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Energy Conservation with Open Source Ad Blockers

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Abstract: Internet-related electricity consumption is rising rapidly as global Internet users spend more than 6.5 h per day online. Open source ad blockers have the potential to reduce the time and thus electricity spent using computers by eliminating ads during Internet browsing and video streaming. In this study, three open source ad blockers are tested against a no-ad blocker control. Page load time is recorded for browsing a representative selection of the globally most-accessed websites, and the time spent watching ads on videos is quantified for both trending and non-trending content. The results show that page load time dropped 11% with AdBlock+, 22.2% with Privacy Badger, and 28.5% with uBlock Origin. Thus, uBlock Origin has the potential to save the average global Internet user more than 100 h annually. The energy conserved if everyone in the United States used the open source ad blocker would save over 36 Americans lives per year if it were to offset coal-fired electricity generated-based pollution. In the United States, if all Internet users enabled Privacy Badger on their computers, Americans would save more than $91 million annually. Globally, uBlock Origin could save consumers more than $1.8 billion/year. Open source ad blockers are a potentially effective technology for energy conservation.

Keywords: energy conservation; energy; open source; free and open source software; FOSS; free software; ad blocker; Internet; Internet advertising; advertising; tracker; browser tracking; internet tracking; web tracking; tracker blocker; tracker protection; malware blocking; malware protection; privacy; internet privacy

1. Introduction

Americans now spend unprecedented amounts of time online. The *Surveying the Digital Future* study found that 92% of Americans are Internet users and that, on average, since 2000, the time they spent online more than doubled from 9.4 h to 23.6 h per week [1]. A lot of this Internet time is at home, which has risen more than fivefold from 3.3 to 17.6 h per week [1]. With this rapid growth in Internet use, concern has arisen over the resultant electricity consumption [2]. Concerns stem from the use of fossil fuel combustion to provide electricity generation and its concomitant negative externalities, which have well known negative environmental and health impacts [3]. For example, eliminating coal-fired air pollution alone in the United States would prevent about 52,000 premature American deaths per year [4]. It is estimated that information tech and services accounted for about 5% of total global electricity use and is increasing [5]. Hence, in America, information technology electricity use is roughly responsible for the premature deaths of 2600 Americans annually from coal-related air pollution alone. Thus, minimizing Internet-related energy use is of great importance.

A lot of this Internet use is funded in some way by ads, as it has been shown that the ad-supported Internet ecosystem is now a major part of the United States economy [6]. In general, online ads are viewed as undesirable by Internet users, and many people attempt to avoid them [7]. Despite significant

research on advertising avoidance [8–10] (which is generally focused on finding determinants of advertising avoidance of online media to provide insights that may suggest strategic ways to decrease advertising avoidance [10–13]), Internet users are still attempting to protect their time [14–16].

Thus, it is not surprising that some of the most popular plugins for both Firefox [17] and Chrome Internet browsers are for ad blocking software, which have been downloaded tens of millions of times [18]. In addition, an increasing number of advertisers are using consumer data and advanced digital technologies to deliver personalized campaigns. The increasingly intrusive nature of advertising has also raised privacy concerns [19–22]. Counter to this trend, the open source paradigm can dramatically increase trustworthiness for and autonomy of the user [23]. Open source development methods have motivated many technologists to solve many types of technical problems [24–30] effectively. Of greatest importance to this study, this has resulted in a number of open source ad blockers becoming available [31].

Open source ad blockers have the potential to reduce the time spent on electricity consuming Internet-tied devices by eliminating ads. In this study, three open source ad blockers were tested against a no-ad blocker control for both web browsing and video watching. The time to load the pages is recorded for browsing, and the time spent watching ads on videos was quantified for both trending and non-trending content. From these values, the potential for open source ad blockers to act as effective energy conservation technologies was estimated. The results are presented and discussed.

