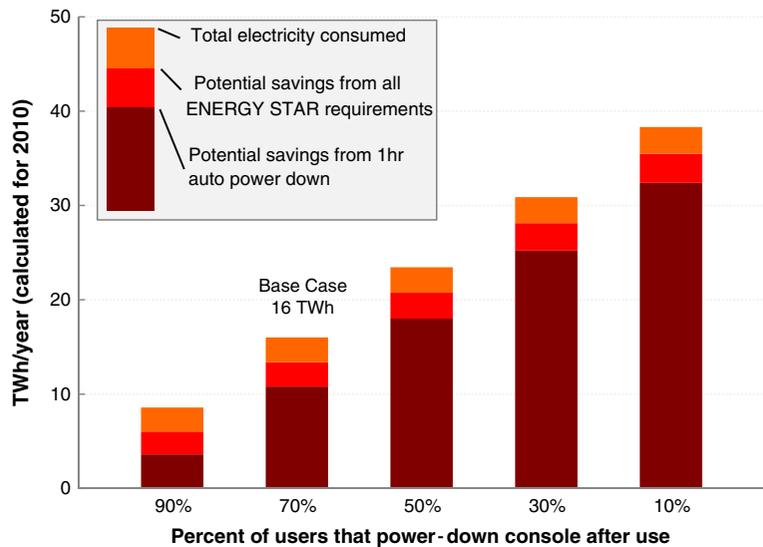
generation of consoles, which are currently being developed. Of the three current console manufacturers, only Nintendo has announced their next generation console (the Wii U, expected to launch in late 2012), though Microsoft and Sony are likely to announce new consoles by the end of 2012 (Boxer 2011).

From these results (Fig. 5), it is apparent that addressing the auto power down feature is the most effective way to reduce energy consumption, even if only 10 % of users leave their consoles on when not in use. In fact, an auto power down feature would save more energy than all other ENERGY STAR requirements combined as long as more than 7 % of users leave their consoles idle when not in use. The second best way to reduce electricity consumption is to meet the ENERGY STAR idle power requirement, which also addresses the energy consumed by inactive consoles but has a much smaller effect. In the base case scenario where 30 % of users leave their console idle between sessions, the energy savings of the sleep, idle, and media playback power requirements combined save only one-fourth as much energy as the auto power down requirement. If all of the current consoles in the market met the Tier 3 ENERGY STAR requirements, energy consumption from console operation would be reduced by 85 % (13.5 GWh in 2010) in the base case scenario, though enabling only the auto power down would reduce overall consumption by 70 % (11 GWh in 2010).

Discussion

The overall energy consumption of video game consoles and the potential savings from efficiency improvements are growing rapidly and becoming increasingly significant. Assuming that consoles are left idle after use 30 % of the time, the overall electricity consumption was 11 TWh in 2007 and 16 TWh in 2010, a growth of 50 % in 3 years. Sixteen terawatt hours is approximately 1 % of residential energy use and costs US consumers \$1.9 billion each year at average electricity prices (Energy Information Administration 2010). The planned ENERGY STAR requirements for game consoles offer an opportunity to address the electricity consumption of game consoles before the launch of next generation consoles. A strict set of efficiency improvements, such as the proposed 2009 ENERGY STAR requirements, could have

Fig. 5 Total electricity consumed by video game consoles and potential savings of auto power down and all ENERGY STAR Tier 3 requirements, as a function of the percent of users that manually power down the console after use. Except when consoles are almost always powered down manually, the 1-h auto power down saves more electricity than the other ENERGY STAR requirements combined



reduced consumption by 85 % if they had been implemented in 2005 and followed for the entire current generation console cycle. An auto power down feature, a simple improvement that could be implemented now via firmware updates to power the console down after 1 h of inactivity, could reduce overall electricity consumption by 70 %. Though two of the three current generation consoles have this capability, it is not enabled by default, a modification that would be trivial for console manufacturers. This small change could save US consumers up to \$1.3 billion annually.

Both the overall energy consumption of game consoles and the potential savings from efficiency measures are highly dependent on the assumption made about the power down behavior of consoles after use, which is largely unknown. There is essentially no available information on this topic, and reasoning by analogy to other consumer electronics is difficult. For example, while some data are available regarding power down of home computers, they show that a large fraction of users rely on the default auto power down functionality of modern PCs, which is not a default feature of game consoles (Energy Information Administration 2005).

