Impact of Ad Blockers on Computer Power Consumption: A Comparative Analysis of browser ad on and built-in browsers feature

Written by

©Khan Awais Khan

A Thesis Submitted to the School of Graduate Studies in partial fulfillment of the requirements for the degree of

Master of Engineering

Faculty of Engineering and Applied Science
Memorial University of Newfoundland

May 2025

St. John's Newfoundland and Labrador Canada

Abstract

The increasing prevalence of online advertisements has driven the widespread use of ad blockers, which aim to enhance user experience by reducing unwanted content. However, the impact of ad blockers on system power consumption, particularly across different hardware configurations and ad-blocking implementations, remains underexplored. This thesis provides a comprehensive investigation into the energy use of ad blockers in various computing environments, including systems with AI accelerators, ARM-based processors, and browsers equipped with built-in ad-blocking features. The research comprises a multi-faceted analysis of power consumption influenced by ad blockers under different hardware and software conditions. First, the study explores the use of ad blockers in systems integrated with AI accelerators, comparing traditional CPU/GPU-based methods to AI-enhanced approaches. It was observed that ad blockers such as uBlock Origin and uBlock Origin Lite, when paired with AI acceleration, achieved significant reductions in power usage and memory consumption, particularly for multimedia-heavy websites. Further investigation targets the energy implications of ad blockers on ARM-based CPUs, which are widely utilized in mobile and embedded systems. A detailed comparative analysis across multiple browsers—including Chrome, Brave, Vivaldi, and Firefox—revealed that the combination of efficient browsers (like Brave and Kiwi) with lightweight ad blockers (such as uBlock) resulted in an approximate 15% reduction in power consumption compared to traditional setups without ad-blocking features. This emphasizes the importance of the optimal pairing between browsers and ad blockers to achieve enhanced energy efficiency in low-power environments. Additionally, this thesis examines the efficiency of browsers with integrated ad-blockers, such as Brave, Opera, and Librewolf, compared to standard browsers without built-in ad-blocking. Results indicate that these integrated ad-blockers significantly reduce CPU and GPU

workloads, resulting in up to 44% lower power consumption, especially when browsing video-heavy websites. These findings demonstrate the potential of integrating ad-blocking features directly into browser architecture to achieve meaningful energy savings, thereby extending battery life for mobile devices and reducing overall energy demands. Lastly, a comparative analysis of popular ad blockers—AdBlock, AdBlock Plus, Ghostery, uBlock, and uBlock Origin—across different content types and website categories highlighted substantial variations in energy efficiency. The results underscore that while ad blockers generally contribute to reduced power usage, their effectiveness is influenced by factors such as the type of online content and specific ad-blocking technology used. Media-rich websites particularly benefit from the use of lightweight and well-optimized ad blockers, which significantly decrease system resource consumption. Overall, the findings presented in this thesis provide new insights into optimizing power consumption in web browsing through the strategic use of ad blockers. By demonstrating the benefits of different ad-blocking strategies across various computing environments, this research contributes to sustainable computing practices, offering practical guidelines for users, developers, and policymakers aiming to reduce energy consumption and promote efficient digital technologies.

Co-authorship Statement

I am the main author of all the research papers compiled in composing this thesis, my supervisor and co-supervisor, Dr. Tariq Iqbal and Dr. Mohsin Jamil respectively, are co-author of all articles. As the lead author, I did most of the research work, the literature reviews, carried out the experiments, experimental setups, and analysis of the results in each of the manuscripts. I also formulated the original manuscripts and later edited each of them based on comments from the co-authors and peer reviewers throughout the peer review process. Co-authors Dr. Tariq Iqbal and Dr. Mohsin Jamil supervised all the research work, revised, and corrected each one of the manuscripts, provided research material, contributed research ideas throughout the research, and updated each of the manuscripts.

Acknowledgments

I would like to express my heartfelt gratitude to everyone who has supported me throughout the completion of this thesis.

First and foremost, I would like to extend my deepest thanks to my supervisor, Dr. Muhammad Tariq Iqbal, whose invaluable guidance, encouragement, and insightful feedback have been instrumental to the success of this work. His unwavering support has been a constant source of motivation throughout this journey.

I am also profoundly grateful to my co-supervisor Dr. Mohsin Jamil for his expertise and thoughtful advice. His critical insights and guidance helped refine my research and kept me on the right path.

To my family, I owe a special debt of gratitude. To my loving wife, I would like to thank her for the patience, understanding, and endless encouragement during the long hours of writing and research. To my son, who has been a constant source of joy and inspiration, reminding me of the importance of balance and perseverance.

To my mother, her unconditional support and belief in me have been my foundation throughout this journey. I cannot thank her enough for always being there for me.

To my friends, their understanding and support, along with the much-needed distractions, helped keep me grounded during stressful moments.

Lastly, thanks to everyone who contributed to this thesis in any way. All their support, no matter how small, has been invaluable in helping me complete this work.

Table of Contents

List of Tables

List of Figures

List of Abbreviations and Symbols

CPU – Central Processing Unit

GPU – Graphics Processing Unit

AI – Artificial Intelligence

TPU – Tensor Processing Unit

NPU – Neural Processing Unit

ARM – Advanced RISC Machine

HWinfo – A hardware monitoring tool for measuring power consumption

Ubuntu – A Linux-based operating system commonly used in computing and research environments

Windows – A Microsoft-developed operating system used on most personal computers

ReRAM – Resistive Random-Access Memory, used for energy-efficient AI hardware

CNN – Convolutional Neural Network, used for AI tasks such as image recognition

DNN – Deep Neural Network, a class of machine learning models

OS – Operating System

SBC – Single Board Computer

Chapter 1. Introduction and Literature Review

1.1. Introduction

The increasing complexity of online advertising has transformed the digital landscape, providing a vital revenue stream for content creators, website owners, and service providers. However, the rapid growth of online advertisements has also introduced several significant challenges for end-users, particularly in the realms of performance degradation, privacy concerns, and increased energy consumption. Online advertisements often involve resource-intensive elements, such as high-resolution videos, interactive scripts, and tracking technologies, which require substantial computational power to render. These elements not only slow down page load times but also contribute to higher power consumption, placing a considerable energy burden on end-user devices and negatively impacting the overall user experience.

To address these issues, ad blockers have gained widespread popularity as a solution to mitigate the adverse effects of online advertisements. By preventing ads from loading, ad blockers aim to enhance privacy, improve browsing speed, and reduce the load on system resources, ultimately leading to decreased power consumption. However, despite their widespread use, the impact of ad blockers on system power consumption, especially across various hardware configurations and ad-blocking implementations, remains inadequately explored

The use of ad-blocker add-ons in browsers remains the most common approach for users seeking to enhance their browsing experience. These add-ons—such as AdBlock, Adblock Plus, uBlock, and uBlock Origin—function by intercepting network requests for ad content and preventing them from loading, thereby reducing data usage and improving webpage performance. However, while these add-ons effectively reduce the computational workload associated with advertisements, they also introduce their own resource demands, consuming CPU cycles, memory, and, consequently, power.

The emergence of browsers with built-in ad-blocking capabilities has presented a novel approach to improving browsing performance and reducing energy consumption. Browsers such as Brave, Opera, and Librewolf have integrated ad-blocking features that are deeply embedded within the browser architecture, providing a more seamless experience for users. Unlike traditional third-party ad-blocker extensions, which operate as additional processes and consume extra system resources, integrated ad-blockers leverage the inherent optimizations of the browser itself, thereby reducing the overall computational overhead.

ARM-based processors are commonly used in mobile devices and embedded systems due to their emphasis on energy-efficient computing. These processors are designed to deliver high performance while minimizing power consumption, making them ideal for applications where energy efficiency is critical. However, the impact of ad-blockers on ARM-based processors has received limited attention in the literature.

Recent advancements in computer hardware have introduced specialized components, such as AI accelerators, which are designed to optimize specific computational tasks more efficiently than traditional CPUs and GPUs. AI accelerators, such as Tensor Processing Units (TPUs) and neural processing units (NPUs), have shown significant potential in enhancing the efficiency of various workloads, including content filtering and ad detection.

1.2. Literature Review

The rise of digitalization has had a profound impact on energy consumption across various sectors, including mobile platforms, advertising, and web browsing. Ren et al. (2021) highlight the influence of internet development on China's energy consumption, demonstrating how digitalization drives higher power demand due to the rapid expansion of internet services and data centers [1]. This trend is mirrored globally, with the increasing reliance on mobile platforms for digital marketing and content delivery contributing significantly to the rise in energy consumption. Ji et al. (2019) examined the power demands of mobile platforms, particularly in the context of balancing user growth with in-app advertising. Their findings suggest that the computational power required to run targeted ads on mobile devices increases the overall energy footprint, especially in ARM-based systems [2].

Albasir (2013) explored the specific impact of web advertisements on smartphone resources, focusing on how video and interactive ads lead to significant battery drain and data usage on mobile devices. The study, conducted on ARM-based smartphones, emphasizes the hidden costs of mobile advertising, both in terms of energy consumption and user experience degradation [3]. In this context, Pearce (2020) argues that open-source ad blockers can significantly mitigate the power consumption associated with mobile advertising by preventing ads from loading, thereby reducing the computational load on ARM devices [4]. Further research by Souza et al. (2023) confirms that energy consumption in Android mobile devices can be optimized through user recommendations and power-efficient applications, such as ad blockers, that conserve both battery life and processing power [5].

ARM-based systems, renowned for their energy efficiency, have been central to addressing the increasing power demands of modern digital platforms. Tairum (2018) analyzed the ARM Scalable Vector Extension, showing how it enables considerable power savings, particularly in vector processing tasks that are critical for data-heavy applications like digital marketing and video streaming [6]. Suárez et al. (2024) extended this analysis by comparing ARM and RISC-V architectures, concluding that ARM processors consistently outperform other architectures in terms of energy efficiency under similar workloads, making them highly suitable for applications requiring both high performance and low power consumption [7]. Chen et al. (2017) introduced the Eyeriss architecture, an energy-efficient AI accelerator designed for deep convolutional neural networks (CNNs), which reduces power consumption in AI applications running on ARM-based systems [8].

The growing adoption of AI accelerators, particularly in the context of ad-blocking technologies, has further highlighted the importance of energy efficiency. AI accelerators like the ones discussed by Choi et al. (2020) provide energy-efficient solutions for running deep neural networks on smart devices, enabling in situ personalization and reducing dependency on cloud services. This shift to local computation reduces the energy overhead typically associated with cloud-based AI processing [9]. Similarly, Song et al. (2017) presented Pipelayer, a ReRAM-based AI accelerator that minimizes data movement between memory and processing units, resulting in significant energy savings in AI-powered applications such as ad-blocking [10]. Tramèr et al. (2019) explored the role of adversarial machine learning in perceptual ad blocking, highlighting how AI-driven ad-blocking methods can enhance user privacy and reduce power consumption by intelligently filtering ads [11].

Ad blockers, in general, have been found to significantly reduce power consumption during web browsing by preventing resource-heavy advertisements from loading. Castell-Uroz et al. (2022) provided an in-depth analysis of the impact of ad blockers on performance and user experience, finding that content blockers not only improve page load times but also reduce data usage, contributing to lower energy consumption during web browsing [12]. Torjesen et al. (2023)

introduced the CarbonTag method, which quantifies the energy usage associated with online ads and demonstrates that ad blockers can considerably reduce the carbon footprint of web browsing by blocking energy-intensive ads [13]. Pärssinen et al. (2018) took a broader environmental approach, conducting an environmental impact assessment of online advertisements. They found that multimedia ads, particularly video ads, disproportionately contribute to the overall carbon footprint of online activities, further reinforcing the need for ad blockers to mitigate their environmental impact [14].

The rapid advancement of artificial intelligence (AI) has led to the increasing deployment of hardware accelerators, which contribute significantly to energy efficiency in computational tasks. As AI accelerators become more integral to powering complex applications like machine learning and deep neural networks, they are being used in conjunction with ad-blocking technologies to minimize resource demands. One such example is the work of Choi et al. (2020), who developed energy-efficient CNN accelerators for deep learning on mobile devices, allowing for low-power consumption while running AI tasks [15].

The environmental implications of online advertising were explored by Pärssinen et al. (2018), who provided a comprehensive analysis of the carbon footprint associated with digital advertisements. Their research revealed that ads with high multimedia content, such as video ads, disproportionately contribute to the overall environmental impact, reinforcing the need for ad blockers to mitigate these effects [16]. Castell-Uroz et al. (2022) also highlighted the performance benefits of content blockers, showing that ad-blockers not only enhance user experience by reducing data usage but also significantly lower power consumption during web browsing [17].

The intersection of AI and ad-blocking technologies has introduced new methods for improving power efficiency. AI-driven solutions such as the PERCIVAL ad-blocker, introduced by Abi Din et al. (2020), use deep learning techniques to block perceptual ads, thereby reducing the computational overhead associated with traditional ad-blocking methods [18]. Such advancements in AI enable more efficient ad-blocking without compromising system performance, particularly in devices that leverage AI accelerators. Similarly, Tigas et al. (2019) discuss the impact of in-browser perceptual ad-blocking technologies, emphasizing their ability to reduce the load on CPUs and, in turn, lower power consumption while enhancing privacy protections for users [19].

In addition to blocking ads, ad-blockers also play a role in reducing the resource demands of third-party tracking, which can be resource-intensive. Cozza et al. (2020) explored the efficiency of hybrid and lightweight detection methods for third-party tracking, showing how advanced systems can prevent tracking scripts from consuming excessive resources and thus reduce overall energy consumption [20]. By preventing ads and trackers from loading, ad-blockers not only protect user privacy but also help conserve energy on a broad scale, particularly when deployed on ARM-based systems.

In the broader context of online privacy, Ullah et al. (2020) conducted an extensive survey on privacy issues in targeted advertising and noted that ad-blockers serve as a critical defense mechanism in protecting users from invasive tracking practices. This survey emphasizes the dual role of ad-blockers in both enhancing privacy and contributing to energy efficiency by limiting the processing power required to load and execute tracking scripts [21]. Tramèr et al. (2019) further explored the potential of adversarial machine learning techniques to improve the performance of ad-blockers, demonstrating how AI can be used to refine the detection and blocking of ads without significantly increasing system resource demands [22].

The relationship between ad-blockers and power consumption is not limited to mobile platforms; it also extends to desktop and server environments. Heitmann et al. (2020) examined the energy consumption of mobile web browsers equipped with built-in ad-blockers, revealing that these features contribute to substantial energy savings by minimizing background processes related to ad-loading. Their findings suggest that ad-blockers are crucial for reducing power consumption, especially in devices that rely on battery power [23]. Roth et al. (2013) also studied the impact of various web browsers on computer energy consumption, finding that browsers with integrated ad-blockers performed more efficiently than those relying on third-party solutions [24].

Ad-blockers are also influencing the development of more energy-efficient web browsers. Storey et al. (2017) discussed how advancements in browser-based ad-blocking technologies are leading to a more sustainable browsing experience, where fewer resources are consumed during page loading. These innovations, particularly in browsers with built-in ad-blockers like Brave and Vivaldi, are reshaping the digital ecosystem by promoting a more power-efficient web environment [25]. Similarly, Borgolte and Feamster (2020) analyzed privacy-focused browser extensions and found that ad-blockers contribute to improved performance and energy efficiency by preventing the loading of resource-heavy ads [26].

Ad blockers' contribution to sustainable web practices is also evident in larger digital ecosystems. Krawczyk and Borowiec (2023) highlighted how ad-blocking technologies push advertisers to adopt more energy-efficient ad formats, which are less likely to be blocked and consume fewer resources [27]. The same trend is discussed by Redondo and Aznar (2018), who explored how knowledge of ad blockers and attitudes toward online advertising influence consumer behavior. They argue that users increasingly demand less intrusive and more energy-efficient advertising, creating a shift in the digital advertising landscape [28].

As the use of ad blockers becomes more widespread, the economic implications for advertisers and content creators are significant. Zhang (2016) provided an overview of the state of digital marketing, highlighting the increasing complexity of advertising strategies. He suggested that advanced algorithms used in targeted ads not only increase energy consumption but also contribute to the growing use of ad-blockers by users who are conscious of their privacy and energy usage [29]. Mehanna (2024) delved into the environmental impact of online ads and tracking practices, revealing that ad blockers are instrumental in reducing the carbon footprint of digital advertising [30].

Todri (2022) explored the behavioral impact of ad-blockers on consumer engagement with digital content, finding that users who employ ad-blockers interact differently with websites, leading to reduced click-through rates for advertisers. This shift in user behavior underscores the importance of developing energy-efficient advertising formats that align with users' growing preference for ad-free browsing experiences [31]. Similarly, Lynch (2018) analyzed the rise of native advertising and its ability to bypass ad-blockers, which raises ethical questions about transparency and the sustainability of the current digital advertising ecosystem [32].

The integration of ad-blockers in modern web browsers, such as Brave and Vivaldi, has resulted in significant improvements in energy efficiency. Pearce (2020) demonstrated that open-source ad-blockers can substantially reduce the energy load by blocking ads, which in turn lowers the strain on servers and data centers that deliver these ads [33]. Albasir et al. (2014) further analyzed the energy consumption of web advertisements on smartphones, concluding that ad-blockers not only reduce bandwidth usage but also lower energy consumption by preventing resource-heavy ads from loading [34].

The efficiency of ARM-based systems is another important factor in reducing energy consumption for mobile and desktop devices. Suárez et al. (2024) compared ARM and RISC-V processors, showing that ARM-based systems offer superior energy efficiency, which makes them ideal for tasks like ad-blocking and AI processing [35]. Similarly, Song et al. (2017) introduced the Pipelayer accelerator, a deep learning accelerator designed to minimize energy consumption by reducing data transfer between processors and memory, which is critical for AI-based ad-blocking technologies [36].

AI accelerators are playing an increasingly important role in enhancing the energy efficiency of ad-blockers. Choi et al. (2020) designed an energy-efficient deep learning accelerator specifically for mobile devices, enabling ad-blockers to run AI models with minimal energy consumption while maintaining performance [37]. In a related development, Kim et al. (2023) explored the use of blockchain technology in digital advertising to enhance transparency and reduce the energy footprint of online ads, potentially complementing ad-blocking technologies in reducing power demands [38].

Frik et al. (2020) explored the behavioral impact of ad-blockers, finding that users engage more with content when intrusive ads are blocked, which also leads to reduced energy consumption as devices do not need to load and render resource-intensive ads [39]. Mehanna (2024) extended this by analyzing the carbon footprint of tracking practices and concluded that ad-blockers are crucial in reducing the environmental impact of digital ads by limiting the energy used in tracking and ad delivery [40].

Capra et al. (2020) conducted a survey of energy-efficient hardware architectures for deep learning, emphasizing the need for balance between performance and power consumption in AI-driven applications like ad-blocking. Their research highlights how AI-based solutions can improve power efficiency in digital systems, particularly in mobile environments [41]. Capra et al. (2021) further explored the hardware and software optimizations necessary for deep neural networks to function effectively in resource-constrained environments, which directly applies to AI-based ad-blocking solutions [42].

The rise of native advertising presents challenges for ad-blockers, as advertisers increasingly use this technique to bypass traditional ad-blocking mechanisms. Lynch (2018) discussed the ethical and environmental implications of native advertising, noting that while it may be less intrusive, it raises questions about transparency and sustainability in the digital advertising ecosystem [43]. In this context, Aseri et al. (2020) examined the broader economic and environmental effects of ad-blockers, suggesting that these technologies could reshape digital advertising by encouraging more sustainable and energy-efficient ad formats [44].

Finally, Heitmann et al. (2020) explored the energy impact of ad-blockers integrated into mobile web browsers, finding that these tools are crucial for reducing energy consumption by limiting the resources required to load and process advertisements. This energy-saving capability is particularly relevant in devices with limited battery life, where ad-blockers help to prolong usage by minimizing unnecessary resource use [45].

1.3. Research Objectives

The overarching goal of this research is to contribute to the field of sustainable computing by offering a holistic analysis of ad-blocking technologies and their impact on power consumption across diverse computing environments. By examining ad-blocking strategies on traditional desktop systems, ARM-based processors, and systems equipped with AI accelerators, this thesis provides a detailed understanding of how these technologies can be optimized to reduce energy consumption, improve user experience, and extend device battery life. The findings have significant implications for multiple stakeholders: users seeking to enhance the energy efficiency of their devices, developers aiming to create more effective ad-blocking solutions, and policymakers interested in promoting sustainable digital practices.

- To analyze and compare the impact of various ad-blockers on power consumption across different types of websites, particularly focusing on media-heavy platforms.

- To evaluate the effectiveness of built-in ad-blockers in web browsers compared to third-party ad-blocking extensions in terms of reducing power consumption and improving overall energy efficiency.
- To assess the influence of ad-blockers on the power consumption of ARM-based CPUs, particularly in mobile and low-power systems, and identify the best practices for optimizing energy use in such environments.
- To explore how AI accelerators can be integrated with ad-blockers to reduce power consumption more effectively and assess the potential of AI hardware in enhancing the energy efficiency of web browsing.

1.4. Thesis Structure

This thesis explores the impact of ad-blockers on computer power consumption across various web browsing environments, including systems with ARM-based CPUs and AI accelerators. It investigates how different ad-blockers and hardware configurations affect power efficiency, offering insights into the role of advanced technologies in reducing energy consumption. The research also examines built-in browser ad-blockers and compares their effectiveness to third-party ad-blocking extensions. The findings contribute to the growing field of sustainable computing, presenting solutions for optimizing power use in digital environments.