2. Materials and Methods

2.1. Ad Blocker Selection

Three open source ad blockers were tested against a no-ad blocker browser for both web browsing and video watching: (1) Adblock plus (https://gitlab.com/eyeo/adblockplus; GPLv3), (2) Privacy Badger (https://github.com/EFForg/privacybadger; GPLv3) and (3) uBlock Origin (https://github.com/gorhill/uBlock/, GPLv3).

Adblock Plus (https://adblockplus.org/) is a traditional ad blocker built as a free browser extension. However, the developers recognize that ads finance many websites and thus offer partial ad blocking using an "Acceptable Ads" initiative [32] with strict criteria that identify nonintrusive ads. Users of Adblock Plus decide through settings the level of ads they view, but the default is to allow "Acceptable Ads". Another approach is taken by Privacy Badger. Privacy Badger was developed by the Electronic Frontier Foundation (EFF) (https://www.eff.org/privacybadger), which is a leading nonprofit organization focused on defending civil liberties and privacy in the digital world. Privacy Badger is a browser extension that automatically analyzes and blocks any tracker or ad that violates the principle of user consent. It was designed to function without any settings, knowledge, or configuration by the user. Finally, uBlock Origin (It should be noted that uBlock.org, is not affiliated with uBlock Origin. The latter which is owned by AdBlock, uses the same "acceptable ads" method, often for which larger publishers pay a fee to make their ads listed as acceptable.) is a wide-spectrum blocker that blocks ads, trackers, and malware sites using (i) EasyList, (ii) EasyPrivacy, (iii) Peter Lowe's list of ad, tracking and malware servers, and various lists of malware sites, including built-in filter lists. In a previous informal study [33] of resources and load times on a wide range of ten different ad blockers, uBlock Origin was found to be the most efficient.

2.2. Ad Blocker Testing on Webpages

Testing the ability of an ad blocker to block ads on a specific website is challenging because ads are served by third parties, so page load time is dependent on essentially random external servers. To overcome this challenge, each website listed in Table 1 was tested with no ad blocker and the three ad blockers for ten iterations. There is still error associated with this method, so any major outliers were removed and replaced with another page load. Table 1 includes three web search engines, two of

the most used sources of information, three news sites, and two of the top Chinese language websites, according to Alexa [34]. The ten page load times were recorded and averaged for each.

Table 1. Analyzed websites and their classification.

Website	Classification
google.com yahoo.com bing.com	Web search
wikipedia.org weather.com	Information
cnn.com foxnews.com nytimes.com	News
sohu.com taobao.com	Chinese search/gaming Chinese e-commerce

Previous studies comparing ad blockers looked at CPU and memory use [33], to see if this had any discernable impact on energy use. A desktop and laptop were monitored by a multimeter during the tests. No discernable difference was observed on several computers, so these data were not further analyzed. Finally, the effectiveness of the ad blockers was determined for their ability to block ads.

2.3. Ad Blocker Testing of Streaming Video

To test the three ad blockers for their ability to screen out in-video ads on a streaming video site, YouTube (www.youtube.com) was selected because it is the largest video website [35]. Three trending channels were selected that would represent ad-heavy content: (i) House of Highlights (2.29 million subscribers), (ii) Good Mythical Morning (16.2 million subscribers), and (iii) jacksepticeye (23.3 million subscribers). Then three non-trending channels were selected: (i) Max and Tony (13 subscribers), (ii) Keeganchu (1.9 thousand subscribers), and (iii) Glitch (115 thousand subscribers). Three videos were selected in each channel, and the total duration and content duration were recorded for each. The percent ad time was determined for no ad blocker control and the three ad blockers described in Section 2.1.

2.4. Energy Conservation Estimates

Annual energy conservation potential in the United States and the world for open source ad blockers speeding up the use of the web, E_y(USA) and E_y(Globe), can be conservatively estimated by first determining the time spent loading web pages on computers.