Despite the uncertainty, the high sensitivity to console power down demonstrates one important implication of this research—while a focus on improving efficiency of a console in its various operational modes will decrease overall consumption, affecting end-use behavior through auto power down is much easier to implement and has a larger effect on overall energy consumption. Additionally, given the historical

focus on high-performance systems at launch, the video game industry is unlikely to produce consoles that meet ENERGY STAR requirements with their initial models. At the same time, the console makers have already demonstrated a pattern of reducing console power consumption over the lifespan of a given system, even without ENERGY STAR requirements (recall Fig. 1). Thus, it seems likely that the ENERGY STAR power requirements will neither greatly influence initial console hardware design nor cause much additional reduction in later revisions. Furthermore, because ENERGY STAR is a voluntary program, power requirements that are difficult to meet may cause manufacturers to forego pursuit of ENERGY STAR certification and abandon implementation of the auto power down functionality, which appears to be the most valuable ENERGY STAR requirement.

One alternative solution, which is well-suited to the game console development cycle, is to have a series of ever-improving efficiency requirements that are phased in based on the time since console launch. Such a plan might allow a newly launched console to get ENERGY STAR certification in the first year as long as they have an auto power down installed and enabled by default. In later years, that console would have to meet increasingly tight efficiency standards to maintain ENERGY STAR status. This alternative would not only be more attractive to console manufacturers, but would achieve almost the same reduction in total energy consumption as a fixed set of requirements, since console sales tend to be low in

the first year due to high initial price. Furthermore, a significant amount of electricity could be saved if the 75 million current generation consoles already in US homes had auto power down enabled by default. While currently discussed ENERGY STAR requirements target the next generation of game consoles, if an exception was made for current consoles that made default auto power down the only ENERGY STAR requirement, it may encourage manufacturers to enable this feature on current consoles, saving significant amounts of electricity immediately.

While attempting to force an auto power down on users is a potential consumer relations hazard, a successful campaign could improve a company's environmental credibility while saving their customers money. One very appropriate tool for game console manufacturers to use is that of "gamification" where game design techniques are used to make (potentially mundane) tasks more engaging (Reeves and Leighton 2009). Manufacturers could provide system themes, achievements, or other virtual items, which have very little real cost but are attractive to gamers, as rewards for enabling or maintaining auto power down settings. By framing energy saving behavior as a game or contest, console manufacturers can motivate consumers through a familiar reward system and direct those rewards to the users of the console (who may not be the person that pays the electricity bill). Furthermore, since many of these virtual rewards (such as achievements or virtual items for online games) are public and viewable by other gamers, this strategy uses the power of social networking to advertise for the desired features or behavior.

The capabilities of consoles continue to improve and change over time. For example, the Microsoft Kinect, an Xbox 360 peripheral device introduced in 2010, has added new capabilities to the Xbox 360. The Kinect allows players to interact with the game console through motion and voice commands, and sold 8 million units in 60 days, setting a record as the fastest selling consumer electronics device (Thorn 2011). For the newest Xbox 360 hardware revision, the Kinect connects directly to the console, but older versions require an additional AC/DC adapter. The Kinect draws 4–5 W⁵ and also causes the system to

⁵ The Kinect electricity use was not included in this study because this study estimates the electricity consumption of consoles over the year 2010, and the Kinect was not released until November 2010. It would thus contribute little to the electricity consumption over the year.

draw an additional 1–3 W, presumably due to the extra processing power required to interpret the data stream from the device (Klug 2010; measured by authors). While video game consoles were once used only to play games, they now serve as a one-stop media hub, resulting in more complex usage patterns and an increase in both overall consumption and the value of energy-saving improvements. Though the ENERGY STAR program or other policies may limit the growth in unit energy consumption, it is reasonable to expect the number of consoles and the usage of consoles to increase in the future, increasing the overall electricity consumption of video game consoles. Further investigation into consumer behavior will help clarify the question of total console electricity use and will enable better decisions about energy saving features and programs.

The magnitudes of electricity consumption and potential savings from game consoles may be small relative to more prominent devices, but the marginal cost of implementing auto power down is likely small or perhaps negligible, meaning that essentially all technically feasible energy savings would generate a consumer surplus. Assuming that 30 % of consoles are left idle, the savings from a 1-h auto power down, which could be enabled on most of the 75 million existing current generation consoles by a firmware update, could have reduced residential energy consumption by about 1 % in 2010. Almost all efficiency measures require years to implement on a large scale, as consumers purchase or install new technology, and most require consumers to make decisions comparing increased upfront costs with expected future savings. While the energy savings from a 1-h auto power down amounts to 1 % of residential electricity, it is perhaps more important to note that it could be done with almost no upfront cost, no change in the quality and level of service provided to consumers, would have no adoption/implementation delay, and does not rely on any action or decision on the part of consumers.

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