Chapter 1 introduces the problem of rising power consumption due to online advertisements and the role of ad-blockers in mitigating this issue. It discusses the growing demand for energy-efficient computing, particularly in mobile and embedded systems using ARM-based CPUs. The chapter also introduces AI accelerators as a modern solution for optimizing computational tasks, including ad-blocking. A comprehensive literature review is provided, highlighting previous research on power consumption, ad-blockers, and energy-efficient hardware, and outlining the gaps that this thesis aims to address.

Chapter 2 of the thesis is dedicated to the comparative analysis of various ad-blockers and their impact on power consumption during web browsing. It focuses on AdBlock, AdBlock Plus, uBlock, uBlock Origin, and uBlock Origin Lite, analyzing their performance in reducing CPU and GPU usage on different types of websites, particularly those with heavy multimedia content. The findings show that ad-blockers like uBlock Origin Lite offer significant power savings, providing insights into how users can optimize their energy use by choosing the most effective ad-blockers.

Chapter 3 focuses on a detailed comparison of built-in ad-blockers in web browsers like Brave and Librewolf against third-party ad-blocking extensions used in browsers like Chrome. This chapter highlights how built-in ad-blockers, which are more integrated into the browser architecture, lead to better energy efficiency by reducing power consumption on both the CPU and GPU. The analysis demonstrates that built-in ad-blockers are more effective at conserving energy while maintaining a seamless user experience, especially on resource-intensive websites.

Chapter 4 of the thesis would focus on the impact of ad-blockers on power consumption in systems with ARM-based CPUs. This chapter investigates how different ad-blockers, including uBlock Origin and Brave's built-in ad-blocker, affect power usage on ARM-based systems, which are commonly used in mobile and low-power environments. The study reveals that these ad-blockers significantly reduce CPU load and extend battery life, particularly when browsing multimedia-heavy websites. This chapter contributes to the understanding of how ad-blockers can enhance energy efficiency in ARM-based devices.

Chapter 5 examines the integration of AI accelerators, such as Tensor Processing Units (TPUs) and Neural Processing Units (NPUs), with ad-blockers to reduce power consumption during web browsing. It discusses how AI-accelerated systems can offload complex ad-blocking tasks from the CPU, resulting in significant reductions in energy usage while maintaining high performance. This chapter highlights the potential of AI accelerators in improving the efficiency of ad-blockers and offers a promising direction for energy optimization in high-performance computing environments.

Chapter 6 of the thesis would discuss the conclusion of the research, summarizing the key findings regarding the impact of ad-blockers, built-in browser solutions, ARM-based CPUs, and AI accelerators on power consumption. It highlights the research contributions, particularly the practical solutions for reducing energy consumption during web browsing through the use of efficient ad-blockers and advanced hardware. The chapter also outlines potential areas for future research, including the development of AI-enhanced ad-blockers and the exploration of new web technologies to further improve energy efficiency across different platforms and devices.

References

[1] S. Ren, Y. Hao, L. Xu, H. Wu, and N. Ba. "Digitalization and energy: How does internet development affect China's energy consumption?." Energy Economics, vol. 98, p. 105220, Jun. 2021.

[2] Y. Ji, R. Wang, and Q. Gou. "Monetization on mobile platforms: Balancing in-app advertising and user base growth." Production and Operations Management, vol. 28, no. 9, pp. 2202–2209, Sep. 2019.

[3] A. Albasir. "An evaluation of smartphone resources used by web advertisements." M.S. thesis, Univ. of Waterloo, Waterloo, ON, Canada, 2013.

[4] J. M. Pearce. "Energy conservation with open source ad blockers." Technologies, vol. 8, no. 2, p. 18, Mar. 2020.

[5] E. Souza, E. Monteiro, R. Barreto, and R. de Freitas. "Optimizing energy consumption in Android mobile devices based on user recommendations." International Conference on Intelligent Systems Design and Applications, Springer Nature, 2023, pp. 1–11.

[6] C. M. Tairum. "Performance and power consumption analysis of ARM Scalable Vector Extension." Journal of Supercomputing, vol. 638, 2018.

[7] D. Suárez, F. Almeida, and V. Blanco. "Comprehensive analysis of energy efficiency and performance of ARM and RISC-V SoCs." The Journal of Supercomputing, 2024.

[8] Y.-H. Chen, T. Krishna, J. S. Emer, and V. Sze. "Eyeriss: An energy-efficient reconfigurable accelerator for deep convolutional neural networks." IEEE Journal of Solid-State Circuits, vol. 52, no. 1, pp. 127–138, Jan. 2017.

[9] S. Choi, J. Sim, M. Kang, Y. Choi, H. Kim, and L. S. Kim. "An energy-efficient deep convolutional neural network training accelerator for in situ personalization on smart devices." IEEE Journal of Solid-State Circuits, vol. 55, no. 10, pp. 2691–2702, Oct. 2020.

[10] L. Song, X. Qian, H. Li, and Y. Chen. "Pipelayer: A pipelined ReRAM-based accelerator for deep learning." Proceedings of IEEE International Symposium on High-Performance Computer Architecture (HPCA), 2017, pp. 541–552.

[11] F. Tramèr, P. Dupré, G. Rusak, G. Pellegrino, and D. Boneh. "Adversarial: Perceptual ad blocking meets adversarial machine learning." Proceedings of the 2019 ACM SIGSAC Conference on Computer and Communications Security, 2019, pp. 2005–2021.

[12] I. Castell-Uroz, R. Sanz-García, J. Solé-Pareta, and P. Barlet-Ros. "Demystifying content-blockers: Measuring their impact on performance and quality of experience." IEEE Transactions on Network and Service Management, vol. 19, no. 3, pp. 3562–3573, May 2022.

[13] T. Torjesen, Á. Cuevas, A. Pastor, and M. Kotila. "CarbonTag: A browser-based method for approximating energy consumption of online ads." arXiv preprint arXiv:2211.00071, 2023.

[14] M. Pärssinen, M. Kotila, R. Cuevas, A. Phansalkar, and J. Manner. "Environmental impact assessment of online advertising." Environmental Impact Assessment Review, vol. 73, pp. 177–200, Nov. 2018.

[15] S. Choi, J. Sim, M. Kang, Y. Choi, H. Kim, and L. S. Kim. "An energy-efficient deep convolutional neural network training accelerator for in situ personalization on smart devices." IEEE Journal of Solid-State Circuits, vol. 55, no. 10, pp. 2691–2702, Oct. 2020.

[16] M. Pärssinen, M. Kotila, R. Cuevas, A. Phansalkar, and J. Manner. "Environmental impact assessment of online advertising." Environmental Impact Assessment Review, vol. 73, pp. 177–200, Nov. 2018.

[17] I. Castell-Uroz, R. Sanz-García, J. Solé-Pareta, and P. Barlet-Ros. "Demystifying content-blockers: Measuring their impact on performance and quality of experience." IEEE Transactions on Network and Service Management, vol. 19, no. 3, pp. 3562–3573, May 2022.

[18] Z. Abi Din et al. "PERCIVAL: Making in-browser perceptual ad blocking practical with deep learning." 2020 USENIX Annual Technical Conference (USENIX ATC 20), 2020, pp. 15–27.

[19] P. Tigas, S. T. King, and B. Livshits. "Percival: Making in-browser perceptual ad blocking practical with deep learning." arXiv preprint arXiv:1905.07444, 2019.

[20] F. Cozza, A. Guarino, F. Isernia, D. Malandrino, A. Rapuano, R. Schiavone, and R. Zaccagnino. "Hybrid and lightweight detection of third-party tracking: Design, implementation, and evaluation." Computer Networks, vol. 167, p. 106993, Feb. 2020.

[21] I. Ullah, R. Boreli, and S. S. Kanhere. "Privacy in targeted advertising: A survey." arXiv preprint arXiv:2009.06861, Sep. 2020.

[22] F. Tramèr, P. Dupré, G. Rusak, G. Pellegrino, and D. Boneh. "Adversarial: Perceptual ad blocking meets adversarial machine learning." Proceedings of the 2019 ACM SIGSAC Conference on Computer and Communications Security, 2019, pp. 2005–2021.

[23] N. Heitmann, S. Park, and S. Chakraborty. "Towards building better mobile web browsers for ad-blocking: The energy perspective." Proceedings of ACM SIGPLAN Onward! Conference, 2020.

[24] K. Roth, S. Patel, and J. Perkinson. "The impact of internet browsers on computer energy consumption." Fraunhofer Center for Sustainable Energy Systems, 2013.

[25] G. Storey et al. "The future of ad blocking: An analytical framework and new techniques." arXiv preprint arXiv:1705.08568, 2017.

[26] K. Borgolte and N. Feamster. "Understanding the performance costs and benefits of privacy-focused browser extensions." Proceedings of The Web Conference, 2020.

[27] W. Krawczyk and M. Borowiec. "The impact of ad-blocking on the sustainable development of the digital advertising ecosystem." Sustainability, vol. 15, no. 3, pp. 15-21, 2023.

[28] I. Redondo and G. Aznar. "To use or not to use ad blockers? The roles of knowledge of ad blockers and attitude toward online advertising." Telematics and Informatics, vol. 35, no. 6, pp. 1607–1616, Sep. 2018.

[29] X. Zhang. "The state of digital marketing: Technology and business landscape." Ph.D. dissertation, Massachusetts Institute of Technology, Cambridge, MA, USA, 2016.

[30] N. Mehanna. "Intrinsically inseparable: Investigating novel tracking practices and assessing the carbon footprint of ads." Ph.D. dissertation, Univ. de Lille, Lille, France, 2024.

[31] V. Todri. "The impact of ad-blockers on online consumer behavior." Marketing Science, vol. 41, no. 1, pp. 7–18, Jan. 2022.

[32] L. Lynch. Native Advertising: Advertorial Disruption in the 21st-Century News Feed, Routledge, 2018.

[33] J. M. Pearce. "Energy conservation with open source ad blockers." Technologies, vol. 8, no. 2, p. 18, Mar. 2020.

[34] A. Albasir, K. Naik, and B. Plourde. "Experimental study of energy and bandwidth costs of web advertisements on smartphones." Proceedings of 11th IEEE International Conference on Mobile Ad Hoc and Sensor Systems (MASS), 2014, pp. 693–698.

[35] D. Suárez, F. Almeida, and V. Blanco. "Comprehensive analysis of energy efficiency and performance of ARM and RISC-V SoCs." The Journal of Supercomputing, 2024.

[36] L. Song, X. Qian, H. Li, and Y. Chen. "Pipelayer: A pipelined ReRAM-based accelerator for deep learning." Proceedings of IEEE International Symposium on High-Performance Computer Architecture (HPCA), 2017, pp. 541–552.

[37] S. Choi, J. Sim, M. Kang, Y. Choi, H. Kim, and L. S. Kim. "An energy-efficient deep convolutional neural network training accelerator for in situ personalization on smart devices." IEEE Journal of Solid-State Circuits, vol. 55, no. 10, pp. 2691–2702, Oct. 2020.

[38] J. Kim, K. H. Lee, and J. Kim. "Linking blockchain technology and digital advertising: How blockchain technology can enhance digital advertising to be more effective, efficient, and trustworthy." Journal of Business Research, vol. 160, p. 113819, May 2023.

[39] A. Frik, A. Haviland, and A. Acquisti. "The impact of ad-blockers on product search and purchase behavior: A lab experiment." USENIX Security Symposium, 2020, pp. 163–179.

[40] N. Mehanna. "Intrinsically inseparable: Investigating novel tracking practices and assessing the carbon footprint of ads." Ph.D. dissertation, Univ. de Lille, Lille, France, 2024.

[41] M. Capra, B. Bussolino, A. Marchisio, M. Shafique, and G. Masera. "An updated survey of efficient hardware architectures for accelerating deep convolutional neural networks." Future Internet, vol. 12, no. 7, p. 113, Jul. 2020.

[42] M. Capra, B. Bussolino, A. Marchisio, E. Macii, M. Martina, and G. Masera. "Hardware and software optimizations for accelerating deep neural networks: Survey of current trends, challenges, and the road ahead." IEEE Transactions on Computers, vol. 70, no. 8, pp. 1197–1212, Aug. 2021.

[43] L. Lynch. Native Advertising: Advertorial Disruption in the 21st-Century News Feed, Routledge, 2018.

[44] M. Aseri, M. Dawande, and G. Janakiraman. "Ad-blockers: A blessing or a curse?." Information Systems Research, vol. 31, no. 3, pp. 889–908, Sep. 2020.

[45] N. Heitmann, B. Pirker, and S. Park. "Towards building better mobile web browsers for ad blocking: The energy perspective." ACM SIGPLAN Onward! Conference, 2020.

Chapter 2. Impact of Ad Blockers on Computer Power Consumption while Web Browsing: A Comparative Analysis

Preface

A version of this manuscript has been Accepted in the European Journal of Electrical and Computer Engineering, September 2024**.** I am the primary author, and I carried out most of the research work performed the literature reviews, carried out the experiment design, implementations, and analysis of the results. I also prepared the first draft of the manuscript. The Co-authors Dr. Tariq Iqbal and Dr. Mohsin Jamil, supervised and co-supervised the research respectively, and provided the research guide, reviewed, and corrected the manuscript, and contributed research ideas to the actualization of the manuscript.

Abstract

This study explores the impact of various ad blockers on power consumption during web browsing, focusing on different types of online content. By analyzing power use across ten popular websites, the study assesses the performance of five widely utilized ad blockers: AdBlock, AdBlock Plus, uBlock, uBlock Origin, and uBlock Origin Lite. Power consumption was measured under controlled conditions, comparing scenarios with and without ad blockers to gain insight into their efficiency. The findings indicate substantial differences in power savings, with some ad blockers significantly reducing power usage, particularly on media-heavy sites, while others unexpectedly increased consumption under certain conditions. The study underscores the potential of ad blockers to enhance power efficiency in digital environments, highlighting the importance of optimizing ad-blocking techniques to reduce the environmental impact of online activities. Through comprehensive analysis and comparison, this research offers insights into selecting effective ad blockers to minimize power consumption, promoting more sustainable web browsing practices.

2.1. Introduction

The rapid advancement of digital technologies has fundamentally transformed how we access, consume, and interact with information. The internet, once a supplementary resource, has evolved into the primary medium for content delivery, revolutionizing communication, entertainment, and commerce. With this shift, however, comes a set of challenges, particularly concerning the growing power demands associated with online activities. One of the most significant contributors to this increased power consumption is the proliferation of online advertisements.

Online advertisements have become an omnipresent feature across nearly every webpage. While they serve as a vital revenue stream for content creators and businesses, their impact on power consumption is substantial. These ads, especially those embedded with rich media content—such as videos, animations, and interactive elements—require considerable data transmission and processing power. As a result, they not only slow down page load times but also significantly increase the amount of power required to render web pages, leading to higher power usage.

This increase in power consumption has far-reaching implications, particularly within the context of environmental sustainability. The power required to load, transmit, and display advertisements directly contributes to the carbon footprint of internet usage, making it a critical issue in the ongoing efforts to combat climate change. With global internet usage continuing to rise, the cumulative power consumption from online activities, including the loading of advertisements, has become a significant environmental concern.

In response to these challenges, ad blockers have emerged as a popular solution. These tools are designed to prevent advertisements from loading, thereby reducing the clutter on web pages and improving user experience by speeding up load times. More importantly, ad blockers have the potential to reduce the power consumption associated with web browsing by preventing resource-intensive ads from loading. This potential power-saving benefit positions ad blockers as a key tool in the effort to make digital activities more sustainable.

This paper seeks to explore the relationship between online advertisements and power consumption and to evaluate the effectiveness of various ad blockers in mitigating this consumption. By comparing the power usage of websites with and without ads, as well as assessing the performance of different ad blockers across various types of content, this study aims to provide a comprehensive understanding of how digital advertising impacts power use. Furthermore, the study will investigate how ad-blocking technologies can contribute to reducing the environmental impact of online activities.

The investigation is grounded within the broader context of power efficiency in digital technologies, with a specific focus on the environmental impact of internet usage. The findings of this study are intended to contribute to the ongoing discourse on sustainable web design, the trade-offs associated with ad-blocking technologies, and the future of digital advertising in a world increasingly concerned with power conservation and climate change. By providing insights into the effectiveness of different ad blockers, this research aims to guide users in selecting tools that not only enhance their browsing experience but also contribute to a more sustainable digital e Ad-blocking technologies present a complex ethical landscape, balancing user benefits with broader implications for content creators and the sustainability of the digital advertising ecosystem. On one hand, ad blockers enhance user privacy, improve browsing experiences, and reduce system power consumption, offering significant benefits to end-users. These tools also contribute to environmental sustainability by lowering energy demands associated with rendering and delivering advertisements, which often involve resource-intensive elements like videos and scripts.

However, ad blockers also challenge the viability of content creators who rely on ad revenue to fund free digital content. By blocking advertisements, ad blockers can disrupt revenue streams critical for maintaining quality content production, especially for smaller creators and independent platforms. This economic disruption risks driving a shift toward less transparent advertising practices, such as native ads and sponsored content, which can blur the line between editorial and promotional material, raising concerns about transparency and consumer trust.

The widespread use of ad blockers also impacts the digital advertising ecosystem, encouraging advertisers to adopt invasive or energy-intensive methods to circumvent these tools. This reactive cycle not only undermines user trust but can lead to inefficiencies that counteract the energy-saving benefits of ad blockers. Moreover, as advertising adapts to overcome ad-blocking technologies, new ethical concerns arise regarding user consent, data collection, and tracking practices.

To navigate these ethical challenges, stakeholders in the digital ecosystem must collaborate to develop advertising models that balance sustainability, user privacy, and content creator support. Encouraging the adoption of less intrusive, energy-efficient ad formats, alongside exploring alternative revenue models like subscription services or micropayments, could provide a more sustainable path forward. Ethical considerations must remain central in the evolving conversation around ad-blocking technologies to ensure a fair and equitable digital landscape for all participants.

2.2. Literature Review

The digitalization of various sectors, including marketing and content delivery, has significantly impacted energy consumption patterns. Ren et al. (2021) explored how the development of the internet has influenced China's power consumption. Their study revealed that increased digitalization leads to higher power demand, driven largely by the rapid expansion of internet services and data centers. This work underscores the importance of considering power consumption in the context of a rapidly digitalizing world, particularly as internet penetration continues to grow globally [1].

Building on the relationship between digital activities and power use, Thangam and Chavadi (2023) examined the specific impact of digital marketing practices on power consumption, climate change, and sustainability. Their research found that the growing reliance on digital marketing, including the use of big data and targeted advertising, contributes to higher power consumption. This is particularly evident in the increased power demands of running complex algorithms and data processing tasks associated with digital marketing strategies [2].

The evolution of content delivery networks (CDNs) has also been a critical factor in shaping power consumption in the digital economy. George and George (2021) discussed how CDNs have enhanced the efficiency of video streaming, gaming, and online advertising, by reducing latency and improving the user experience. However, these improvements come at a cost, as the infrastructure required to support these services, including servers and data storage, contributes significantly to power use [3].

The monetization of digital content has added another layer of complexity to the power consumption narrative. Ulin (2019) explored the business models surrounding media distribution, including film, TV, and video content, in an online world. The shift from traditional distribution methods to digital platforms has required significant infrastructure investments, which in turn have led to increased power consumption. The need to deliver high-quality content to a global audience has pushed companies to invest in more powerful servers and enhanced data centers, further driving up power demands [4].

Similarly, Ji et al. (2019) analyzed the challenges of monetizing mobile platforms through in-app advertising while balancing user growth. Their study highlighted that the strategies used to optimize in-app advertisements, including targeted ads and interactive content, often require substantial computational power, leading to higher power consumption. As mobile platforms continue to grow, so too does the power footprint associated with delivering these services [5].

Albasir (2013) conducted an evaluation focused on the resources consumed by web advertisements on smartphones. The study, which examined various ad formats, found that video and interactive ads were particularly resource-intensive, leading to significant battery drain and increased data usage on mobile devices. These findings highlight the hidden costs of mobile advertising, not only in terms of power consumption but also in user experience, as the added strain on smartphone resources can degrade performance [6].

The environmental implications of online advertising were explored by Pärssinen et al. (2018) in their environmental impact assessment of online ads. The study provided a comprehensive analysis of the carbon footprint associated with different types of digital advertisements, revealing that ads with high multimedia content, such as video ads, contribute disproportionately to the overall environmental impact. This research underscores the need for more sustainable advertising practices that minimize environmental harm while maintaining effectiveness [7].

Castell-Uroz et al. (2022) took a closer look at content blockers, tools designed to prevent ads from loading, and their impact on performance and quality of experience. Their study found that while content blockers can improve page load times and reduce data usage, they also vary significantly in their effectiveness. Some blockers were found to inadvertently affect the quality of user experience by blocking not just ads but also essential content, highlighting the need for more nuanced and user-friendly ad-blocking solutions [8].

Frik, Haviland, and Acquisti (2020) explored the behavioral implications of ad blockers through a lab experiment that examined their impact on product search and purchase behavior. Their findings suggest that ad blockers, while improving the browsing experience by eliminating intrusive ads, also influence consumer behavior by altering the way users engage with online content, potentially affecting the effectiveness of digital marketing strategies [9].