The time per year saved per person who uses the web in hours, $t_{h/y}$, for a specific population (*pop*) is given by:

$$t_{h/y}\,(pop)\left[\frac{hours}{year}\right] = p_r \times l_h \times w_{h/y}(pop) \times t_l \times \left(\frac{1hr}{3600\ s}\right) \times s_{block-x} \quad (1)$$

where p_r is the percent of time web users are rapidly clicking through the web, l_h is the page loads per hour during this rapid click time, $w_{h/y(pop)}$ is the hours spent per day on the web × 365 days/year, and t_l is the average load time per page in seconds, and $s_{block-x}$ is the percent time savings using ad block x where x is one of the three ad blockers evaluated. *Time* reports that 55% of Internet use is spent with fewer than 15 s actively on a page [34], so the rapid clicking percent, p_r is 0.55, and the page loads per hour, l_h is 240. In this study, two populations will be considered: (1) the world and (2) the United States. In the United States, the time spent using the Internet is 6 h and 31 min per day, and the world average is 6 h 42 min per day [35]. Thus, $w_{h/y(U.S.)}$ is 2372.5 h/year and $w_{h/y(Globe)}$ is 2445.5 h/year. This study will provide t_l and $s_{block-x}$ for the three open source ad blockers.

The energy, $E_y(pop)$, used for web users to watch ads on their own devices (Please note that any external or server-based energy conservation, which consumers do not pay for directly, will be left for future work.) can be calculated by:

$$E_y(pop)\left[\frac{kWh}{year}\right] = f_c \times P_c \times t_{h/y}(pop) \times \frac{kW}{1000W} \times P_{pop} \quad (2)$$

where f_c is the fraction of web devices that are computers, P_c is the power in Watts of the average computer in the population, and P_{pop} is the total population in the specific population. In 2019, the mobile share of web use was 48%, which means the computer user fraction, F_c, of web use is 0.52 [35]. It was assumed here that Internet use is the same for both types of devices. This use may differ, and the complexities of tracking that across the globe are left for future work. To be conservative, for this estimate for the energy used on mobile phones will be ignored and also left for future work. Lawrence Berkeley National Lab performed a detailed analysis of computer energy use and found the average power draw for a desktop was 66.1 W and a laptop was 32.0 W. The overall average was 58.5 W, which is used for P_c [36]. Finally, the population, P_{globe}, for the globe is made up of 4.4 billion Internet users worldwide [35]. The United States has more than 312 million Internet users with over a 95% penetration rate [37].

Web users that use open source ad blockers would thus save the following money, $S_y(pop)$, if everyone used ad blockers:

$$S_y(pop)\left[\frac{US\$}{year}\right] = E_y(pop) \times r_e(pop) \quad (3)$$

where $r_e(pop)$ is the electric rate for the given population. The average electric rate for the globe is 0.14 USD/kWh and for the United States it is 0.1269 USD/kWh [38]. These calculations can be extended in future work by considering the costs of electricity around the world [39].

For non-rapid web clicking, there would also be energy saved with the ad blockers, but it will be far less than during the rapid clicking time. One of the times, however, when people are using the web and not clicking frantically, is when they are watching movies, tv, music videos, etc., via streaming video.

Finally, to get a conservative estimate of the energy consumed for streaming video, calculations are based on YouTube data. YouTube is the second most used website, according to Alexa [40]. The time YouTube watchers globally can save with ad blockers is estimated as:

$$t_{h/d-YouTube}\left[\frac{hours}{day}\right] = t_{view} \times p_{ads} \quad (4)$$

where t_{view} is the total hours spent watching YouTube by all users globally per day, and p_{ads} is the percent of time streaming spent on ads. YouTube has over 2 billion users worldwide, who watch over 1 billion h of streaming videos per day [41], so t_{view} is approximately 1 billion h. The value of p_{ads} will be supplied by data from this study using a high and low sensitivity bounded by the more frequently watched trending channels and the less frequently watched non-trending channels.

The energy saving from ad blockers functioning on YouTube, $E_{YouTube}$, can be estimated for the entire globe only because Alphabet, an ad revenue-based company that owns Google and YouTube, does not make their data public (Alphabet does, however, keep a significant amount of data about their users. Users can access some of this data and possibly stop some of the Google tracking activity following Nielo [42]):

$$E_{YouTube}\left[\frac{kWh}{year}\right] = f_{c-YouTube} \times P_c \times t_{h/d-YouTube} \times \frac{365\ days}{Year} \frac{kW}{1000W} \quad (5)$$

where $f_{c-YouTube}$ is the fraction of web devices that are computers. Seventy percent of YouTube watch time comes from mobile devices [41], so $f_{c-YouTube}$ is set at a conservative 0.25. For this estimate, again, the energy used on mobile phones will be ignored and left for future work.

Finally, the economics savings potential for YouTube users that deploy an effective open source ad blocker can be estimated as:

$$S_{YouTube}\left[\frac{US\$}{year}\right] = E_{YouTube} \times r_e(Globe) \tag{6}$$

3. Results and Discussion

All of the open source ad blockers tested were able to eliminate at least some ads for webpage browsing effectively. This is demonstrated with screenshot data of two representative websites: the Weather Channel website (Figure 1) and the Yahoo website (Figure 2) without ad blockers and the results for AdBlock+, Privacy Badger, and uBlock Origin. With no ad blocker (Figure 1a), the front page of the Weather Channel had two ads showing a horizontal ad at the top and a box ad on the right. These ads took up enough screen area that the trending stories are not completely visible. With AdBlock+ enabled (Figure 1b), both ads were removed, and the page enabled viewing of the trending stories. Privacy Badger, as seen in Figure 1c, also eliminated all ads from the viewer, but did not reformat, so no additional screen area was obtained. Finally, as seen in Figure 1d), uBlock Origin provided identical results to AdBlock+. This, however, was not always the case, as shown in Figure 2.