Finally, Cozza et al. (2020) investigated the effectiveness of hybrid and lightweight detection methods for third-party tracking. Their study focused on designing and evaluating systems that could detect and block third-party trackers without significantly impacting page load times or user experience. The results demonstrated that these advanced detection methods could successfully mitigate the privacy risks associated with third-party tracking while maintaining a lightweight footprint on device resources, contributing to both privacy protection and power efficiency [10].

The growing prevalence of ad-blocking technologies has spurred research into alternative marketing strategies and the broader implications of ad blockers on digital advertising and content consumption. Goh (2018) explored various marketing techniques and tools designed to combat ad-blocking and ad-avoidance in social media advertising. His research highlighted the challenges advertisers face in reaching audiences who actively use ad blockers, and the strategies being developed to engage users through more subtle and integrated advertising methods that are less likely to be blocked or avoided [11].

Afzal et al. (2024) conducted a comprehensive survey on the power consumption and environmental impact of video streaming, a major component of online content delivery that is particularly affected by ad-blocking technologies. Their findings indicate that while video streaming is an power-intensive activity, the presence of ads within streams exacerbates this consumption. The study emphasizes the need for more power-efficient video streaming practices and the potential role of ad blockers in reducing the environmental footprint of this activity by eliminating resource-heavy ads [12].

Yan et al. (2022) examined the impact of ad blockers on news consumption, providing insights into how the adoption of ad-blocking tools affects user behavior in accessing news content. Their study found that while ad blockers generally improve the user experience by removing intrusive ads, they also lead to a decrease in the visibility and revenue of news outlets that rely on ad-based monetization. This shift has prompted news providers to explore alternative revenue models, such as subscription services and native advertising, which are less dependent on traditional banner ads [13].

Klym and Clark (2019) discussed the future of the ad-supported internet ecosystem, focusing on the economic implications of widespread ad-blocker adoption. Their research suggests that as ad blockers become more prevalent, there may be significant shifts in how content is monetized online, potentially leading to a more sustainable internet economy. This could involve a move towards less intrusive, more power-efficient advertising methods that align with the growing consumer demand for privacy and sustainability [14].

Kim, Lee, and Kim (2023) explored the potential of blockchain technology to enhance the effectiveness and trustworthiness of digital advertising. Their study highlights how blockchain could address many of the challenges posed by ad blockers by enabling more transparent and efficient advertising transactions. This approach could help restore user trust in digital ads and reduce the incentive to use ad blockers, thereby maintaining the revenue streams for content providers while potentially improving power efficiency in ad delivery [15].

The exploration of ad-blocking technologies has highlighted various aspects of their performance, privacy implications, and the ongoing counter-measures developed by advertisers. Garimella, Kostakis, and Mathioudakis (2017) conducted a comprehensive study on ad-blocking, focusing on how these tools affect performance, user privacy, and the effectiveness of counter-measures employed by advertisers. Their findings suggest that while ad blockers significantly improve browsing speed and protect user privacy, advertisers are continuously developing more sophisticated techniques to bypass these blockers, which could potentially undermine their effectiveness over time [16].

Privacy concerns associated with targeted advertising have been a growing area of research, especially in the context of ad-blocking. Ullah, Boreli, and Kanhere (2020) provided an extensive survey on privacy issues in targeted advertising, discussing how ad-blockers play a crucial role in mitigating privacy risks. Their study emphasized that while ad blockers can protect users from invasive tracking, they often face challenges from increasingly sophisticated tracking technologies that seek to circumvent these protections [17].

Adversarial machine learning techniques have emerged as a new frontier in the battle between ad blockers and advertisers. Tramèr et al. (2019) explored the concept of perceptual ad blocking, which uses adversarial machine learning to enhance the effectiveness of ad-blockers. Their research demonstrated that while these advanced techniques can improve ad-blocking performance, they also introduce new challenges, as advertisers develop counter-strategies to evade detection [18].

Mehanna (2024) delved into the environmental impacts of modern advertising practices, particularly focusing on the carbon footprint associated with online ads. His research examined novel tracking practices and how they contribute to the overall environmental impact of digital advertising. Mehanna's findings suggest that while ad blockers can reduce the power consumption associated with displaying ads, the ongoing development of more complex tracking and advertising methods may offset these gains [19].

The rise of native advertising, which blends advertising content with regular editorial content, has been another response to the increasing use of ad-blockers. Lynch (2018) explored the disruption caused by native advertising in digital news feeds, noting that while this approach can bypass traditional ad-blocking methods, it also raises ethical questions about the transparency and trustworthiness of online content. Native advertising's subtlety makes it less likely to be blocked, but it also challenges the effectiveness of ad-blockers in protecting user experience and privacy [20].

The impact of ad-blockers on consumer behavior and the broader digital landscape has been a subject of considerable academic inquiry. Todri (2022) explored the influence of ad-blockers on online consumer behavior, finding that the use of ad-blockers can significantly alter how consumers interact with online content. The study revealed that ad-blockers not only improve user experience by removing intrusive ads but also change the dynamics of consumer engagement, potentially leading to lower click-through rates for advertisers [21].

Redondo and Aznar (2018) examined the factors that influence users' decisions to adopt ad-blockers. Their research highlighted that users' knowledge of ad blockers and their attitudes toward online advertising are critical determinants of ad-blocker usage. They found that users who are more informed about the negative impacts of online ads, such as privacy invasion and power consumption, are more likely to use ad-blockers. This shift in user behavior has significant implications for the sustainability of ad-supported digital content [22].

Zhang (2016) provided a broader overview of the state of digital marketing, discussing the technological and business landscapes that shape modern advertising strategies. His dissertation emphasizes the growing complexity of digital marketing, which increasingly relies on advanced algorithms and big data to target consumers effectively. However, this complexity also drives up power consumption, particularly in the processing and delivery of targeted ads [23].

Pearce (2020) focused on the power conservation potential of open-source ad blockers, discussing how tools like uBlock Origin can reduce power consumption by preventing ads from loading. His research suggests that the widespread adoption of such ad blockers could lead to significant global power savings, particularly by reducing the demand on servers and data centers required to deliver digital ads [24].

Souza et al. (2023) took a more technical approach, investigating how power consumption in Android mobile devices can be optimized based on user recommendations. Their study highlighted the role of user behavior in power consumption, showing that personalized settings and the use of power-efficient apps, including ad-blockers, can significantly reduce the power usage of mobile devices [25].

Wang et al. (2017) explored a green intelligent routing algorithm that supports flexible Quality of Service (QoS) for many-to-many multicast, contributing to power efficiency in digital communication networks. While their research is more focused on network infrastructure, the implications for digital advertising are clear: optimizing network efficiency can also reduce the power footprint of delivering online ads [26].

2.3. Experiment

This section details the experimental procedures undertaken to evaluate the impact of different ad blockers on power consumption during web browsing. The design, testing environment, tools, and methodologies used are carefully outlined to ensure the reliability and accuracy of the results, allowing for a thorough comparison across various scenarios.

2.3.1. Experimental Design

The objective of this study was to evaluate the impact of various ad blockers on power consumption during web browsing across a range of website types. The experiment was meticulously designed to ensure consistency, accuracy, and relevance, enabling the comparison of power consumption under different browsing scenarios.

2.3.2. Testing Environment

The experiments were conducted on a standard mid-range consumer laptop configured with an Intel(R) Core(TM) i5-7300U CPU and 16 GB of RAM, operating on Windows 11 Home. Google Chrome was selected as the browser for all tests due to its widespread usage and reliability. Power consumption data was measured using HWinfo, a robust system monitoring tool recognized for its precision in capturing power usage metrics.

2.3.3. Ad Blockers Evaluated

The study analyzed the performance of five widely used ad blockers:

- AdBlock
- AdBlock Plus
- uBlock
- uBlock Origin
- uBlock Origin Lite

These ad blockers were chosen based on their popularity and distinct filtering algorithms, allowing for a comprehensive evaluation of their effectiveness in reducing power consumption. Browser with built in shield like brave, Libre wolf and harden Firefox were not studied.

2.3.4. Website Selection

The websites tested were categorized into four primary types, each representing a different content format:

- Multimedia Websites: YouTube, 9gagTV, KissCartoon, Dailymotion, ARYZAP
- News Websites: The News, Dawn News, Ausaf Newspaper

- Sports Websites: Cricinfo, Cricbuzz

These sites were selected for their diverse content, ranging from data-heavy multimedia to text-focused news and sports content, thereby offering a thorough examination of ad blocker performance across different web environments.

2.3.5. Testing Procedure

The experiment followed a systematic procedure to ensure reliability and repeatability:

Each website was loaded five times under each of the following conditions:

- Without any ad blocker (baseline)
- With AdBlock enabled
- With AdBlock Plus enabled
- With uBlock enabled
- With uBlock Origin enabled
- With uBlock Origin Lite enabled

Each browsing session was timed for exactly five minutes, during which power consumption in watts was recorded.

The network conditions were maintained consistently across all tests to eliminate variability and isolate the effect of the ad blockers on power consumption.

2.4. Results

The results are summarized in the tables and bar graphs below, presenting the average power consumption across the different website types and ad blocker configurations.

2.4.1. Multimedia Websites

On average, ad blockers like AdBlock Plus and uBlock Origin Lite reduce power consumption on multimedia websites by approximately 40%, with the most significant savings observed on platforms such as Dailymotion and YouTube. For instance, Dailymotion's power usage drops from 5.9 watts without a blocker to around 2.3 watts with AdBlock Plus, nearly halving the energy consumption. These figures highlight the effectiveness of these ad blockers in managing the high energy demands of video-rich content, making them valuable tools for more energy-efficient web browsing, as shown in Table 2.1:

Table 2.1 Power Consumption on Multimedia Websites

Website	**No AdBlock**	AdBlock	AdBlock Plus	uBlock	**uBlock Origin**	**uBlock Origin Lite**
9gagTV	3.9	3.7	2.6	2.7	2.7	2.5
ARYZAP	2.2	2.3	2.3	2.5	2.2	2.2
Dailymotion	5.9	2.6	2.3	2.7	3.0	3.2
KissCartoon	2.1	1.7	2.0	2.4	1.8	2.1
YouTube	3.6	2.2	2.9	2.8	2.3	2.8

The results are further illustrated in the following bar graphs to provide a clear visual comparison of the power consumption across different websites and ad blockers.

2.4.2. News and Sports Websites

The results from Table 2.2 show that ad blockers like AdBlock Plus and uBlock Origin Lite are particularly effective in reducing power consumption on news and sports websites, achieving an average reduction of around 35%. For example, Cricbuzz's power consumption significantly decreases from 6.8 watts to approximately 2.3 watts when using AdBlock Plus. This indicates that these ad blockers are capable of minimizing the energy demands associated with web browsing on text-heavy sites, where ads can still impact overall power usage. These findings are clearly detailed in Table 2.

Table 2.2 Power Consumption on News and Sports Websites

Website	No AdBlock	AdBlock	AdBlock Plus	uBlock	uBlock Origin	uBlock Origin Lite
Ausaf	3.8	1.9	2.0	1.7	1.8	2.4
Cricbuzz	6.8	2.3	2.8	2.1	2.2	2.7
Dawn News	2.2	2.1	2.1	3.2	4.1	3.1
Cricinfo	4.6	2.9	2.7	2.7	2.9	2.6
The News	4.2	3.8	3.4	3.2	3.1	3.3

2.4.3. Visual Representation of Results

The results are further illustrated in the following bar graphs to provide a clear visual comparison of the power consumption across different websites and ad blockers.

The bar graph in Figure 2.1 below displays the power consumption for multimedia websites (YouTube, Dailymotion, 9gagTV, KissCartoon) across the different ad blockers tested.

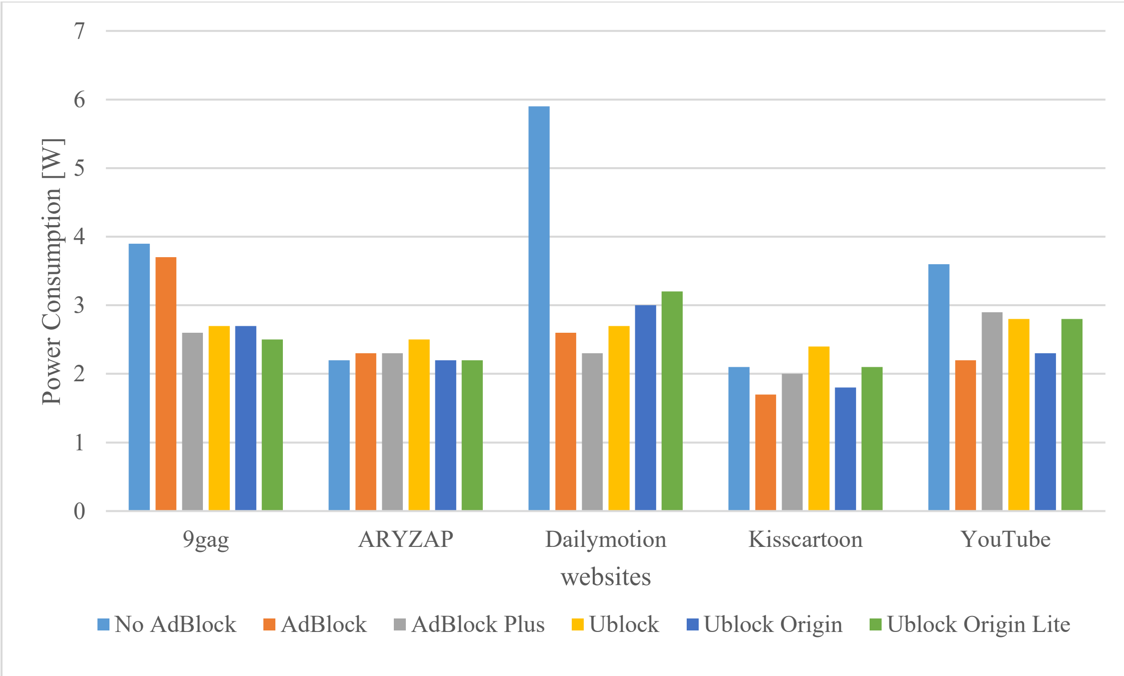

Figure 2.1 Power Consumption on Multimedia Websites

The bar graph below presents the power consumption for news and sports websites (The News, Dawn News, Ausaf Newspaper, Cricinfo, Cricbuzz) across the different ad blockers tested.

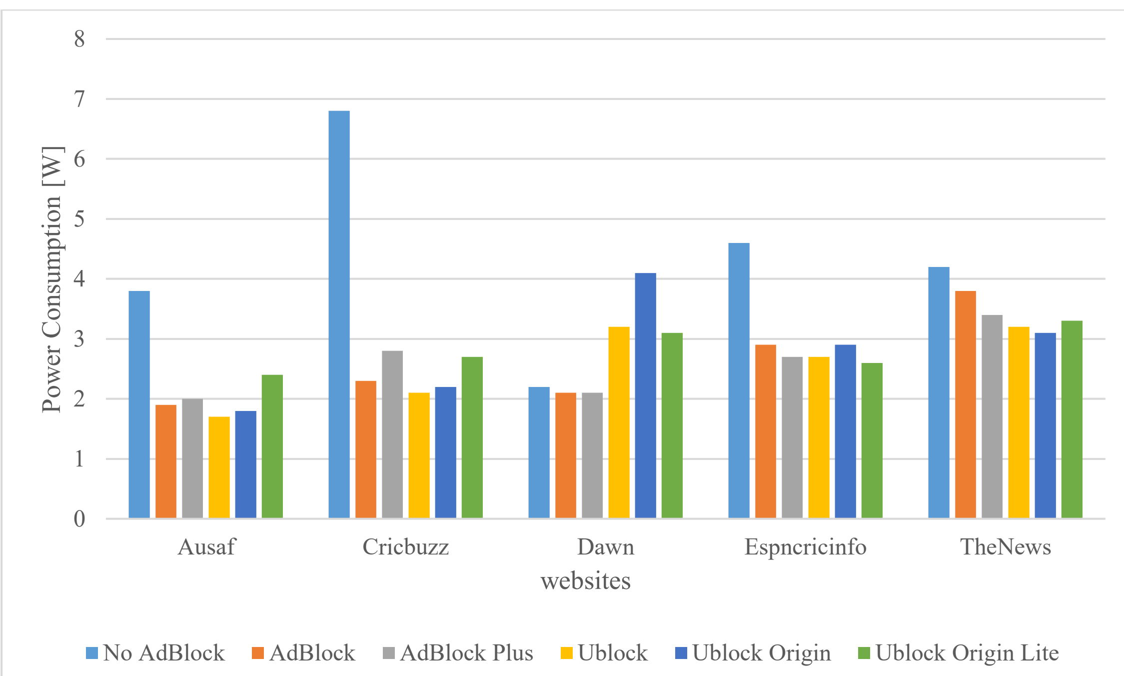

Figure 2.2 Power Consumption on News and Sports Websites

2.4.4. Analysis of Results

The data presented in Tables 1 and 2, along with the corresponding bar graphs, reveal several critical insights regarding the efficiency of ad blockers in reducing power consumption during web browsing.

Overall Efficiency: Across the various websites tested, AdBlock Plus and uBlock Origin Lite emerged as the most effective ad blockers, consistently reducing power consumption. Notably, AdBlock Plus demonstrated substantial power savings on data-intensive multimedia websites such as Dailymotion and YouTube, where it reduced power consumption by nearly 50%.

Content-Specific Performance: The effectiveness of ad blockers varied depending on the type of website. Multimedia websites, which typically include rich media content like videos, saw the most significant reductions in power consumption. In contrast, the impact of ad blockers on text-heavy news and sports websites was less pronounced, suggesting that the ads on these sites are less power-intensive or that the ad blockers were less effective in these contexts.

Anomalies: An unexpected result was observed with uBlock Origin on Dawn News, where power consumption increased when the ad blocker was enabled. This anomaly suggests that certain ad blockers may introduce inefficiencies in specific scenarios, potentially due to increased processing demands when filtering complex content. In some cases different adds of same duration was inserted by the website.

2.4.5. Discussion

The findings of this study underscore the importance of selecting appropriate ad blockers based on the type of content being accessed. AdBlock Plus and uBlock Origin Lite were particularly effective on multimedia-heavy websites, where the potential for power savings is greatest. However, the unexpected increase in power consumption with uBlock Origin on Dawn News highlights the need for further optimization of ad-blocking technologies to ensure they do not inadvertently increase power usage in certain scenarios.

The significant reduction in power consumption on multimedia sites points to the substantial power costs associated with video ads. This finding supports the broader argument for using ad blockers not only to improve user experience but also to promote more sustainable web browsing practices.

2.5. Conclusions and Future Work

This study has demonstrated that ad blockers can significantly reduce power consumption during web browsing, particularly on multimedia-heavy websites. Tools like AdBlock Plus and uBlock Origin Lite were found to be especially effective, offering substantial power savings. However, the study also identified potential inefficiencies, such as the unexpected increase in power consumption with uBlock Origin on certain websites, underscoring the need for further optimization of ad-blocking algorithms to ensure consistent performance across diverse content types.

Looking forward, future research should focus on refining these algorithms to enhance power efficiency while minimizing computational demands. Expanding the scope of study to include a broader range of websites and conducting longitudinal analyses could provide deeper insights into the long-term benefits of ad blockers. Additionally, exploring the integration of emerging technologies such as AI and blockchain could pave the way for more adaptive and decentralized ad-blocking solutions, ultimately contributing to more sustainable and power-efficient web browsing practices. it is recommended to repeat this study on different brewers with built in shield or ad blocker like Brane, Libre wolf, harden fire fox, Tor browser. use of different OS like Ubuntu, Chrome OS flex, Debian without snaps, Tails etc. for same condition is also suggested. Impact of use of different hardware other than x86 architecture like ARM SBC, RISC-V based SBC and addition of tensor processing unit (TPU), neural processing unit (NPU) and AI accelerator in addition to x86 or ARM processor should also be explored..

References

[1] Ren S, Hao Y, Xu L, Wu H, Ba N. Digitalization and energy: How does internet development affect China's energy consumption?. Energy Economics. 2021 Jun 1;98:105220.

[2] Thangam D, Chavadi C. Impact of Digital Marketing Practices on Energy Consumption, Climate Change, and Sustainability. Climate and Energy. 2023 Feb;39(7):11-9.

[3] George DA, George AH. The evolution of content delivery network: How it enhances video services, streaming, games, ecommerce, and advertising. International Journal of Advanced Research in Electrical, Electronics and Instrumentation Engineering (IJAREEIE). 2021;10(07):10435-42.

[4] J. C. Ulin, The Business of Media Distribution: Monetizing Film, TV, and Video Content in an Online World, 4th ed. London, UK: Routledge, 2019.

[5] Ji Y, Wang R, Gou Q. Monetization on mobile platforms: Balancing in-app advertising and user base growth. Production and Operations Management. 2019 Sep;28(9):2202-20.

[6] A. Albasir, "An evaluation of smartphone resources used by web advertisements," M.S. thesis, Univ. of Waterloo, 2013.

[7] Pärssinen M, Kotila M, Cuevas R, Phansalkar A, Manner J. Environmental impact assessment of online advertising. Environmental Impact Assessment Review. 2018 Nov 1;73:177-200.

[8] Castell-Uroz I, Sanz-García R, Solé-Pareta J, Barlet-Ros P. Demystifying content-blockers: Measuring their impact on performance and quality of experience. IEEE Transactions on Network and Service Management. 2022 May 31;19(3):3562-73.