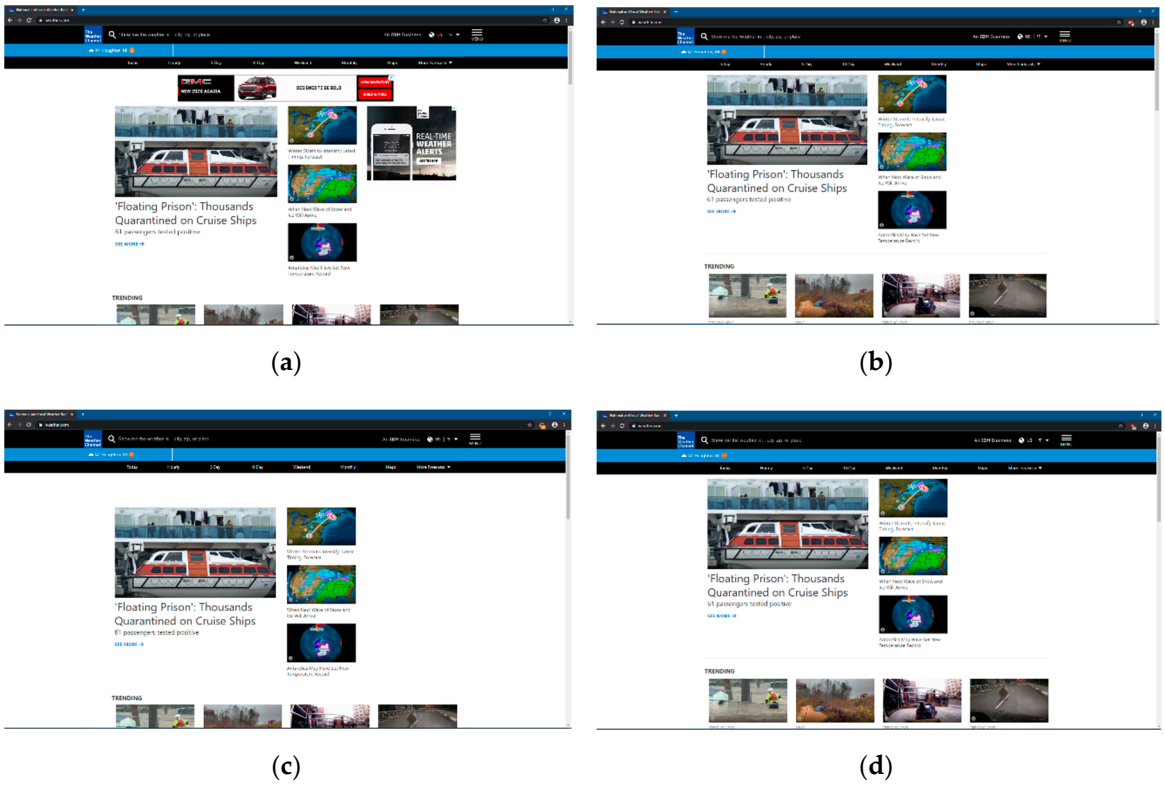

Figure 1. The impact of open source ad blockers on the Weather Channel website: (**a**) no ad block, (**b**) AdBlock+, (**c**) Privacy Badger, and (**d**) uBlock Origin.

With no ad blocker (Figure 2a), the front page of Yahoo was dominated by a large horizontal ad taking up roughly a quarter of the pages content area. With AdBlock+ enabled (Figure 2b), this large ad was removed, but a smaller horizontal ad replaced it at the top, and an additional small ad was still visible in the middle right-hand side of the content area. These were presumed to be 'acceptable ads' following the AdBlock+ business model and were objectively less intrusive than with no ad blocker.

Privacy Badger, on the other hand, as seen in Figure 1c, eliminates all ads from the viewer as before. However, white space was left in the place that ads were located without the ad blocker enabled. Finally, as seen in Figure 1d, uBlock Origin not only eliminated all ads but also eliminated the white space. This effectively provided more content per screen than all of the other options, including those, such as Yahoo, that presumably paid AdBlock+ to be deemed "acceptable".

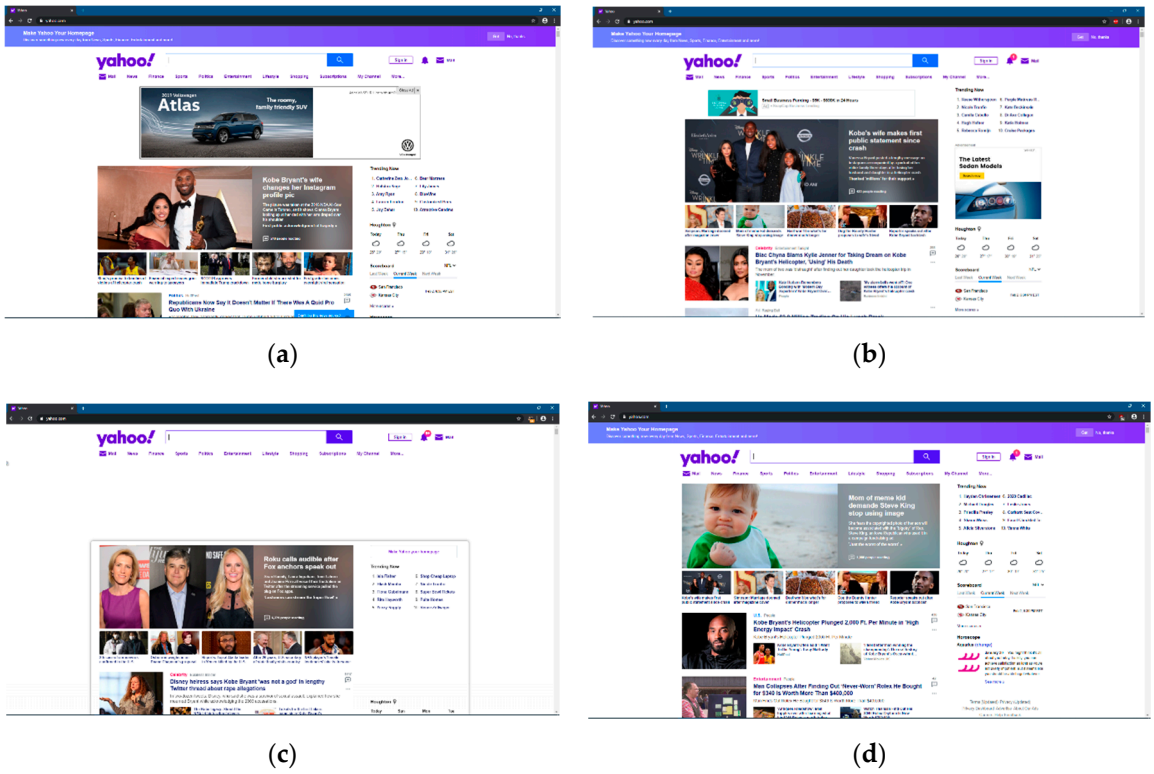

Figure 2. The impact of open source ad blockers on the Yahoo.com website: (**a**) no ad block, (**b**) AdBlock+, (**c**) Privacy Badger, and (**d**) uBlock Origin.

The results of the visual results indicated by the screen captures in Figures 1 and 2 agree with the average page load time data, which is summarized in Table 2. For the ten websites analyzed, the average of the average page load time was 3.9 s (t_l). Table 2 also shows the percent of saved load time for each open source ad blocker. The page load time dropped 11% with AdBlock+, 22.2% with Privacy Badger, and 28.5% with uBlock Origin, which provides $s_{block-x}$. Clearly, uBlock Origin has the greatest potential of the three open source ad blockers tested to save Internet users the most time.

However, there is other interesting information provided by Table 1 that can explain the observations in Figures 1 and 2, AdBlock+, for example, took more time than the no ad blocker case for Yahoo, which could be caused by the reformatting to have different ads and/or the speed of the various servers providing those effective ads. Whereas, for the Weather Channel, all of the open source ad blockers tested cut down the page load time by 33 to 43 percent compared to the no ad blocking case. Due, in large part, to the remarkable click rate of Internet users (240 per day) during rapid browsing, the potential time saved by enabling open source ad blockers is substantial. These values were calculated for all of the open source ad browsers and are summarized in Table 3.

As can be seen in Table 3, the time per year saved per person who uses the web over the entire globe using Equation (1), ranged from 38.9 h for AdBlock+ to over 100 h using uBlock Origin. For the latter, this is equivalent to 2.5 working weeks of productivity lost watching ads per year for the average net citizen. In the United States. because of slightly less Internet usage per day, the results were a few percent less. It again should be pointed out here that this is a conservative estimate as none of the

time lost to ad loading times is included for non-rapid web surfing, which makes up nearly half of Internet use.

Table 2. Average page load times (in seconds) for no ad block, AdBlock+, Privacy Badger, and uBlock Origin as well as the percent of saved load time for each open source ad blocker.