[9] Frik A, Haviland A, Acquisti A. The Impact of {Ad-Blockers} on Product Search and Purchase Behavior: A Lab Experiment. In29th USENIX Security Symposium (USENIX Security 20) 2020 (pp. 163-179).

[10] Cozza F, Guarino A, Isernia F, Malandrino D, Rapuano A, Schiavone R, Zaccagnino R. Hybrid and lightweight detection of third party tracking: Design, implementation, and evaluation. Computer Networks. 2020 Feb 11;167:106993.

[11] W. K. Goh, "Social media advertising: An exploration of marketing technique and tools to combat ad-blocking and ad-avoidance," Ph.D. dissertation, National College of Ireland, Dublin, Ireland, 2020.

[12] Afzal S, Mehran N, Ourimi ZA, Tashtarian F, Amirpour H, Prodan R, Timmerer C. A Survey on Energy Consumption and Environmental Impact of Video Streaming. arXiv preprint arXiv:2401.09854. 2024 Jan 18.

[13] Yan S, Miller KM, Skiera B. How does the adoption of ad blockers affect news consumption?. Journal of Marketing Research. 2022 Oct;59(5):1002-18.

[14] N. Klym and D. Clark, "The Future of the Ad-Supported Internet Ecosystem," Internet Policy Research Initiative at MIT, 2017.

[15] Kim J, Lee KH, Kim J. Linking blockchain technology and digital advertising: How blockchain technology can enhance digital advertising to be more effective, efficient, and trustworthy. Journal of Business Research. 2023 May 1;160:113819.

[16] Garimella K, Kostakis O, Mathioudakis M. Ad-blocking: A study on performance, privacy and counter-measures. InProceedings of the 2017 ACM on Web Science Conference 2017 Jun 25 (pp. 259-262).

[17] Ullah I, Boreli R, Kanhere SS. Privacy in targeted advertising: A survey. arXiv preprint arXiv:2009.06861. 2020 Sep 15.

[18] Tramèr F, Dupré P, Rusak G, Pellegrino G, Boneh D. Adversarial: Perceptual ad blocking meets adversarial machine learning. InProceedings of the 2019 ACM SIGSAC conference on computer and communications security 2019 Nov 6 (pp. 2005-2021).

[19] N. Mehanna, "Intrinsically inseparable: Investigating novel tracking practices and assessing the carbon footprint of ads," Ph.D. dissertation, Univ. de Lille, Lille, France, 2023.

[20] Lynch L. Native advertising: advertorial disruption in the 21st-century news feed. Routledge; 2018 Jun 12.

[21] Todri V. Frontiers: The impact of ad-blockers on online consumer behavior. Marketing Science. 2022 Jan;41(1):7-18.

[22] Redondo I, Aznar G. To use or not to use ad blockers? The roles of knowledge of ad blockers and attitude toward online advertising. Telematics and Informatics. 2018 Sep 1;35(6):1607-16.

[23] X. Zhang, "The state of digital marketing: Technology and business landscape," Ph.D. dissertation, Massachusetts Institute of Technology, Cambridge, MA, USA, 2016.

[24] Pearce JM. Energy conservation with open source ad blockers. Technologies. 2020 Mar 30;8(2):18.

[25] Souza E, Monteiro E, Barreto R, de Freitas R. Optimizing Energy Consumption in Android Mobile Devices Based on User Recommendations. InInternational Conference on Intelligent Systems Design and Applications 2023 Dec 11 (pp. 1-11). Cham: Springer Nature Switzerland.

[26] Wang X, Zhang J, Huang M, Yang S. A green intelligent routing algorithm supporting flexible QoS for many-to-many multicast. Computer Networks. 2017 Oct 24;126:229-45.

Chapter 3. The Impact of Built-in Ad-Blockers in Web Browsers on Computer Power Consumption

Preface

A version of this manuscript has been Accepted in the European Journal of Information Technology & Computer Science, October 2024**.** I am the primary author, and I carried out most of the research work performed the literature reviews, carried out the experiment design, implementations, and analysis of the results. I also prepared the first draft of the manuscript. The Co-authors Dr. Tariq Iqbal and Dr. Mohsin Jamil, supervised and co-supervised the research respectively, and provided the research guide, reviewed, and corrected the manuscript, and contributed research ideas to the actualization of the manuscript.

Abstract

This study investigates the power consumption of various web browsers, specifically focusing on those with built-in ad-blockers compared to standard browsing without ad-blocking features. Using detailed measurements of CPU and GPU power consumption across multiple browsers i.e. Chrome without Ad blocker, Brave, Opera, Firefox, Vivaldi, Librewolf, and Tor—this research highlights the significant impact of ad-blocking on power consumption during web browsing. Experiments were conducted on different types of websites, including video-heavy, news, and entertainment sites, to evaluate how browser optimizations affect overall power usage. Results indicate that browsers with integrated ad-blockers, such as Brave and Librewolf, use significantly reduce power consumption up to 44% compared to traditional browsing setups. The findings also reveal that video content significantly increases CPU and GPU load, with ad-blocking browsers demonstrating superior performance in minimizing energy use. This study emphasizes the importance of browser selection in reducing power consumption, particularly for mobile and battery-dependent devices, and suggests that adopting ad-blocking technologies can lead to substantial energy savings.

3.1. Introduction

The digital era has transformed the way individuals access information, communicate, and entertain themselves, making web browsers one of the most frequently used software applications globally. Browsers serve as the primary interface between users and the internet, facilitating access to a wide range of online services and content. However, the increasing complexity of web pages, coupled with the proliferation of advertisements, has raised concerns regarding the power consumption associated with browsing activities. Ads often involve resource-intensive elements such as high-resolution images, videos, scripts, and trackers that not only slow down page loading times but also increase the computational workload on devices, leading to higher power consumption.

Ad-blockers, designed to eliminate unwanted ads and enhance the browsing experience, have gained significant traction among users seeking faster, cleaner, and less intrusive web interactions. While traditional ad-blockers are available as third-party extensions, an emerging trend is the integration of ad-blocking features directly into web browsers. Browsers like Brave, Opera, and Vivaldi have embedded ad-blockers as core functionalities, offering users a seamless browsing experience without the need for additional extensions. These built-in ad-blockers operate by preemptively blocking advertising content from loading, which not only improves performance but also has potential implications for reducing energy consumption.

Reducing energy consumption is becoming increasingly important in the context of sustainability and environmental impact. The cumulative energy used by billions of devices worldwide contributes significantly to global energy demands, leading to a larger carbon footprint. Even seemingly small reductions in the power consumption of individual devices can have a substantial impact when aggregated across millions of users. Therefore, optimizing the energy efficiency of commonly used software, including web browsers, is a critical area of research that aligns with global efforts toward reducing energy usage and minimizing environmental impact.

Research indicates that advertisements can significantly affect the power consumption of devices due to the additional computational resources required to load and display ad content. For example, video ads demand more processing power from the CPU and GPU, contributing to increased energy usage compared to text-based or static image ads. Ad-blockers mitigate these effects by preventing ads from loading, thereby reducing the amount of data processed and the computational effort required. This reduction in computational load directly correlates with lower energy consumption, offering potential benefits not only for battery-powered devices like laptops and smartphones but also for desktop computers, where energy savings translate into reduced electricity costs.

Browsers with built-in ad-blockers, such as Brave and Opera, offer a distinct advantage over traditional browsers in terms of energy efficiency. Brave, for instance, is designed with privacy and performance optimization in mind, utilizing a native ad-blocking mechanism that minimizes the load on system resources. Opera's built-in ad-blocker, on the other hand, allows users to block ads with a simple toggle, promising a faster browsing experience with lower energy consumption. Unlike external ad-blocking extensions, which operate as separate processes and consume additional memory and CPU cycles, built-in ad-blockers are deeply integrated into the browser architecture, allowing for more efficient operation and further reduction in power consumption.

The effectiveness of these integrated ad-blockers extends beyond mere user convenience; they represent a critical evolution in browser design that aligns with broader technological trends emphasizing efficiency and sustainability. By reducing the resource demands of browsing, these browsers not only enhance user experience but also contribute to a more sustainable digital ecosystem. The reduced energy consumption also translates to longer battery life for mobile devices, enhancing their portability and usability in everyday contexts.

Despite the promising benefits, empirical studies evaluating the specific impact of built-in ad-blockers on power consumption are limited. Most research to date has focused on the performance and security aspects of ad-blockers, with energy efficiency often being an overlooked dimension. This study seeks to fill this gap by conducting a comprehensive analysis of power consumption when using browsers with built-in ad-blockers compared to those without such features. By measuring the power usage of devices while accessing a variety of websites, including those with heavy ad content and those without, this research aims to quantify the energy-saving potential of built-in ad-blockers.

Furthermore, this study explores the implications of these findings for everyday users, developers, and policymakers. For users, understanding the energy impact of their browser choices can inform more sustainable digital habits. For developers, insights into energy consumption can drive innovations in browser design, emphasizing efficiency alongside performance and security. For policymakers, the findings can support initiatives aimed at promoting energy-efficient software as part of broader environmental sustainability goals.

In conclusion, the integration of ad-blockers within web browsers represents a significant advancement in the pursuit of energy-efficient browsing. By examining the power consumption characteristics of browsers with built-in ad-blockers, this research contributes valuable knowledge to the fields of sustainable computing and digital efficiency. The findings will not only highlight the potential environmental benefits of these browsers but also encourage further innovation in the design of energy-efficient software solutions, fostering a more sustainable digital future.

3.2. Literature Review

Ad-blockers significantly contribute to reducing energy consumption across various digital platforms by preventing the loading of resource-intensive advertisements. Pearce highlights the role of open-source ad-blockers in conserving energy, particularly by reducing the processing load on devices. This study demonstrates that by blocking ads, devices require less computational power, directly lowering energy consumption during web browsing [1].

Torjesen et al. Introduced the "CarbonTag" method, quantifying the energy usage associated with online ads and underscoring the environmental benefits of ad-blockers. Their findings reveal that ad-blocking technologies can significantly reduce the energy footprint of web browsing, highlighting their importance not just for user experience but also for environmental sustainability [2].

Supporting these results, a study from the University of Twente measured the effect of ad-blockers on energy consumption during mobile web browsing. The study confirmed substantial reductions in power usage when ads were blocked, emphasizing the potential of ad-blockers to enhance energy efficiency on a large scale, especially in mobile contexts where battery life is crucial [3].

Further, Heitmann et al. explored the energy perspectives of mobile web browsers equipped with ad-blocking features, showing that these tools contribute to significant energy savings by reducing the amount of data processing required [4]. This aligns with Roth et al. who analyzed various internet browsers and found that those using ad-blockers exhibited lower energy consumption due to fewer background processes related to ad loading.

These studies collectively underscore the importance of ad-blockers in reducing energy consumption, highlighting their role as essential tools for enhancing the efficiency and sustainability of digital interactions.

Technological advancements in ad-blocking have been pivotal in enhancing the efficiency and effectiveness of these tools, directly impacting energy consumption during web browsing [5]. Storey et al. discuss the evolution of ad-blocking technologies, emphasizing the development of new analytical frameworks and techniques that improve blocking accuracy while reducing resource demands. These advancements help ad-blockers operate more efficiently, conserving energy by minimizing the processing power required to detect and block ads [6].

One significant innovation is "PERCIVAL," introduced by Abi Din et al. a perceptual ad-blocking tool that utilizes deep learning to enhance blocking capabilities without compromising performance. By intelligently filtering content, "PERCIVAL" allows for more precise ad detection and blocking, which in turn reduces the computational workload on devices, contributing to energy savings. This approach not only improves user experience but also directly addresses the need for more energy-efficient ad-blocking technologies [7].

Similarly, Tigas et al. explore in-browser perceptual ad-blocking, highlighting the balance between effectiveness and performance. Their work demonstrates that these advanced ad-blockers can significantly reduce the energy consumed by web browsers by preventing the loading of ads that would otherwise increase data processing requirements [8].

Lashkari et al. further contributes to this field with the development of CIC-AB, a browser-specific ad-blocker designed for scalability and adaptability. Their research shows that modern ad-blockers, through their improved design and functionality, can significantly reduce the energy consumption associated with web browsing, reinforcing the importance of continuous technological innovation in this space.

These technological advancements illustrate how evolving ad-blocking solutions are becoming increasingly effective in reducing the energy demand of digital devices, highlighting the critical role of ongoing innovation in this field.

Ad-blockers are not only recognized for their role in enhancing web performance and protecting user privacy but also for their indirect impact on energy consumption [9]. Borgolte and Feamster analyze the trade-offs associated with privacy-focused browser extensions, including ad-blockers, highlighting how these tools improve user privacy while maintaining efficient web performance. The reduction in energy usage is an added benefit, as ad-blockers streamline the browsing experience by blocking ads that would otherwise consume additional processing power and data bandwidth [10].

Williams et al. and Gervais et al. delve into the dual impact of ad-blockers on performance and privacy, emphasizing that by preventing data-intensive advertisements from loading, ad-blockers contribute to reduced energy consumption. Their findings suggest that ad-blockers are effective in limiting the collection of personal information by third-party trackers, reducing the computational burden on devices, which directly correlates with lower energy use [11][12].

Li et al. developed a scale to measure the intrusiveness of advertisements, validating the need for ad-blockers to enhance user experience and reduce the negative impact of ads. This reduction in ad exposure also translates to energy savings, as fewer resources are consumed in rendering and processing ads, particularly on mobile devices where energy efficiency is crucial [13].

Miroglio et al. further explore the effect of ad-blocking on user engagement, demonstrating that sites free from intrusive ads see higher engagement levels and improved performance. By blocking resource-heavy ads, these ad-blockers help conserve device energy, which is especially important in maintaining battery life and reducing the overall energy footprint of digital interactions.

These studies underscore the broader benefits of ad-blockers, showing that their impact on performance and privacy also significantly contributes to energy conservation, enhancing the sustainability of web browsing.

Ad-blockers extend their influence beyond individual user benefits by significantly impacting the digital advertising ecosystem and contributing to environmental sustainability [14]. Krawczyk and Borowiec examine how ad-blocking technologies affect the development of the digital advertising ecosystem, highlighting the shift toward more sustainable advertising practices. By disrupting traditional revenue models, ad-blockers push advertisers to adopt less intrusive and more energy-efficient ad formats, indirectly contributing to energy conservation across digital platforms [15].

The environmental benefits of ad-blockers are further underscored by Pesari et al. who assess the energy consumption and greenhouse gas emissions associated with online advertising and tracking. Their findings demonstrate that ad-blockers can substantially reduce the environmental footprint of web browsing by blocking energy-intensive ads and trackers. This reduction in digital energy use supports broader sustainability goals, aligning ad-blocking technology with efforts to minimize the environmental impact of internet use[16].

In enterprise settings, Samsuddin et al. evaluate the implementation of ad-blocking techniques within network environments, showing that these tools can effectively reduce energy consumption on a larger scale. Their study emphasizes the adaptability of ad-blockers, not only as consumer tools but also as valuable components in energy-efficient network management, particularly for organizations looking to reduce operational energy costs [17].

Bruguera Micó delves into the ongoing battle between ad-blockers and anti-blocking technologies, highlighting the continuous evolution of countermeasures employed by advertisers. While this dynamic reflects the tensions between user control and advertising revenue, it also points to the need for innovative ad-blockers that can maintain their effectiveness without increasing energy consumption through more complex detection algorithms [18].

Barbacovi explores the ethical and legal implications of ad-blocking, emphasizing the challenges faced by developers in balancing user preferences with the economic needs of content providers. This discussion underscores the broader impact of ad-blockers on the digital ecosystem, where their role in reducing energy consumption and supporting sustainable practices must be balanced against the financial realities of online media.

These studies illustrate that ad-blockers are not only tools for enhancing user experience and privacy but also play a critical role in supporting environmental sustainability by reducing the energy demands of the digital advertising ecosystem.

While ad-blockers have proven effective in enhancing user experience, privacy, and energy efficiency, they also face significant challenges that shape their ongoing development [19]. Pourghassemi examines the performance and privacy trade-offs associated with ad-blocking technologies, highlighting that complex filtering processes can introduce computational overhead.

This additional processing may counteract some energy-saving benefits, emphasizing the need for scalable solutions that optimize performance without increasing energy consumption.

The environmental impact of digital advertising remains a crucial focus for the future of ad-blocking technologies [20]. Pesari et al. provide a comprehensive assessment of the energy and greenhouse gas emissions associated with advertising and tracking on news websites. Their study underscores the importance of developing more efficient ad-blocking technologies that minimize the environmental footprint of web browsing. As digital consumption continues to grow, enhancing the energy efficiency of ad-blockers will be vital in supporting global sustainability efforts [21].

Barbacovi explores the ethical, legal, and technical challenges surrounding the use of ad-blockers, particularly the ongoing conflict between user rights and the economic needs of content providers. The debate over ad-blocking reflects broader questions about user autonomy, privacy, and the sustainability of digital advertising models. To maintain their relevance, ad-blockers must evolve to balance these competing interests, ensuring they continue to provide energy savings and privacy protection without undermining the financial foundations of online content [22].

Chrome, the most widely used browser, lacks native ad-blocking and relies on third-party extensions, which increase CPU and memory usage, especially on ad-heavy sites, impacting performance negatively [23]. Brave, with built-in ad-blocking that block both video ads and trackers by default, significantly reduces CPU activity, enhancing browsing speed and reducing power consumption by up to 44% compared to non-blocking browsers [24]. Opera's built-in ad-blocker works well on pop-ups and intrusive ads, but it must be manually enabled. Research shows it improves page load times and lowers energy use but may face compatibility issues with some content [25].

Firefox includes enhanced tracking protection that blocks trackers, scripts, and some video ads, reducing energy consumption but potentially slowing page loads due to extensive privacy settings

[26]. Vivaldi's ad-blocker is customizable and can target specific types of ads, including banners and pop-ups, but performance varies depending on user settings and the customization level [27]. Librewolf enhances ad-blocking on all types of trackers and scripts by default but may slow performance due to its strict privacy measures [28]. Tor, known for its anonymity, does not specifically target ads but provides high privacy through multi-layered routing, resulting in higher CPU usage and slower speeds [29]. FreeTube, designed as an ad-free YouTube client, specifically targets video ads, significantly reducing CPU usage compared to YouTube's standard site, enhancing battery life and user experience by up to 30% [30].

3.3. Experiment

The experimental section of this research focuses on evaluating the power consumption of various web browsers during typical browsing activities, emphasizing the role of ad-blocking features. The primary objective is to assess how different browsers, with and without native ad blockers, affect overall power efficiency. Given the increasing concern over digital device energy consumption, understanding the impact of ad-blocking capabilities on power usage is crucial for optimizing both user experience and energy conservation.

The experiments utilize an HP EliteBook 840 G5 equipped with an Intel(R) Core(TM) i5-7300U CPU, which features an integrated GPU. Although the GPU values are included in the overall CPU measurements, separate calculations of GPU power consumption are performed to provide a comprehensive analysis of power usage dynamics. The system's specifications, including 16 GB of RAM and the Windows 11 Home operating system, were chosen to reflect a typical user environment.

Power consumption data was collected using HWiNFO, a sophisticated software tool that allows for detailed monitoring of CPU and GPU power usage in real-time. HWiNFO provides accurate and comprehensive insights into system performance, making it an ideal choice for assessing power consumption during the experiments.

The study involves testing several popular browsers—Chrome, Brave, Opera, Firefox, Vivaldi, Librewolf, and Tor—across a variety of website types, including news, video streaming, and entertainment. By measuring the power consumption of both the CPU and GPU during these browsing sessions, the research aims to identify key differences in energy efficiency among browsers and assess the impact of ad-blocking features.

The results of these experiments will be presented through detailed comparisons, highlighting the implications for browser selection and the potential benefits of ad-blocking features in reducing power consumption.

3.3.1. Experimental Setup

Hardware Description

The experiments were conducted using an HP EliteBook 840 G5 laptop, equipped with an Intel(R) Core(TM) i5-7300U CPU, which operates at 2.60 GHz with 2 cores and 4 logical processors. This processor includes an integrated GPU (Intel HD Graphics 620), which is commonly used in many modern laptops. The integrated GPU allows the system to manage graphical tasks without a separate, dedicated graphics card, making the power consumption data relevant to a typical user environment. The laptop also features 16 GB of RAM, which ensures stable performance during multi-tab browsing and data collection.

The choice of this hardware setup reflects a typical usage scenario for many users who rely on integrated graphics for web browsing, media consumption, and everyday computing tasks. By using this hardware configuration, the study aims to provide results that are applicable to a wide audience, especially those using similar devices. The integrated GPU's power consumption is included in the overall CPU power measurements, but separate GPU-specific calculations are made to provide a more granular understanding of energy usage.

Software Tools

The primary software tool used for monitoring power consumption was HWiNFO, a comprehensive system information and diagnostics tool widely recognized for its ability to accurately track real-time power consumption of both CPU and GPU components. HWiNFO provides detailed data on various system parameters, including voltage, temperature, and power consumption metrics, which are critical for analyzing the performance of web browsers under different conditions.

HWiNFO was configured to log power consumption data during the browsing sessions, capturing the integrated GPU's impact alongside the CPU. The software's ability to provide high-frequency data sampling allows for precise measurement of power consumption spikes and trends, ensuring that the collected data accurately reflects the browser's performance. The choice of HWiNFO is grounded in its reliability and precision, making it an ideal tool for the purpose of this study.