	Website	Use of Ad Blocker						
		None	AdBlock+	AdBlock+ Percent	Privacy Badger	Badger Percent	uBlock Origin	uBlock Origin Percent
1	google.com	0.997	0.962	3.5%	0.9476	5.0%	0.9889	0.8%
2	yahoo.com	2.359	2.696	−14.3%	1.92	18.6%	1.343	43.1%
3	bing.com	0.799	0.532	33.4%	0.5404	32.3%	0.5402	32.3%
4	wikipedia.org	2.294	2.260	1.5%	2.11	8.0%	2.498	−8.9%
5	weather.com	1.491	0.993	33.4%	0.9029	39.4%	0.8561	42.6%
6	cnn.com	3.258	3.347	−2.7%	2.678	17.8%	2.514	22.8%
7	foxnews.com	5.647	5.550	1.7%	3.776	33.1%	3.602	36.2%
8	nytimes.com	3.683	3.600	2.3%	2.322	37.0%	2.658	27.8%
9	sohu.com	16.920	8.960	47.0%	13.68	19.1%	4.01	76.3%
10	taobao.com	1.970	1.890	4.1%	1.75	11.2%	1.74	11.7%
	Average	3.942	3.079	11.0%	3.063	22.2%	2.075	28.5%
	SD	4.779	2.551	19.7%	3.850	12.5%	1.176	24.2%

Table 3. Average time per year saved per person who uses the web in the world and the United States if AdBlock+, Privacy Badger, and uBlock Origin were used.

	t (*Globe*) [Hours/Year]	t (*USA*) [Hours/Year]
AdBlock+	38.9	37.7
Privacy Badger	78.4	76.1
uBlock Origin	100.7	97.7

The electrical energy conserved using the three ad blockers was calculated following Equation (2), and resultant electricity bill savings following Equation (3) are shown in Table 4. Again, this is a conservative estimate as it not only used the conservative times from Table 3 but also only included the energy used on the fraction of computers used and only considered the users' side of the energy use (e.g., what consumers would pay for in their utility bills). Despite these conservative assumptions, both the energy conservation potential of the various open source ad blockers as well as the economic savings for consumers is remarkable. So, for example, the 1.35×10^{10} kWh saved globally for using uBlock Origin is equivalent to more than 1.0% of the electricity generated per year from coal in the United States, which is responsible for the premature deaths of about 52,000 American every year from air pollution [43,44]. The energy savings potential in the United States from using uBlock Origin was a much smaller 0.07%. However, if we assume that the electricity used to power the computers to watch ads came from coal, the reduced coal-fired pollution from using uBlock Origin could save over 36 American lives per year. Although far more pollution could be cut by converting to renewable energy and nearly all the lives could be saved [4,45], 36 lives are still considerable as it is more than the number of people murdered in the 2007 Virginia Tech shooting rampage [46] (It has previously been questioned why the coal industry is allowed to continue profiting from the deaths of Americans when there are ample and lower-cost alternative sources of electricity [47]).

Table 4. Electrical energy conserved and consumer electric bill savings per year from the use of open source ad blockers in the world and the United States during rapid Internet use for AdBlock+, Privacy Badger, and uBlock Origin.

	$E_y(Globe)$ [kWh/year]	$S_y(Globe)$ [USD/year]	$E_y(USA)$ [kWh/year]	$S_y(USA)$ [USD/year]
AdBlock+	5.20×10^9	728,300,000	3.58×10^8	45,432,000
Privacy Badger	1.05×10^{10}	1,469,800,000	7.23×10^8	91,690,000
uBlock Origin	1.35×10^{10}	1,886,960,000	9.28×10^8	117,710,000

Significant future work is needed to determine the energy conservation potential on the server side. Data servers use a substantial and growing amount of energy, and there is considerable effort to reduce that energy use [48–50] using both thermal management [51–54], electrical management [55], configuration [56], and smart systems [57]. The concept of green data centers [58,59] is growing. Facebook open sourced their designs [60], and there is even open hardware that could be used to help monitor and improve them [61]. Despite this effort, the results of this study indicate some of the lowest-hanging fruit is simply to eliminate the need for some servers by expanding the deployment of open source ad blockers. Future work should consider policies to encourage this deployment for energy conservation alone, although there are clearly arguments for saving Internet users' time as well as consumers' money.

Economically the savings for the use of open source ad blockers are potentially easier to understand. For example, in the United States, if all Internet users enabled Privacy Badger on their computers, they would expect to save more than 91 million dollars annually. Globally, if all Internet users used uBlock Origin, they would collectively save more than 1.8 billion U.S. dollars a year.

These savings (Table 4) only considered the rapid page loading portion of Internet users' time spent on the web. Much of the remainder of the time is spent streaming videos in general and YouTube in particular. Due to the lack of data on what ratio of YouTube ad time is spent on trending and non-trending content, a sensitivity between the two resulted in a minimum estimated ad time of 0.06% up to 21%. Time spent watching YouTube ads determined using Equation (4) ranges from 600,000 h/day 210 billion h/day globally. $E_{YouTube}$ from Equation (5) ranges from 3.6 million to 1.13 billion kWh/year, and the economic savings from using uBlock Origin would range from just under half a million dollars to $158 million per year globally. This obviously is an enormous range due to the uncertainty of YouTube viewer habits and the ad algorithms. The YouTube analysis can be treated as a preliminary study just to determine if future work is warranted. It appears to be the case as that if the majority of YouTube viewing is for trending or popular videos that have substantial ads, both the energy used and money spent watching them on electricity could be on the order of 8% of the expenditures for rapid web browsing from Table 4.

Although this study had clear limitations on both the size and scope (e.g., number of open source ad blockers analyzed as well as websites analyzed), elasticity of Internet use (e.g., consumers may not reduce their Internet use by the time saved from not having to allow ads to load), and access to information (e.g., YouTube ad algorithms and users' statistics), the preliminary results were enough to provide interesting insights into the use of open source software for energy conservation. Historically the use of free and open source software aimed at energy conservation could be grouped into broad categories of software for green computing and manufacturing [62,63], simulation [64], energy conservation education and knowledge dissemination [65–67], or energy conservation controls [68,69]. Now those that fund energy conservation efforts, such as the Department of Energy in the United States, may want to look closely at the return on investment for investing directly in open source development of software and hardware that consumers have an incentive to use to maximize returns on public funding [70–74]. Providing increased economic motivation for free and open source software development to maintain the virtual arms race with well-funded advertising-based companies may

be needed [75–77]. As Malloy et al. pointed out, "ad blockers are a formidable threat" to online advertising [78], and efforts to thwart their effectiveness are underway [77,79]. Overall, the evaluations in this study agreed with the effectiveness of ad blockers seen before [80], and as ads annoy users [81], ad blocker use can be expected to continue to expand [82]. To accelerate the pace of this expansion, further work is needed in both informing Internet users about the costs of advertising (both in Internet users' time as well as energy and environmental impact) as well as the technical development of ad blockers to win the "virtual arms race" with advertisers. For countries looking for easy and low-cost energy conservation measures, opportunities to implement policies to encourage the development and deployment of open source ad blockers are clear from the results of this study.

4. Conclusions

This study, although preliminary, clearly showed enormous potential for open source ad blockers to reduce consumer time waiting for Internet ads to load as well as the electricity needed to run their computers (and other electronic technologies) during that time. In addition, the externalities (including premature fatalities) associated with fossil-fuel-based electricity spent using computers by eliminating ads during Internet browsing and video streaming would be reduced. The results show that page load time was reduced for all open source ad blockers: 11% with AdBlock+, 22.2% with Privacy Badger, and 28.5% with uBlock Origin. Strikingly, uBlock Origin has the potential to save the average global Internet user more than 100 h annually. The energy conserved if everyone in the United States used an open source ad blocker would save over 36 Americans lives per year if it were to offset coal-fired electricity generated-based pollution. Similarly, in the United States, if all American Internet users enabled Privacy Badger on their computers, Americans would save more than $91 million annually. Globally, the results with the most efficient open source ad blocker tested, uBlock Origin, would be even more substantial: ad blocking would save consumers more than $1.8 billion/year. It is clear from this study that open source ad blockers are an effective technology for energy conservation.

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