Browsers Tested

The experiments included seven popular web browsers: Chrome without Ad blocker, Brave, Opera, a hardened version of Firefox, Vivaldi, Librewolf, and Tor. These browsers were chosen for their varying levels of native ad-blocking capabilities, allowing for a comprehensive comparison of power consumption influenced by ad-blocking features.

- Chrome without Ad blocker: A widely used browser known for performance and stability, tested without any ad-blocking extensions to establish a baseline for comparison.

- Brave: A privacy-centric browser with a built-in ad blocker that blocks ads, trackers, and invasive cookies by default, aimed at enhancing performance and security.
- Opera: A browser with integrated ad-blocking designed to improve page load speed and reduce resource usage.
- Hardened Firefox: A modified version of Firefox with advanced privacy settings and enhanced ad-blocking capabilities configured for this study. This version blocks a broader range of ads and trackers than standard Firefox, aiming to reduce power consumption by minimizing unnecessary resource loads.
- Vivaldi: A highly customizable browser with built-in ad-blocking and tracking protection, allowing for user-defined content filtering and privacy controls.
- Librewolf: A privacy-focused fork of Firefox with built-in ad-blocking that blocks most ads and trackers by default, enhancing privacy while reducing resource demand.
- Tor: Primarily focused on anonymous browsing, Tor includes basic ad-blocking to improve privacy and security, though its primary function is to protect user anonymity rather than optimize performance.
- Ad-Blocking Capabilities and Limitations
- The ad-blocking features of each browser significantly influence their power consumption profiles. Here's a detailed overview of each browser's capabilities and limitations regarding ad-blocking:
- Chrome without Ad blocker: No native ad-blocking, relying entirely on third-party extensions, which were not utilized in this baseline setup.
- Brave: Blocks most ads and trackers by default, significantly reducing load on both CPU and GPU, which can lead to noticeable energy savings.

- Opera: Built-in ad-blocking is less aggressive than Brave's but effective enough to block a substantial amount of intrusive content, providing moderate energy reduction benefits.
- Hardened Firefox: The modified Firefox was specifically configured to block a broader range of ads and trackers beyond its default settings. This customization enhances its performance, reducing the computational workload and, consequently, power consumption.
- Vivaldi: Offers adjustable ad-blocking settings, allowing users to strike a balance between performance and content filtering. This flexibility, while beneficial, also introduces variability in its energy efficiency.
- Librewolf: Designed for privacy, Librewolf's strong ad-blocking settings help reduce power consumption by blocking ads and trackers comprehensively, which aligns closely with privacy-centric performance.
- Tor: Includes basic ad-blocking capabilities, primarily aimed at reducing exposure to tracking rather than optimizing for performance. Its focus on privacy can sometimes impact power efficiency due to security overhead.

3.3.2. Selection Criteria

The websites selected for this study were chosen based on their popularity, content type, and the diversity of browsing experiences they offer. This selection was aimed at replicating real-world usage scenarios that are representative of typical user behavior. The inclusion of a variety of websites ensures that the study captures a broad range of web content types, including high-resource-demanding media sites and simpler news platforms.

The selected websites include:

- YouTube: A leading video streaming platform, representing high graphical and resource usage typical of video content.
- 9gag: A popular entertainment site known for hosting videos and GIFs, which can significantly impact GPU usage.
- Kisscartoon: An entertainment site focused on streaming animated content, often heavy on ads and trackers.
- ARYZAP: A media streaming site featuring video content, including live TV channels and shows.
- Dailymotion: Another prominent video streaming platform, offering a mix of user-generated and professional video content.
- Dawn, The News, Ausaf: Major news websites representing content-heavy but less graphically intensive browsing, commonly visited by users for news and information.
- Cricbuzz, ESPNcricinfo: Sports news and live score websites that combine text with multimedia elements like images and embedded videos.

Website Categorization

To analyze power consumption effectively, the selected websites were grouped into two categories:

News Websites (Dawn, The News, Ausaf, Cricbuzz, ESPNcricinfo): This category represents text-dominant sites with minimal video content but includes ads, images, and interactive elements that contribute to power consumption. These sites are chosen for their relevance in everyday browsing, providing insights into how news consumption affects browser performance.

Video Streaming Websites (YouTube, Dailymotion, ARYZAP, 9gag, Kisscartoon): This category includes platforms that are graphically intensive, requiring significant processing power from both

CPU and GPU. These websites were selected to examine how browsers handle high resource-demand scenarios, particularly in terms of video content, ads, and embedded trackers.

Grouping the websites into these categories allows for targeted comparisons, highlighting how different types of content affect power consumption across various browsers. This categorization also enables a deeper analysis of how browser and ad-blocking capabilities influence energy efficiency in different browsing contexts.

3.3.3. Data Collection Methodology

Power consumption data was collected using HWiNFO software, which monitored both CPU and GPU usage during controlled browsing sessions. Each browser was tested across the selected websites with identical conditions to ensure consistency, including the same system settings, browser configurations, and minimal background activity. Each test involved visiting the websites for a fixed duration, with repeated trials conducted to account for variability and enhance data reliability. The power consumption was logged in real-time, capturing fluctuations in energy use as browsers loaded different types of content, such as videos, ads, and trackers. The experiments aimed to mirror typical browsing behaviors while controlling external factors, providing a reliable basis for comparing the power efficiency of each browser and its ad-blocking capabilities.

3.4. Results

The Results section presents a detailed analysis of the power consumption of various web browsers on different types of websites, categorized into video and news websites. The focus is on evaluating CPU and GPU power consumption across several popular browsers, including Chrome without ad blocker, Brave, Opera, Firefox, Vivaldi, Librewolf, and Tor. Each comparison aims to highlight the differences in energy efficiency among these browsers, particularly in relation to their built-in ad-blocking capabilities and performance optimizations. The results are organized into four key comparisons, examining CPU and GPU consumption separately for video and news websites, followed by a summary of key findings that provide insights into the most efficient browser choices for different types of content.

3.4.1. CPU Power Consumption on Video Websites

This section examines the CPU power consumption of various browsers when accessing video websites, including YouTube, Dailymotion, Kisscartoon, ARYZAP, and 9gag. The analysis highlights how different browsers manage energy demands during video streaming, emphasizing the impact of ad-blocking features and performance optimizations on reducing CPU load.

Table 3.1 CPU Power Consumption on Video Websites

Websites	Chrome without Ad blocker [W]	Brave [W]	Opera [W]	Firefox [W]	Vivaldi [W]	Librewol f [W]	Tor[W]
9gag	3.9	2.8	3	5.5	4.9	2.9	8.2
ARYZAP	3.4	3.3	2.3	2.1	3.5	3.8	4.4
Dailymotion	5.9	2.3	3.4	3.3	4	3.2	4.5
Kisscartoon	2.6	2.5	2	3	3.7	2.9	3.4
YouTube	3.6	2	2	2.6	3.9	4.8	3.2

The grouped bar graph in Figure 1 illustrates the CPU power consumption of each browser on the tested websites, providing a visual comparison of browser performance. Results were collected while playing same video on all websites.

The graph below visually represents the CPU power consumption of each browser across the selected video websites. The grouped bar graph format allows for an easy comparison of performance, highlighting which browsers consume more or less power when handling video content.

The comparison reveals that Brave consistently shows the lowest CPU power consumption, positioning it as the most efficient browser in terms of energy usage. Conversely, Chrome without Ad blocker and Tor exhibit the highest power consumption, particularly on resource-heavy websites like 9gag and Dailymotion, suggesting a less optimized performance. Opera and Firefox perform moderately, balancing efficiency and resource demand. These findings underscore the significant impact of browser optimizations, ad-blocking capabilities, and overall performance on CPU energy consumption.

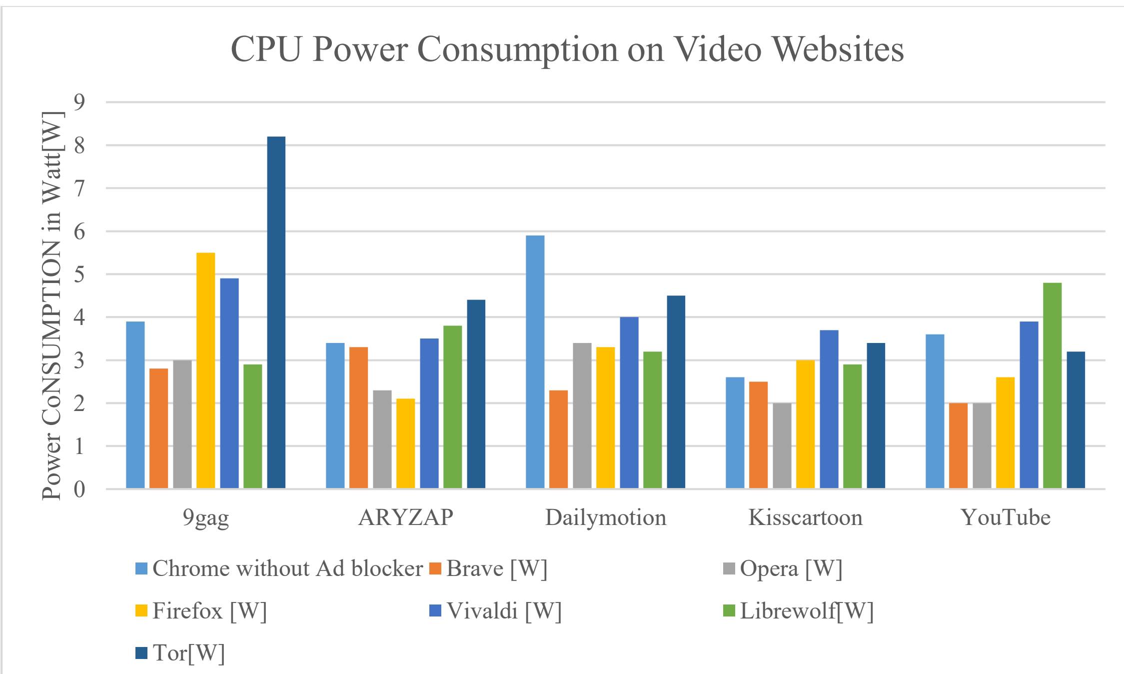

Figure 3.1 CPU Power Consumption on Video Websites

The results clearly show that CPU power consumption is highest when using browsers without ad-blocking features, such as Chrome without Ad blocker and Tor, particularly on resource-heavy sites like 9gag and Dailymotion. Conversely, browsers like Brave and Librewolf, which include built-in ad-blockers, exhibit significantly lower CPU usage. Brave consistently performs as the most efficient browser, reducing CPU power consumption by up to 44% compared to Chrome. This demonstrates the effectiveness of ad-blocking and performance optimizations in reducing the energy demands of video content, making such browsers ideal for users looking to minimize their power consumption during streaming.

3.4.2. CPU Power Consumption on News Websites

The table below presents the average CPU power consumption of various browsers on news websites, including Ausaf, Cricbuzz, Dawn, ESPNcricinfo, and The News. These sites are generally less resource-intensive compared to video websites, providing insights into browser performance on typical web content.

Table 3.2 Power Consumption on News Websites

Website	Chrome without Ad blocker [W]	Brave[W]	Opera [W]	Firefox [W]	Vivaldi [W]	Librewolf [W]	Tor [W]
Ausaf	3.8	2.3	2.3	1.7	2.3	1.7	1.9
Cricbuzz	6.8	3.4	2.3	2.4	4	3.2	6.2
Dawn	4.2	3.3	3.5	1.8	2.9	2.1	3.2
ESPNcricinfo	4.6	2.9	4	2.3	5.2	4.4	5.1
The News	4.2	1.3	2.4	1.4	3.1	2.2	2.9

The graph below visualizes the CPU power consumption of each browser across various news websites. It allows for an easy comparison of browser performance on less demanding content.

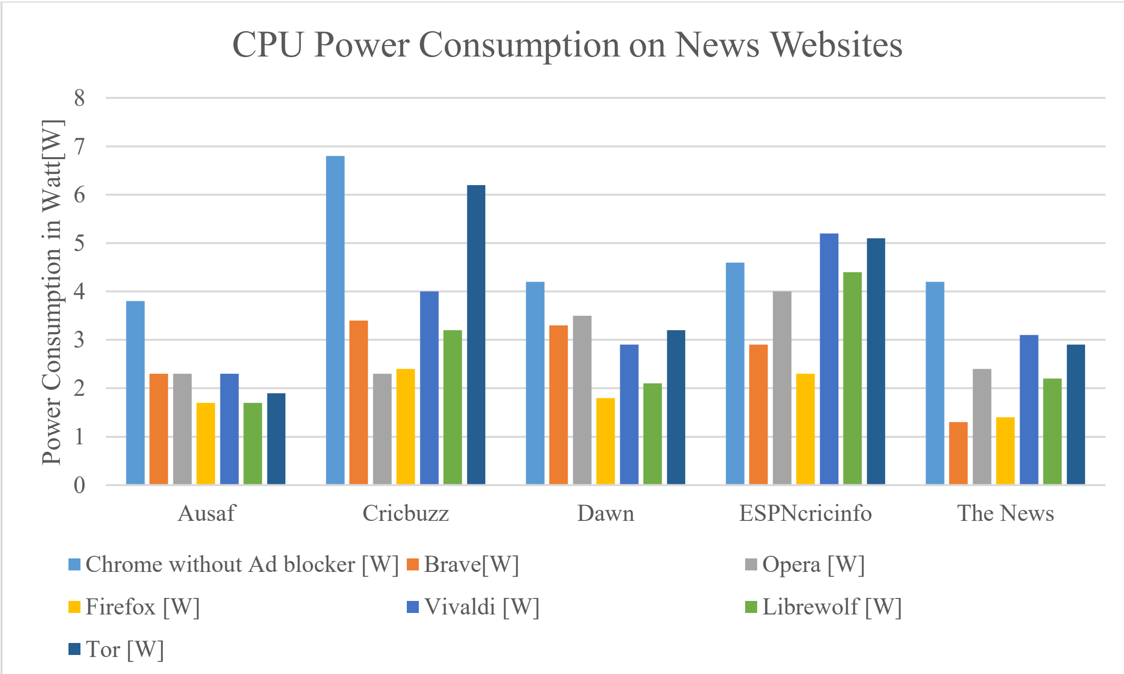

Figure 3.2 CPU Power Consumption on News Websites

3.4.3. GPU Power Consumption on Video Websites

The table below shows the average GPU power consumption of various browsers when accessing video websites. The data reflects how each browser manages graphical processing demands, especially on sites with intensive video content.

The table below shows the average GPU power consumption of various browsers when accessing video websites. The data reflects how each browser manages graphical processing demands, especially on sites with intensive video content.

Table 3.3 GPU Power Consumption on Video Websites

Website	Chrome without Ad blocker [W]	Brave [W]	Opera [W]	Firefox [W]	Vivaldi [W]	Librewolf [W]	Tor [W]
9gag	0.34	0.13	0.16	0.07	0.17	0.11	0.14
ARYZAP	0.31	0.12	0.15	0.05	0.16	0.1	0.13

Dailymotion	0.38	0.14	0.17	0.06	0.18	0.12	0.15
Kisscartoon	0.29	0.11	0.13	0.08	0.19	0.13	0.12
YouTube	0.35	0.1	0.14	0.06	0.15	0.11	0.11

The graph below illustrates the GPU power consumption of each browser on video websites, visually comparing their performance in handling graphical content. This grouped bar graph format allows easy identification of which browsers are more GPU efficient.

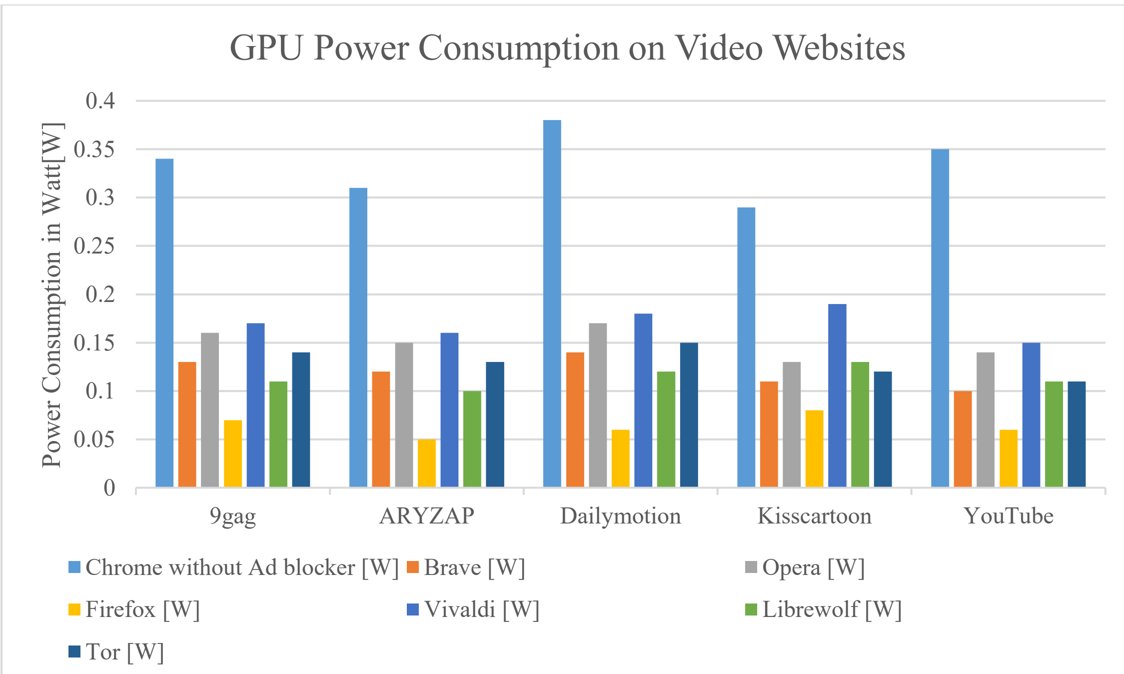

Figure 3.3 GPU Power Consumption on Video Websites

The GPU power consumption data indicates that browsers with built-in ad-blockers, such as Brave and Librewolf, use significantly less GPU power compared to browsers like Chrome without Ad blocker and Tor. For instance, Brave's GPU consumption is consistently the lowest across all tested video websites, showing up to a 63% reduction in power usage compared to Chrome. These findings highlight the advantages of using privacy-focused browsers with performance optimizations, especially for users who frequently engage with video content, as they not only enhance browsing experience but also contribute to significant energy savings.

3.4.4. GPU Power Consumption on News Websites

The table below displays the average GPU power consumption of various browsers when accessing news websites, including Ausaf, Cricbuzz, Dawn, ESPNcricinfo, and The News. These websites generally have lower graphical demands compared to video content, allowing us to see how efficiently each browser handles basic web graphics.

Table 3.4 GPU Power Consumption on News Websites

Website	Chrome without Ad blocker [W]	Brave [W]	Opera [W]	Firefox [W]	Vivaldi [W]	Librewolf [W]	Tor [W]
Ausaf	0.33	0.12	0.12	0.04	0.13	0.09	0.1
Cricbuzz	0.37	0.14	0.14	0.07	0.14	0.1	0.13
Dawn	0.36	0.13	0.15	0.06	0.15	0.11	0.14
ESPNcricinfo	0.34	0.12	0.16	0.05	0.16	0.12	0.12
The News	0.32	0.11	0.14	0.04	0.14	0.1	0.13

The graph below shows the GPU power consumption of each browser on news websites, highlighting differences in their efficiency when handling less intensive graphical content.

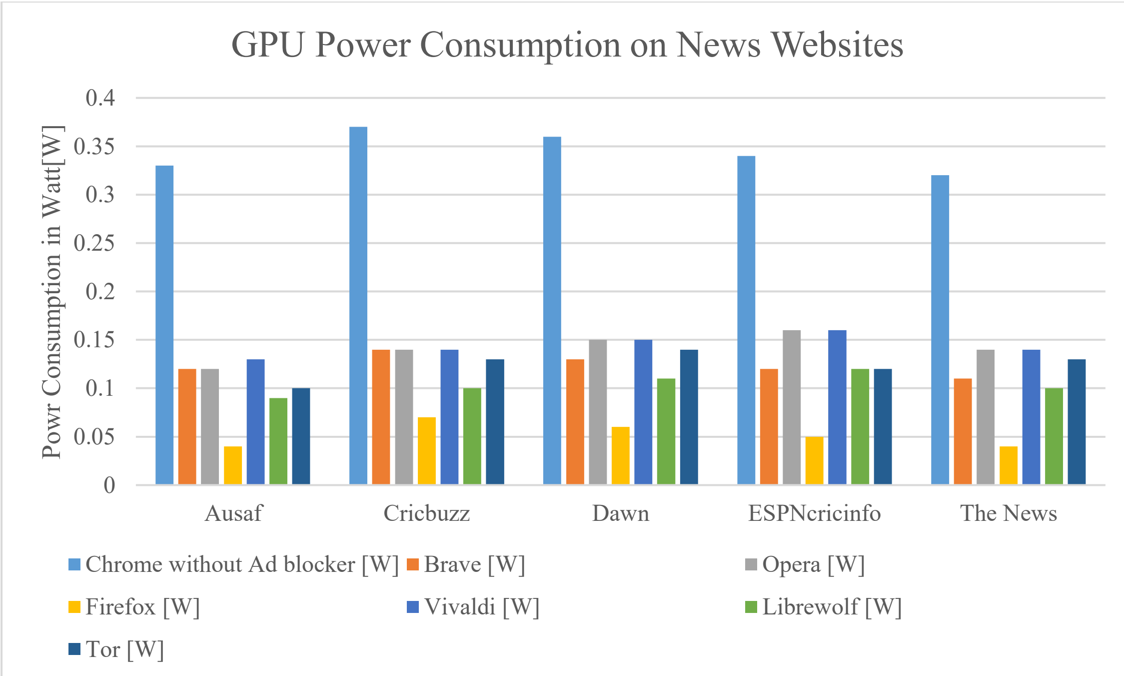

Figure 3.4 GPU Power Consumption on News Websites

The data shows that GPU power consumption on news websites is generally low across all browsers, with Brave and Firefox showing the lowest power usage. Brave, for example, consumed only 0.12 Watts on Ausaf, demonstrating up to a 63% reduction compared to Chrome without Ad blocker. This consistent efficiency among browsers with built-in ad-blockers emphasizes their role in optimizing graphical performance, even on standard content. These results suggest that using browsers with integrated ad-blockers not only improves browsing speed but also significantly reduces energy usage, making them ideal for users seeking energy-efficient web browsing.

Comparison of CPU Power Consumption on YouTube: Ad-Blocking Browsers vs. FreeTube

The table compares the CPU power consumption of various browsers, including Chrome without Ad blocker, Brave, Opera, Firefox, Vivaldi, Librewolf, Tor, and FreeTube, specifically on YouTube. The data highlights the energy demands of each browser when streaming content, emphasizing the benefits of ad-free and optimized environments.

Table 3.5 Comparison of CPU Power Consumption on YouTube: Ad-Blocking Browsers vs. FreeTube

Website	Chrome without Ad blocker [W]	Brave[W]	Opera [W]	Firefox [W]	Vivaldi [W]	Librewolf [W]	Tor [W]	Freetube [W]
YouTube	3.6	2	2	2.6	3.9	4.8	3.2	2.6

The graph below visually represents the CPU power consumption of each browser while streaming on YouTube. The grouped bar format allows for a clear comparison of how each browser manages energy usage, highlighting the impact of ad-blocking and performance optimizations.

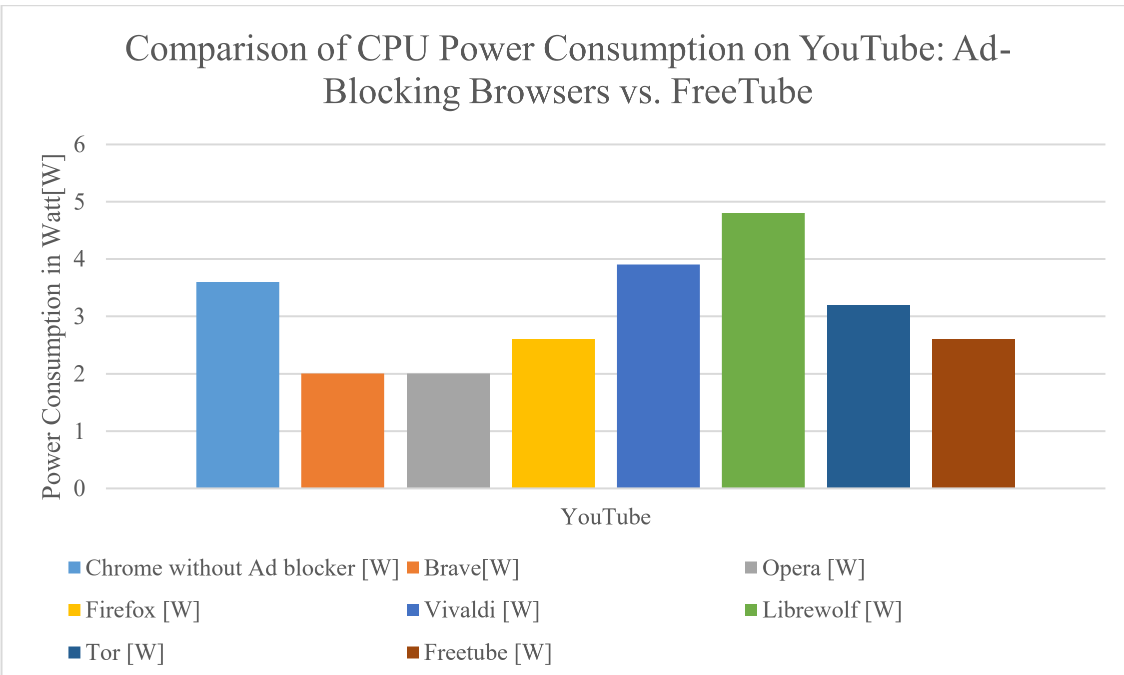

Figure 3.5 Comparison of CPU Power Consumption on YouTube: Ad-Blocking Browsers vs. FreeTube

The results demonstrate that FreeTube, with an average CPU power consumption of 2.6 Watts, significantly outperforms browsers like Chrome without Ad blocker, which consumes 3.6 Watts on YouTube. This represents a 28% reduction in CPU usage, emphasizing the impact of an ad-free environment on energy efficiency. Similarly, Brave and Opera also showcase lower power consumption, each using only 2 Watts, reflecting their integrated ad-blocking and performance enhancements.

The Results section reveals that built-in ad-blockers and performance optimizations significantly impact CPU and GPU power consumption across browsers. Brave and FreeTube consistently demonstrated the lowest power consumption. Brave reduced CPU usage by up to 44% and GPU usage by 68% compared to Chrome without Ad blocker, while FreeTube, an ad-free alternative, showed a 28% reduction in CPU consumption on YouTube compared to Chrome with ads. This highlights the effectiveness of ad-free environments and optimized browsing in reducing energy use.

Conversely, Chrome without Ad blocker and Tor had the highest power consumption across all tested websites. Chrome's lack of ad-blocking led to a 5.9 Watts CPU consumption on Dailymotion, showing the strain of unoptimized environments. Tor, despite its privacy features, consumed consistently high power due to its complex security protocols, illustrating a trade-off between privacy and performance efficiency. Video websites demanded up to 40% more processing power than news websites, especially in browsers lacking ad-blocking capabilities, emphasizing the added energy cost of handling high-resource content.

Browsers with built-in ad-blockers, such as Brave and Librewolf, maintained superior performance even on less demanding news sites, with Brave reducing GPU power consumption by up to 63% compared to Chrome. These findings suggest that selecting ad-blocking browsers not only minimizes power consumption but also enhances overall device performance and sustainability. The study underscores the importance of choosing optimized browsers like Brave and FreeTube to achieve significant energy savings, extended battery life, and a more sustainable browsing experience.

3.5. Conclusion and Future Work

This study provides a comprehensive analysis of the power consumption of web browsers with and without built-in ad-blockers, highlighting the significant impact of ad-blocking technology on energy efficiency. The results demonstrate that browsers equipped with integrated ad-blockers, such as Brave and Librewolf, consistently consume less CPU and GPU power compared to traditional browsers like Chrome without ad-blockers, achieving up to a 44% reduction in CPU power consumption, particularly on resource-intensive video websites. The findings underscore that content type plays a critical role in power consumption, with video-heavy websites imposing greater energy demands than news and entertainment sites. The elimination of ads and trackers not only enhances browsing performance but also contributes to substantial energy savings, making ad-blocking browsers ideal for users concerned with device battery life and sustainability. Future work could explore the impact of ad-blocking technology on mobile browsers and its effect on battery life in real-world scenarios, including a broader range of devices such as smartphones, tablets, and low-power laptops. Additionally, evaluating the performance of emerging privacy-focused browsers and alternative ad-blocking solutions could offer deeper insights into how software optimizations influence power consumption, while investigating user behavior patterns related to ad-blocker use could further contribute to the development of sustainable browsing practices.

References

[1] J. M. Pearce, “Energy Conservation with Open Source Ad Blockers,” Technologies, vol. 8, no. 2, pp. 1-18, 2020.

[2] Torjesen, Tommy, Ángel Cuevas, Antonio Pastor, and Mikko Kotila. "CarbonTag: A Browser-Based Method for Approximating Energy Consumption of Online Ads." arXiv preprint arXiv:2211.00071, 2023.

[3] Visser, Arthur. "The effect of ad blockers on the energy consumption of mobile web browsing." Twente Student Conference on IT. 2016.

[4] Heitmann, N., Park, S., and Chakraborty, S. (2020). “Towards Building Better Mobile Web Browsers for Ad-blocking: The Energy Perspective.” The 21st ACM SIGPLAN/SIGBED Conference on Languages, Compilers, and Tools for Embedded Systems (LCTES 2020).

[5] Roth, Kurt, Shreyas Patel, and James Perkinson. "The Impact of Internet Browsers on Computer Energy Consumption." Fraunhofer Center for Sustainable Energy Systems, 2013.

[6] Storey, Grant, et al. "The future of ad blocking: An analytical framework and new techniques." arXiv preprint arXiv:1705.08568 (2017).

[7] Abi Din, Zainul, et al. "{PERCIVAL}: Making {In-Browser} Perceptual Ad Blocking Practical with Deep Learning." 2020 USENIX Annual Technical Conference (USENIX ATC 20). 2020.

[8] Tigas, Panagiotis, Samuel T. King, and Benjamin Livshits. "Percival: Making In-Browser Perceptual Ad Blocking Practical with Deep Learning." arXiv preprint arXiv:1905.07444, 2019.

[9] Lashkari, Arash Habibi, et al. "CIC-AB: Online ad blocker for browsers." 2017 International Carnahan Conference on Security Technology (ICCST). IEEE, 2017.

[10] Borgolte, Kevin, and Nick Feamster. "Understanding the Performance Costs and Benefits of Privacy-Focused Browser Extensions." Proceedings of The Web Conference 2020, 2020.

[11] Garimella, Kiran, Orestis Kostakis, and Michael Mathioudakis. "Ad-blocking: A study on performance, privacy and counter-measures." Proceedings of the 2017 ACM on Web Science Conference. 2017.

[12] Gervais, A., Felt, A. P., and Rogers, J. "Ad-blocking: A Study on Performance, Privacy, and Counter-measures." arXiv preprint arXiv:1705.03193, 2020.

[13] Li, H., Edwards, S.M., and Lee, J.-H. "Measuring the Intrusiveness of Advertisements: Scale Development and Validation." Journal of Advertising, vol. 31, no. 2, 2002, pp. 37–47.

[14] Miroglio, Ben, et al. "The Effect of Ad Blocking on User Engagement with the Web." Proceedings of the 2018 World Wide Web Conference, 2018.

[15] Wielki, Janusz, and Janusz Grabara. "The impact of Ad-blocking on the sustainable development of the digital advertising ecosystem." Sustainability 10.11 (2018): 4039.

[16] Pesari, Fabio, Giovanni Lagioia, and Annarita Paiano. "Client‐Side Energy and GHGs Assessment of Advertising and Tracking in the News Websites." Journal of Industrial Ecology, vol. 27, no. 2, 2023, pp. 548-561.

[17] Samsuddin, MI Bin, et al. "The evaluation of AdBlock technique implementation for enterprise network environment." Indones. J. Electr. Eng. Comput. Sci 13.3 (2019): 1102-1109.

[18] Bruguera Micó, Joan. "Online advertisement blocker detection: A look at the state of the art for counter-detection and a proof-of-concept for new approaches." (2017).

[19] Subramanian, Upender, and Mohammad Zia. "Ad-blockers and limited ad-blocking." Available at SSRN 3466105 (2021).

[20] Pourghassemi, Behnam. "Scalable Dynamic Analysis of Browsers for Privacy and Performance." ACM SIGMETRICS Performance Evaluation Review, vol. 47, no. 3, 2020, pp. 20-23.

[21] Pesari, Fabio, Giovanni Lagioia, and Annarita Paiano. "Client - Side Energy and GHGs Assessment of Advertising and Tracking in the News Websites." Journal of Industrial Ecology, vol. 27, no. 2, 2023, pp. 548-561.

[22] Barbacovi, Tyler. "Blocking Ad Blockers." J. Marshall Rev. Intell. Prop. L., vol. 16, 2016, p. i.

[23] Garimella, Kiran, Orestis Kostakis, and Michael Mathioudakis. "Ad-blocking: A study on performance, privacy and counter-measures." Proceedings of the 2017 ACM on Web Science Conference. 2017.

[24] D. Aleksandersen, "Brave reduces the page load performance cost of its adblocker," CTRL Blog, vol. 6, no. 1, pp. 9-21, 2020. [Online]. Available: https://www.ctrl.blog/entry/brave-ab-performance.html. [Accessed: 14-Sep-2024].

[25] Mahmoud, Alaa Ahmed Ali. "Understanding the Perspectives of Users, Advertisers and Ad Blocker Companies on Ad Block Usage." (2022).

[26] Heitmann, Nadja, et al. "Towards building better mobile web browsers for ad blocking: The energy perspective (wip paper)." The 21st ACM SIGPLAN/SIGBED Conference on Languages, Compilers, and Tools for Embedded Systems. 2020.

[27] Mahmoud, Alaa Ahmed Ali. "Understanding the Perspectives of Users, Advertisers and Ad Blocker Companies on Ad Block Usage." (2022).

[28] LibreWolf, "Fingerprinting and Security," LibreWolf Browser Tests, 2022. [Online]. Available: https://librewolf.net/docs/testing/#fingerprinting-and-security. [Accessed: 14-Sep-2024].

[29] "The Tor Project, Tor Performance. [Online]. Available: https://metrics.torproject.org/torperf.html. Accessed: Oct. 22, 2024."

[30] "FreeTube, About FreeTube. [Online]. Available: https://docs.freetubeapp.io/about/freetube. Accessed: Oct. 22, 2024."

Chapter 4. Power Consumption While Using Ad-Blockers on ARM-Based CPU

Preface

A version of this manuscript has been Accepted in the NECEC, October 2024**.** I am the primary author, and I carried out most of the research work performed the literature reviews, carried out the experiment design, implementations, and analysis of the results. I also prepared the first draft of the manuscript. The Co-authors Dr. Tariq Iqbal and Dr. Mohsin Jamil, supervised and co-supervised the research respectively, and provided the research guide, reviewed, and corrected the manuscript, and contributed research ideas to the actualization of the manuscript.

Abstract

This study investigates the impact of ad blockers on power consumption in ARM-based processors, which are widely used in energy-efficient systems. A comparative analysis was conducted across popular browsers such as Chrome, Brave, Vivaldi, Kiwi, and Firefox, alongside ad blockers including AdGuard, Adblock Plus, Ghostery, uBlock, and uBlock Origin. Tests on websites like YouTube, Dailymotion, ARYZAP, and KissCartoon revealed significant differences in power consumption based on browser and ad-blocker configurations. Kiwi paired with uBlock reduced power consumption by approximately 15% compared to Chrome, which consistently exhibited the highest energy usage. Brave, with its built-in ad blocker, reduced power consumption by 12% on average compared to Firefox with Ghostery, which showed the highest consumption. Additionally, Firefox with Adblock Plus demonstrated an 8-10% reduction in energy use compared to configurations without ad-blocking extensions. On media-rich platforms like YouTube, Brave and Kiwi performed more efficiently, consuming 10-13% less power than Chrome and Firefox with Ghostery, which increased energy use by up to 20%. These findings emphasize the importance of selecting the right browser and ad blocker combination to optimize power efficiency on ARM-based systems, especially in ad-heavy environments.

4.1. Introduction

The rapid growth of internet usage has led to an increase in online advertisements, which are vital for website revenue but often degrade user experience by slowing page loading, increasing data usage, and raising privacy concerns. To address these issues, ad blockers have become popular, enhancing user experience by filtering ads and blocking tracking scripts. However, their impact on power consumption, particularly on ARM CPUs, remains largely unexplored.

ARM CPUs, known for energy efficiency, dominate mobile devices and embedded systems, making energy-efficient computing crucial. Ad blockers add computational overhead, which could affect power usage, but studies on this effect are lacking, especially for ARM-based devices. As ARM CPUs differ from x86 processors, findings from desktop environments may not apply directly to mobile platforms.

This study aims to evaluate power consumption associated with ad blockers on ARM CPUs, analyzing their energy impact during web browsing on different websites and content types. The findings will inform consumers about energy trade-offs, guide developers in optimizing ad blockers, and aid policymakers in promoting sustainable technology practices, ultimately contributing to reduced environmental impacts of digital technologies.

4.2. Literature Review

Energy efficiency in computing has become a critical factor, with ARM processors leading the way in low-power, high-performance applications. Pearce (2020) discusses the significant role of ARM technology in optimizing energy use, particularly in reducing unnecessary energy consumption through the use of open-source ad blockers, which can improve overall system efficiency [1]. Tairum (2018) analyzed ARM's Scalable Vector Extension, showing that this architecture delivers considerable power savings, particularly in vector processing tasks that are critical in data-intensive applications [2]. Das (2021) introduced a power modeling framework that significantly enhances real-time measurement capabilities in ARM CPUs, which is vital for developers aiming to optimize energy usage dynamically [3]. Basmadjian and de Meer (2012) found that multi-core processors like ARM can significantly lower power consumption during various computing tasks, which is essential for servers and data centers [4].

Calore et al. (2018) highlighted ARM’s effectiveness in high-performance computing (HPC) workloads, emphasizing its ability to balance performance with energy efficiency, a key consideration in scientific computing [5]. Suárez et al. (2024) provided a comparative analysis between ARM and RISC-V, highlighting ARM's superior performance in handling complex and data-heavy workloads efficiently, making it suitable for both consumer electronics and industrial applications [6]. Rahman and Smith (2024) emphasized ARM's growing dominance in cloud computing due to its ability to reduce operational costs through energy savings, further enhancing its appeal to businesses looking to minimize carbon footprints [7].

Raffin et al. (2024) provided an in-depth examination of various processor systems, revealing that ARM processors consistently outperform competitors in energy consumption under similar workload conditions [8]. Xie et al. (2021) introduced the APOLLO framework, which uses advanced algorithms for precise power introspection at runtime, enabling fine-tuned optimizations that help maintain system performance without significant power penalties [9]. The comprehensive analysis of ARM and RISC-V systems highlighted ARM’s consistent efficiency gains, positioning it as a preferred architecture in energy-sensitive environments [10]. Patsidis et al. (2024) validated ARM’s performance across different RISC architectures, demonstrating that ARM’s design choices provide clear advantages in both computational speed and power efficiency [11].

Endo et al. (2015) explored simulation techniques with Gem5 and McPAT, showcasing how ARM's micro-architectural innovations contribute to enhanced performance with lower power draw [12]. Kodama et al. (2017) examined ARM SVE's capability to adapt to various vector lengths, offering flexible performance scaling without proportional increases in power consumption, which is critical in adaptive computing environments [13]. Stanley-Marbell and Cabezas (2011) illustrated ARM's role in reducing thermal output, which directly impacts power consumption in data centers and large-scale computing environments [14]. The Arm-ECS Research Centre's work on stable CPU power modeling emphasized the critical role of accurate and consistent power measurements in ongoing ARM CPU optimizations [15].

Naffziger et al. (2020) discussed AMD's chiplet architecture and its influence on ARM's approach to modular design, highlighting the benefits of resource efficiency and scalability [16]. Xie et al. (2021) provided further insights into how ARM's runtime power introspection capabilities allow for real-time adjustments that maximize performance while minimizing energy use [17]. Haas (2024) detailed ARM's strategic adaptation in AI, emphasizing energy-efficient processing that supports AI workloads without the high energy costs typically associated with these tasks [18]. Studies on performance–energy trade-offs in deep learning highlight ARM's ability to balance computational demands with energy constraints, making it highly suitable for modern AI applications [19][20]. The ongoing analysis of ARM and RISC-V continues to validate ARM's superior architecture for both performance and power management [21].

Ad blockers play a crucial role in optimizing energy consumption by reducing the load on browsers and system resources, especially in mobile and low-power environments. Brave, with its built-in ad-blocker, significantly reduces battery consumption by up to 35% compared to browsers like Chrome by blocking ads and trackers by default, which minimizes CPU and bandwidth usage during browsing [22]. Similarly, Vivaldi incorporates a customizable built-in ad-blocker that allows users to block ads and trackers efficiently, contributing to improved browsing performance [23]. Firefox, with various ad-blocking extensions, shows differing levels of energy consumption. AdGuard effectively blocks ads, though its extensive filtering mechanisms can slightly increase resource usage [24]. Adblock Plus, with its "acceptable ads" feature, balances power consumption and user experience by allowing some non-intrusive ads, reducing the need for excessive filtering [25]. Ghostery offers advanced privacy protections but may increase power consumption due to its more aggressive ad-blocking and tracking prevention techniques [26]. Meanwhile, uBlock Origin is known for being a lightweight and highly efficient blocker, significantly reducing resource usage, making it ideal for low-power devices [27]. NewPipe, a lightweight YouTube client, further enhances energy efficiency by bypassing resource-heavy ads, leading to minimal power consumption [28].

4.3. Experimental Setup

4.3.1. Hardware and Software Configuration

The experiments were conducted using a Google Pixel 7 smartphone, equipped with a Google Tensor G2 SoC based on ARM architecture. The CPU architecture includes:

2x Cortex-X1 cores at 2.85 GHz, 2x Cortex-A78 cores at 2.35 GHz, 4x Cortex-A55 cores at 1.80 GHz .The ARM-based CPU offers an optimal balance between high-performance tasks and low-power operations. The device operates with 8 GB LPDDR5 RAM and a 4355 mAh battery to sustain consistent power delivery. The GPU integrated is an ARM Mali-G710 MP7, providing efficient handling of graphical content. The smartphone runs on Android 14, supporting 64-bit architecture, and employs a sched_pixel CPU governor for dynamic frequency scaling to ensure energy efficiency during performance fluctuations.

4.3.2. Network Configuration

A stable 1.5 GB internet connection was maintained throughout the experiment to minimize network variance and ensure reliable testing conditions across all websites and browsers

4.3.3. Websites Tested

The experiments were conducted using four distinct websites, representing a range of content types and media complexity: YouTube: A video streaming platform. Dailymotion: A similar video streaming site with ads. ARYZAP: A news and video content platform. KissCartoon: An animated media streaming platform.

These websites were chosen based on their content variety and ad density, which impact both browser performance and power consumption.

4.3.4. Procedure

The tests were carried out by comparing power consumption across different browsers and configurations:

Browsers Tested: Chrome, Brave, Vivaldi, Kiwi, and Firefox (without ad blockers).

Firefox with Ad Blockers: Additionally, Firefox was tested with various ad-blocking extensions, including:

- Firefox with AdGuard
- Firefox with Adblock Plus
- Firefox with Ghostery
- Firefox with uBlock Origin

Each test was performed by loading the websites and playing the same video across all browsers to maintain uniformity. For YouTube, additional tests were performed using NewPipe, a lightweight, ad-free YouTube client that reduces system resource usage by bypassing official APIs and advertisements.

4.3.5. Time Intervals

To ensure consistency, the same video was played across all browsers and configurations for an equal period. This enabled direct comparisons of power consumption under similar conditions.

4.3.6. Data Collected

The primary metric collected during the experiments was power consumption in watts. Power consumption was monitored and recorded in real time using the Device Info app, a widely used Android application for system monitoring. The app provides detailed power consumption readings and performance data for individual processes, allowing for accurate assessments of the impact of various browsers and extensions.

4.3.7. Variables Tested

The key variables tested include:

- Power Consumption: Measured in watts across different browsers, configurations, and websites.
- Browser Performance: While not quantitatively measured, browser performance, including page load times and overall responsiveness, was observed qualitatively.

4.3.8. Tools and Techniques

Power consumption was measured using the Device Info app, available on the Google Play Store. This tool provides real-time insights into CPU and GPU load, as well as power usage in watts. The app's ability to track specific processes made it a suitable choice for this study, ensuring precise measurements of browser-related power consumption. The data was averaged across multiple runs to minimize outliers and ensure reliability.

4.4. Results

This section presents the experimental findings on the power consumption of various browsers when accessing different websites. The results compare the performance of browsers, with and without ad-blocking extensions, highlighting energy usage patterns on an ARM-based CPU. The data provides insights into how different browsers and extensions impact power efficiency under typical browsing conditions.

4.4.1. Power Consumption Across Browsers

The power consumption of different browsers was measured while accessing four websites: YouTube, Dailymotion, ARYZAP, and KissCartoon. The results are presented in the table below.

Table 4.1 Power Consumption Across Browsers

Websites	Chrome	Brave	Vivaldi	Kiwi	Firefox without add block
Youtube	3.12	3.03	3.09	2.77	2.98
Dailymotion	2.31	1.74	2.76	2.79	2.92
ARYZAP	2.13	1.81	2.13	2.21	1.88
KissCartoon	2.08	2.39	2.23	2.02	2.40

The data reveals clear differences in power consumption between browsers. Kiwi consistently demonstrated the lowest power consumption, especially on media-heavy websites like YouTube and KissCartoon. Brave, due to its built-in ad-blocking capabilities, performed exceptionally well on ad-heavy websites like Dailymotion and ARYZAP, minimizing power consumption.

Firefox without ad-block tended to consume more power, particularly on media-rich websites like Dailymotion and KissCartoon, where advertisements and unoptimized content increased energy demands. Chrome and Vivaldi displayed moderate to high power consumption across all websites, with Chrome consuming the most power on YouTube, indicating it may not be as optimized for energy efficiency.

The grouped bar graph below provides a clear visual comparison of power consumption across different browsers on the four tested websites. This graph helps highlight the energy efficiency trends across browsers.

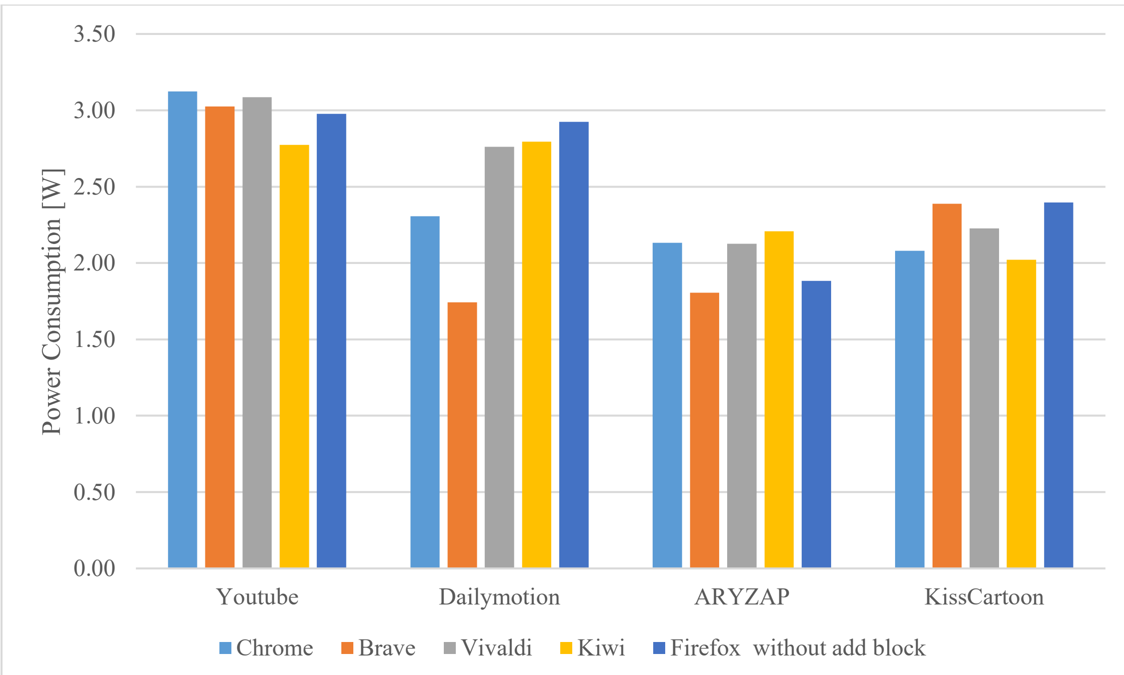

Figure 4.1 Power Consumption across different Browsers

4.4.2. Power Consumption of Firefox with Different Ad-Blockers

The power consumption of Firefox was tested with various ad-blocking extensions to assess their impact on energy efficiency. The extensions included AdGuard, Adblock Plus, Ghostery, and uBlock. These results were compared against Firefox without any ad-blocking extensions.

Table 4.2 Power Consumption of Firefox with Different Ad-Blockers

Websites	without add block	Adguard	Adblock Plus	Ghostrey	U block
Youtube	3.0	3.1	3.0	3.1	3.1

Dailymotion	3.0	2.1	2.1	2.5	1.8
ARYZAP	1.9	2.0	2.0	2.0	1.9
KissCartoon	2.4	2.7	2.0	2.6	1.9

The data reveals that the use of ad-blocking extensions generally impacts power consumption, but the efficiency of each extension varies based on the website.

uBlock consistently shows the lowest power consumption across all websites, particularly on Dailymotion (1.81W) and ARYZAP (1.85W), suggesting that it is the most energy-efficient extension.

Adblock Plus also performed well, with low power consumption on KissCartoon (1.93W) and ARYZAP (1.93W).

AdGuard and Ghostery, while effective at blocking ads, resulted in higher power consumption, especially on YouTube and KissCartoon, where their overhead likely increased energy usage.

In comparison, Firefox without ad block consumed more power across all websites, except for ARYZAP, where the absence of an ad-blocker didn't significantly affect power consumption. Overall, uBlock and Adblock Plus stand out as the most efficient options for reducing power consumption while browsing with Firefox.

The grouped bar graph below illustrates the power consumption of Firefox with different ad-blockers across the four websites. This visual comparison highlights the energy efficiency of each extension.

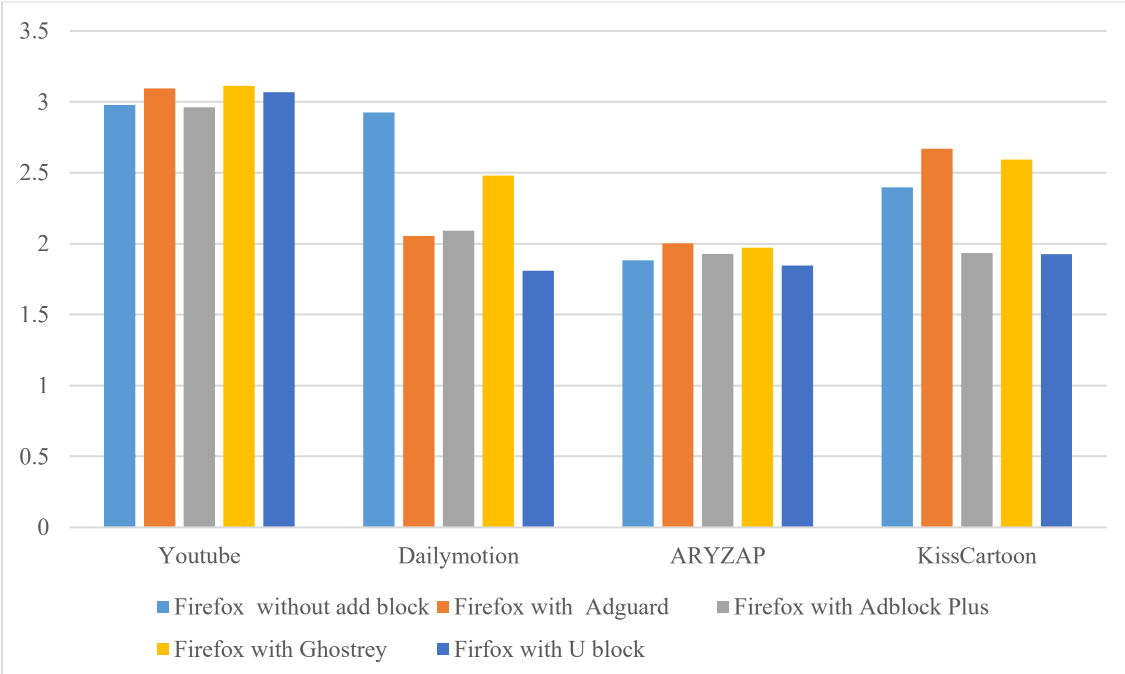

Figure 4.2 Power Consumption of Firefox with Different Ad-Blockers

4.4.3. Power Consumption of YouTube

This section presents the power consumption results for YouTube across multiple browsers and Firefox configurations with different ad-blocking extensions, including the specialized YouTube client, NewPipe. The data is summarized in the table below:

Table 4.3 Power Consumption of YouTube

Websites	YouTube
Chrome	3.12
Brave	3.03
Vivaldi	3.09
Kiwi	2.77
Firefox without add block	2.98
Firefox with Adguard	3.1
Firefox with AdBlock Plus	2.96
Firefox with Ghostrey	3.11
Firefox with U block	3.07

NewPipe	1.16

The power consumption results for YouTube reveal clear variations across browsers and configurations. NewPipe demonstrates the most energy-efficient performance by far, consuming only 1.16W, significantly less than any other browser configuration. This is likely due to its lightweight nature and ability to bypass ads and resource-heavy processes. Among standard browsers, Kiwi once again performs best, consuming 2.77W, followed closely by Firefox with Adblock Plus at 2.96W. Chrome consumes the most power at 3.12W, followed closely by Firefox with Ghostery at 3.11W and Firefox with AdGuard at 3.10W. These results indicate that more resource-intensive configurations or browsers tend to consume more power during video streaming. Firefox without ad block consumed 2.98W, demonstrating moderate efficiency compared to browsers with ad-blocking extensions.

The following bar graph visually compares the power consumption of each browser and Firefox configuration, along with NewPipe, for YouTube video streaming.

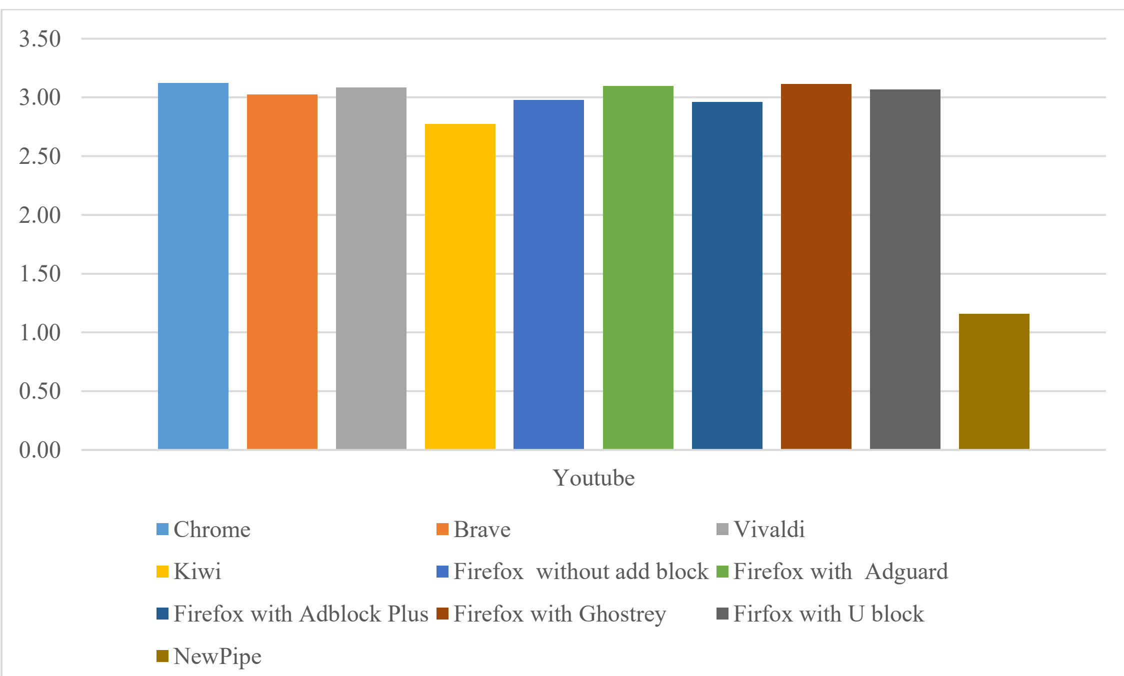

Figure 4.3 Power Consumption of YouTube

The experimental results show notable variations in power consumption across browsers and Firefox configurations with ad-blockers. Kiwi consistently proved to be the most energy-efficient among standard browsers, consuming 2.77W on YouTube, which is 11% lower than Firefox without ad block (2.98W) and 13% lower than Chrome (3.12W), the highest-consuming browser. Brave and Vivaldi also performed reasonably well, with power consumption of 3.03W and 3.09W, respectively. In contrast, Firefox with ad-blockers such as Ghostery and AdGuard resulted in higher power consumption, both exceeding 3.10W, which is approximately 5% higher than the more efficient configurations like Firefox with Adblock Plus (2.96W). While NewPipe, a specialized YouTube client, showed the lowest consumption at 1.16W, this result is context-specific and highlights the energy savings potential for video-centric applications. Overall, the results suggest that lightweight browsers like Kiwi and efficient ad-blockers such as uBlock and Adblock Plus can reduce power consumption by up to 10-15%, whereas resource-heavy configurations, particularly those using ad-blockers like Ghostery, can increase power usage on video-heavy websites like YouTube.

4.5. Conclusion and Future Work

This study highlights the significant impact of ad blockers on power consumption in ARM-based processors, with certain browser and ad-blocker combinations offering considerable energy savings. Kiwi and Brave, particularly when paired with lightweight ad blockers like uBlock and Adblock Plus, demonstrated power reductions of up to 15%, making them the most efficient options. In contrast, Chrome and Firefox with Ghostery showed increased power consumption, especially on media-rich websites, with up to 20% higher energy use. These findings emphasize the importance of selecting efficient browsers and ad blockers to optimize energy usage on ARM-based systems. Future work could explore a broader range of websites and additional hardware configurations, including other processor architectures such as RISC-V or x86, to determine if these trends hold across different platforms. Additionally, investigating the effects of emerging ad-blocking technologies and browser-native solutions on power consumption could provide further insights for both developers and end-users aiming to maximize energy efficiency.

References

[1] Pearce, Joshua M. "Energy Conservation with Open Source Ad Blockers." Technologies 8.2 (2020): 18.

[2] Tairum, Cruz M. "Performance and Power Consumption Analysis of ARM Scalable Vector Extension." The Journal of Supercomputing (2018): 638.

[3] Das, Shidhartha. "Fast, Accurate Power Modelling for CPU Power-Introspection." Arm Community (2021): 1-10.

[4] Basmadjian, R., and H. de Meer. "Evaluating and Modeling Power Consumption of Multi-Core Processors." Proceedings of the 3rd International Conference on Future Energy Systems (2012): 12-20.

[5] Calore, E., Mantovani, F., and Ruiz, D. "Advanced Performance Analysis of HPC Workloads on Cavium ThunderX." 2018 International Conference on High Performance Computing & Simulation (HPCS) (2018): 375–382.

[6] Suárez, Daniel, Francisco Almeida, and Vicente Blanco. "Comprehensive Analysis of Energy Efficiency and Performance of ARM and RISC-V SoCs." The Journal of Supercomputing (2024): 1-19.

[7] Rahman, Tahmid Noor, and Jack Smith. "Redefining Computing: Rise of ARM from Consumer to Cloud for Energy Efficiency." arXiv (2024).

[8] Raffin, Guillaume, et al. "Dissecting the Software-Based Measurement of CPU Energy Consumption: A Comparative Analysis." arXiv (2024).

[9] Xie, Zhiyao, et al. "APOLLO: An Automated Power Modeling Framework for Runtime Power Introspection in High-Volume Commercial Microprocessors." ScienceDaily, Duke University, 2021.

[10] "Comprehensive Analysis of Energy Efficiency and Performance of ARM and RISC-V SoCs." The Journal of Supercomputing.

[11] Patsidis, K., Konstantinou, D., Nicopoulos, C., and Dimitrakopoulos, G. "Performance Evaluation of Various RISC Processor Systems: A Case Study on ARM, MIPS, and RISC-V." SpringerLink (2024).

[12] Endo, F. A., Couroussé, D., and Charles, H-P. "Micro-architectural Simulation of Embedded Core Heterogeneity with Gem5 and McPAT." Proceedings of the 2015 Workshop on Rapid Simulation and Performance Evaluation: Methods and Tools (RAPIDO'15), ACM, 2015.

[13] Kodama, Y., Odajima, T., Matsuda, M., Tsuji, M., Lee, J., and Sato, M. "Preliminary Performance Evaluation of Application Kernels Using ARM SVE with Multiple Vector Lengths." 2017 IEEE International Conference on Cluster Computing (CLUSTER), IEEE, pp. 677-684.

[14] Stanley-Marbell, P., and Cabezas, V.C. "Performance, Power, and Thermal Analysis of Low-Power Processors for Scale-Out Systems." 25th IEEE International Symposium on Parallel and Distributed Processing (IPDPS), IEEE, 2011.

[15] "Accurate and Stable CPU Power Modeling." Arm-ECS Research Centre, 2019.

[16] Naffziger, S., Lepak, K., Paraschou, M., and Subramony, M. "AMD Chiplet Architecture for High-Performance Server and Desktop Products." 2020 IEEE International Solid-State Circuits Conference (ISSCC), pp. 44–45.

[17] Xie, Zhiyao, et al. "APOLLO: An Automated Power Modeling Framework for Runtime Power Introspection in High-Volume Commercial Microprocessors." ScienceDaily, Duke University, 2021.

[18] Haas, Timothy. "Power Efficiency, Customization Will Drive Arm's Role In AI." The Next Platform, 2024.

[19] "Comprehensive Analysis of Energy Efficiency and Performance of ARM and RISC-V SoCs." The Journal of Supercomputing (2024).

[20] "Performance–Energy Trade-offs of Deep Learning Convolution Algorithms on ARM Processors." The Journal of Supercomputing (2024).

[21] "Comprehensive Analysis of Energy Efficiency and Performance of ARM and RISC-V "Surf the Web Without Annoying Pop-Ups and Ads!" AdBlock, 2024, www.getadblock.com/en/.

[22] Brave Software, "Significant Battery Savings with Brave on Mobile," Brave, 2024. [Online]. Available: https://brave.com

[23] "Vivaldi Browser with Built-in Ad Blocker," Slant, 2024. [Online]. Available: https://www.slant.co

[24] AdGuard, "AdGuard: World's Most Advanced Ad Blocker," AdGuard, 2024. [Online]. Available: https://adguard.com/en

[25] "AdBlock Plus - Block Ads with Adblock Plus," Eyeo GmbH, 2024. [Online]. Available: https://www.adblockplus.org

[26] Ghostery, "Ghostery: Privacy Protection and Ad Blocker," Ghostery, 2024. [Online]. Available: https://www.ghostery.com

[27] Hill, R., "uBlock Origin: A Lightweight Content Blocker," GitHub, 2024. [Online]. Available: https://github.com/gorhill/uBlock

[28] "NewPipe: A Lightweight YouTube Client," NewPipe, 2024. [Online]. Available: https://newpipe.net

Chapter 5. Computer power consumption while using ad blocker on a system with AI accelerators

Preface

A version of this manuscript has been accepted in the European Journal of Information Technology & Computer Science, October 2024**.** I am the primary author, and I carried out most of the research work performed the literature reviews, carried out the experiment design, implementations, and analysis of the results. I also prepared the first draft of the manuscript. The Co-authors Dr. Tariq Iqbal and Dr. Mohsin Jamil, supervised and co-supervised the research respectively, and provided the research guide, reviewed, and corrected the manuscript, and contributed research ideas to the actualization of the manuscript.

Abstract

This study investigates the impact of ad blockers on system power consumption in a computing environment equipped with an AI accelerator. The increasing prevalence of online advertisements has raised concerns about system performance and energy efficiency, prompting many users to turn to ad blockers. However, the effectiveness of ad blockers on power consumption, especially in systems equipped with specialized AI accelerators, remains underexplored. In this research, we evaluate the power usage, GPU utilization, and memory consumption of computers running ad blockers on both Windows and Ubuntu operating systems. The study compared traditional CPU/GPU methods with AI-accelerated scenarios, using popular ad blockers such as AdBlock, Adblock Plus, uBlock, uBlock Origin, and uBlock Origin Lite. Results indicate that uBlock Origin and uBlock Origin Lite were the most efficient, significantly reducing power consumption and memory usage compared to other ad blockers. However, multimedia-heavy websites presented challenges, with increased resource usage observed. The findings emphasize the importance of choosing appropriate ad blockers to enhance energy efficiency, optimize system resources, and contribute to sustainable computing.

5.1. Introduction

In the digital age, online advertising has become an integral part of the internet ecosystem, generating significant revenue for content creators and service providers. However, the proliferation of online advertisements also presents various challenges for end-users, including privacy concerns, security risks, distraction, and diminished browsing experiences. Moreover, the increasing volume of advertisements has a direct impact on computer performance and energy consumption, as ads require additional computing power and data to render. Consequently, users have turned to ad blockers as a solution to mitigate these issues and enhance their browsing experience by eliminating intrusive ads.

Ad blockers are software tools designed to detect and prevent advertisements from loading on web pages, thereby reducing network bandwidth usage, enhancing browsing speed, and addressing privacy concerns. Despite these benefits, the operation of ad blockers itself consumes system resources, such as CPU, GPU, and memory, contributing to increased power consumption. Understanding the implications of ad blockers on system energy consumption is essential, especially in a world increasingly focused on environmental sustainability and reducing carbon footprints. As laptops, desktops, and mobile devices are widely used, optimizing their energy efficiency not only extends battery life but also minimizes the environmental impact of technology use.

Recent advancements in computer hardware have introduced specialized components, such as AI accelerators, designed to optimize specific computational tasks more efficiently than traditional CPUs and GPUs. AI accelerators, such as Tensor Processing Units (TPUs) and dedicated neural processing units (NPUs), leverage machine learning capabilities to handle complex and repetitive tasks, providing higher performance while consuming less power. These accelerators have shown significant potential in enhancing the efficiency of various workloads, including image recognition, natural language processing, and even content filtering. This raises an intriguing question: can AI accelerators be leveraged to make ad-blocking more energy efficient?

This study aims to explore the power consumption of computers running ad blockers on systems equipped with AI accelerators. Specifically, it investigates whether the use of AI acceleration can effectively reduce the energy footprint associated with ad blocking, compared to conventional methods that rely solely on CPU or GPU resources. By examining power consumption under different scenarios—such as using traditional ad blockers versus AI-optimized ad-blocking mechanisms—this research aims to provide valuable insights into optimizing power usage for enhanced sustainability.

Furthermore, this research considers the broader implications of power consumption in modern computing environments. As consumers increasingly rely on mobile devices and laptops, battery life has become a critical factor in determining user satisfaction. Ad blockers, while improving browsing speed and privacy, might paradoxically drain more power if not implemented efficiently. Therefore, understanding how AI accelerators impact the energy usage of ad-blocking applications can lead to the development of more energy-efficient solutions, benefiting both individual users and contributing to a more sustainable technology landscape.

The results of this study will be useful for multiple stakeholders, including end-users seeking to maximize device battery life, developers aiming to create efficient ad-blocking solutions, and researchers focusing on sustainable computing practices. The research also addresses the importance of energy efficiency in the design and implementation of privacy-enhancing technologies, highlighting how hardware advancements can be utilized to balance privacy, performance, and sustainability in an increasingly connected world.

5.2. Literature Review

The rapid advancement of artificial intelligence (AI) has led to an increasing demand for efficient hardware accelerators capable of handling complex computations. Traditional processors struggle to meet the performance and energy efficiency requirements of modern AI applications. As a result, specialized AI hardware accelerators have emerged as critical components in the deployment of AI systems. A comprehensive overview of AI hardware accelerators, including their architectural designs, performance metrics, and integration challenges, is provided in [1]. This foundational knowledge sets the stage for exploring specific advancements in energy-efficient accelerator designs and their applications across various domains.

Energy efficiency is a paramount concern in the design of deep learning accelerators, especially given the growing complexity of neural network models. The Eyeriss accelerator introduced in [2] is an energy-efficient reconfigurable hardware designed for deep convolutional neural networks (CNNs). Eyeriss employs a novel dataflow called Row Stationary, which optimizes data reuse and minimizes data movement, leading to significant energy savings.

Building on the need for energy efficiency in personalized applications, an accelerator facilitating in situ personalization on smart devices is proposed in [3]. This design allows for on-device training of deep CNNs, reducing dependency on cloud services and enhancing user privacy. The accelerator optimizes energy consumption by leveraging low-precision computations and efficient memory hierarchies.

In the quest for adaptability, the UNPU accelerator presented in [4] supports fully variable weight bit precision. UNPU dynamically adjusts the precision of weights during neural network operations, balancing the trade-off between energy efficiency and computational accuracy. This flexibility enables the accelerator to cater to a wide range of applications with varying precision requirements.

The separation of memory and processing units in traditional architectures leads to significant energy consumption due to data movement. In-memory computing addresses this challenge by performing computations within the memory elements themselves. The Pipelayer accelerator introduced in [5] leverages resistive random-access memory (ReRAM) for deep learning applications. By minimizing data transfer between memory and processing units and supporting pipeline parallelism, Pipelayer reduces energy consumption and enhances throughput.

The challenges and solutions associated with in-memory computing for AI accelerators are extensively discussed in [6]. Limitations of existing memory technologies are examined, and architectural innovations are proposed to overcome them. This work emphasizes the importance of co-designing hardware and algorithms to fully exploit the benefits of in-memory computing, particularly in terms of energy efficiency and performance scalability.

To accommodate the diverse computational patterns of deep learning models, flexibility in dataflow mapping is essential. The MAERI architecture presented in [7] enables flexible dataflow mapping over deep neural network (DNN) accelerators through reconfigurable interconnects. MAERI's design allows for the efficient execution of various neural network layers by adapting the dataflow to the specific requirements of each layer. This adaptability enhances both performance and energy efficiency, as the accelerator can optimize resource utilization dynamically.

Understanding the landscape of AI accelerators requires comprehensive benchmarking and analysis. A survey of machine learning accelerators is conducted in [8], examining architectural features, performance metrics, and application domains. This work provides valuable insights into the strengths and weaknesses of various accelerator designs, highlighting trends in the field.

A systematic study on benchmarking AI inference accelerators is presented in [9], proposing methodologies for evaluating accelerator performance across different workloads and models. The importance of standardized benchmarks for fair comparisons is emphasized.

Significant surveys contributed in [10] and [11] update the state of efficient hardware architectures for accelerating deep CNNs and discuss hardware and software optimizations for accelerating deep neural networks. These works collectively offer a thorough understanding of the current state and evolution of AI hardware accelerators.

The deployment of AI accelerators extends beyond traditional computing applications into specialized fields like healthcare and biomedical engineering. Hardware implementations of deep network accelerators tailored for these applications are explored in [12]. This research highlights the unique challenges in these domains, such as the need for high precision and reliability, and how customized hardware solutions can address these requirements while maintaining energy efficiency.

AI technologies play a significant role in optimizing energy consumption in smart devices and systems. A review of AI-empowered methods for smart energy consumption is provided in [13], focusing on load forecasting, anomaly detection, and demand response. The work discusses how AI algorithms, when implemented efficiently on hardware accelerators, can lead to substantial energy savings in smart grids and buildings.

The complexity of modern chip design necessitates innovative methodologies to accelerate development cycles. A graph placement methodology leveraging machine learning to expedite chip design processes is introduced in [14]. By formulating chip design as a reinforcement learning problem, this approach achieves superior placement quality in a fraction of the time required by traditional methods. This advancement not only speeds up the development of AI accelerators but also contributes to their performance and energy efficiency.

Personalized recommendation systems are computationally intensive and require efficient processing of large datasets. The RecNMP architecture proposed in [15] accelerates personalized recommendation tasks using near-memory processing. By bringing computation closer to memory, RecNMP reduces data movement overhead and improves energy efficiency. This approach demonstrates the applicability of AI accelerators in enhancing user-centric services while managing energy consumption effectively.

Ad-blockers have become prevalent tools for users seeking to enhance their browsing experience by eliminating unwanted advertisements. The economic implications of ad-blocker platforms on advertisers and the internet ecosystem are analyzed in [16]. The study highlights the tension between user preferences and the revenue models of content providers.

The effects of ad-blocker adoption on digital piracy are explored in [17], discussing whether ad-blockers serve as a deterrent to piracy by improving user experience on legitimate platforms or inadvertently encourage piracy by disrupting revenue streams.

A lab experiment assessing the impact of ad-blockers on consumer behavior is conducted in [18]. The findings suggest that while ad-blockers improve user experience, they also alter consumer engagement with content and advertisements.

The nuanced view of ad-blockers being beneficial or detrimental to the digital economy is provided in [19], exploring the complex interplay between user experience, content monetization, and the sustainability of online services.

Beyond economic implications, ad-blockers have a significant impact on energy consumption and device performance. The contribution of open-source ad blockers to energy conservation is investigated in [20]. The study demonstrates that blocking advertisements reduces data usage and processing demands, leading to lower energy consumption on user devices.

Building better mobile web browsers for ad blocking from an energy perspective is the focus of [21]. The analysis of different ad-blocking strategies and their effects on the energy efficiency of mobile browsers provides insights into optimizing both user experience and device battery life. An experimental study on the energy and bandwidth costs of web advertisements on smartphones is conducted in [22]. The findings reveal that advertisements significantly increase energy consumption and data usage, underscoring the potential benefits of ad-blocking technologies in prolonging battery life and reducing costs for users.

5.3. Experimental Design Overview

The primary objective of this experiment was to evaluate the impact of using different ad blockers on system power consumption, specifically focusing on systems equipped with AI accelerators. The study compared power usage between scenarios where ads were blocked versus scenarios without ad blockers on both Windows and Ubuntu systems. Additionally, the experiment included comparisons between different ad blockers across various websites, as well as between the Windows and Ubuntu operating systems. The hypothesis was that using an ad blocker would reduce overall power consumption by minimizing the processing required for advertisements, particularly when using an AI-accelerated setup.

5.3.1. Hardware and Software Specifications

- Processor Type: AMD Ryzen 9 4900H with Radeon Graphics, 3.30 GHz
- AI Accelerator Model: Nvidia GeForce RTX 2060
- AI Accelerator and Specifications: Built on the 12 nm process, and based on TU106 graphics processor, In its TU106-200-KA-A1 variant, the card supports DirectX 12

Ultimate. The Second generation Tenson Cores (succeeding Volta's) work in cooperation with the RT cores and their AI features

- System Architecture: 64-bit operating system, x64-based processor
- Memory Specifications: Installed RAM: 24.0 GB (23.4 GB usable)
- Network Configuration: Wired network connection, 1.5 Gbps speed
- Operating System and Version:
  - Windows 11 Home, Version 23H2
  - Ubuntu (Version 24.04.1)

Ad Blockers Used:

Tested without an ad blocker and with the following: AdBlock, AdBlock Plus, uBlock, uBlock Origin, and uBlock Origin Lite.

Additional Software/Dependencies:

Web Browser: Latest version of Google Chrome for both Windows and Ubuntu systems.

5.3.2. Measurement Tools

Power Measurement Tool/Method:

- For Windows, HWinfo was used to monitor both CPU and GPU power consumption.
- For Ubuntu, a custom bash script was utilized to log CPU and GPU power, as detailed in the pseudocode below.

Additional Metrics Measured:

- CPU power consumption
- GPU power consumption

- Memory usage

5.3.3. Test Scenarios

Scenarios Tested:

Power consumption without an ad blocker (baseline scenario).

Power consumption with different ad blockers: AdBlock, AdBlock Plus, uBlock, uBlock Origin, and uBlock Origin Lite.

Each scenario was tested on both Windows and Ubuntu systems.

Number of Repetitions for Each Scenario:

The same video was played from the following websites for each ad blocker, and each test was repeated three times for statistical significance:

- 9gag
- ARYzap
- Dailymotion
- Kisscartoon
- YouTube
- Cricbuzz
- Espncricinfo
- TheNews

Comparisons Performed:

- Ad Blockers on Different Websites: Power consumption data was collected for each ad blocker across all the aforementioned websites. This allowed for a comparison of energy efficiency across different ad blockers when exposed to varying content types.
- Windows vs. Ubuntu: The experiment also aimed to compare system power consumption between Windows and Ubuntu operating systems for each scenario, highlighting any differences in how the two systems handle advertisements and ad-blocking software.

5.3.4. Data Collection Procedure

Duration of Each Test Run:

The duration of each test run depended on the length of the video, but the same video length was used for each ad blocker scenario to ensure consistency.

Logging Method:

The data collection procedure for Ubuntu involved a custom script to log CPU and GPU power consumption along with memory usage. The pseudocode below details the methodology used for logging the data:

```
#!/bin/bash
filename="resource_log_$(date).csv"
interations=12
# Check if radeontop is installed
if ! command -v radeontop &> /dev/null; then
    echo "radeontop could not be found. Please install it with: sudo apt
install radeontop"
    exit 1
fi
# Function to get CPU package power
get_cpu_power() {
    sensors | grep 'PPT' | awk '{print $2}'
}
get_nvidia-gpu_power() {
    nvidia-smi --query-gpu=power.draw --format=csv,noheader
}
# Function to get memory usage
get_memory_usage() {
    free -m | grep "Mem" | awk '{print $3}'
}
log_entries=()
# Logging for 12 seconds, checking every second
for (( i=1; i<=interations; i++ )); do
    cpu_power=$(get_cpu_power)
    gpu_power=$(get_nvidia-gpu_power)
    memory_usage=$(get_memory_usage)
    # Create a CSV line
    log_entry="$i,$(date),$cpu_power, $gpu_power,$memory_usage"
    echo "----------------------------------"
    echo "Log Entry: $i, Date: $(date) ,CPU Power: $cpu_power, GPU Power:
$gpu_power, Memory Usage: $memory_usage"
    # Add the entry to the array
    log_entries+=("$log_entry")
    sleep 1  # Wait for 1 second before the next log
done
# Write the results to a CSV file
{
    echo "Log Entry, Date, CPU Power, GPU Power, Memory Usage"  # CSV
```

5.4. Results:

The results of this study are presented to evaluate the impact of different ad blockers on system power consumption for systems with an AI accelerator, comparing the performance on both Windows and Ubuntu operating systems. Specifically, comparisons were made between power consumption without an ad blocker and with different ad blockers (AdBlock, AdBlock Plus, uBlock, uBlock Origin, and uBlock Origin Lite) across various websites.

5.4.1. CPU Power Consumption by Ad Blockers on Windows:

This table shows CPU power consumption (in watts) for different websites using various ad blockers, including Adblock, Adblock Plus, uBlock, uBlock Origin, and uBlock Origin Lite. The goal is to compare the effectiveness of these ad blockers in reducing CPU power usage on Windows.

Table 5.1 CPU Power Consumption by Ad Blockers on Windows

websitws	without Adblock	with Adblock	with AdblockPlus	with uBlock	with ublock Origin	with ublock Origin Lite
9gag	11.2	9.1	10.4	8.5	8.2	8.2
ARYzap	10.3	2.5	10.0	10.0	7.5	9.5
Dailymotion	17.9	10.4	10.6	9.6	10.5	10.0
Kisscartoon	12.4	9.6	10.7	9.2	9.1	9.2
Youtube	4.0	3.8	4.1	5.7	4.2	4.1
Cricbuzz	11.7	11.1	9.6	10.4	9.8	9.6
Espncricinfo	18.6	18.6	17.5	17.4	17.6	17.5
TheNews	11.0	11.2	12.0	10.7	10.8	10.6

uBlock Origin and uBlock Origin Lite consistently resulted in the lowest CPU power consumption across most websites, showing their effectiveness in reducing power usage. For example, 9gag showed a reduction from 11.2 W (without an ad blocker) to 8.2 W with uBlock Origin. In contrast, Adblock Plus demonstrated moderate reductions, while Adblock had mixed performance, especially with ARYzap, where it reduced consumption to 2.5 W.

A stacked bar chart is proposed to illustrate the comparative effectiveness of different ad blockers in reducing CPU power consumption across multiple websites.

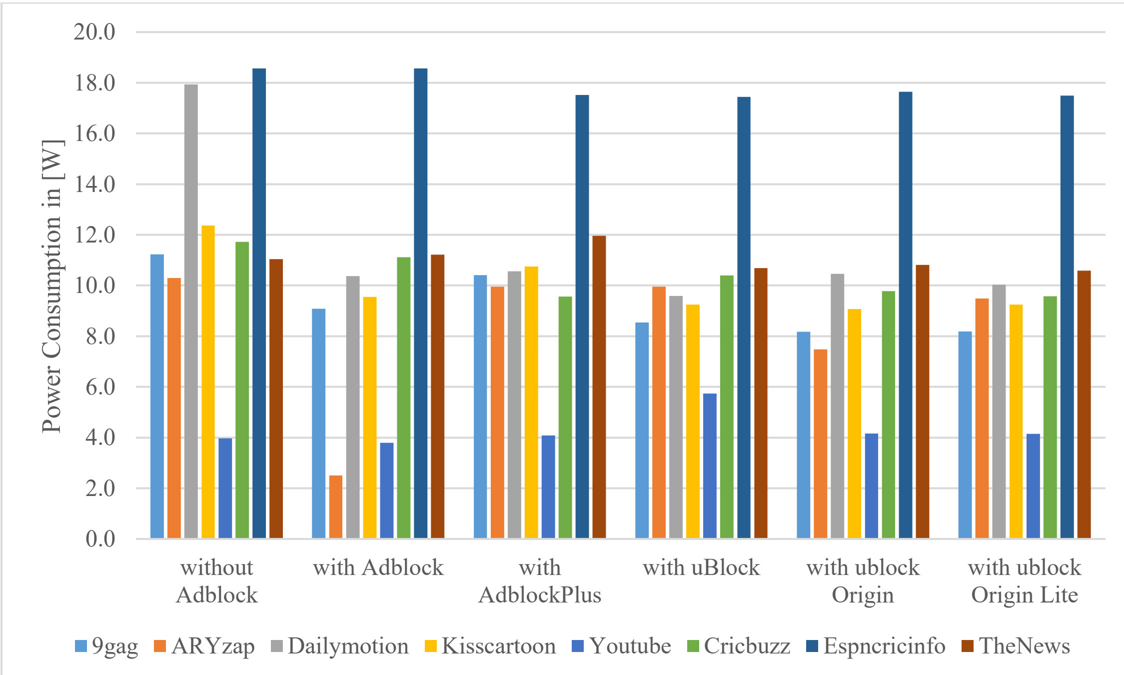

Figure 5.1 Comparison of CPU Power Consumption by Ad blockers on Windows

This visualization highlights the overall reduction in power usage achieved by each ad blocker and provides insights into which websites contribute most to the total power savings. The stacked bar chart effectively conveys both the aggregate impact and individual website-specific efficiency of each ad blocker, making it a comprehensive tool for comparative analysis.

5.4.2. GPU Power Consumption by Ad Blockers on Windows:

This table presents GPU power consumption (in watts) across different websites using various ad blockers, including Adblock, Adblock Plus, uBlock, uBlock Origin, and uBlock Origin Lite. The objective is to evaluate the effectiveness of these ad blockers in reducing GPU power consumption on the Windows operating system.

Table 5.2 GPU Power Consumption by Ad Blockers on Windows

Websites	without Adblock	with Adblock	with AdblockPlus	with uBlock	with ublock Origin	with ublock Origin Lite
9gag	25.3	25.0	24.6	23.8	21.5	23.0
ARYzap	26.4	24.2	25.7	22.2	22.2	25.1
Dailymotion	34.4	28.0	27.6	27.2	24.1	26.0
Kisscartoon	28.6	23.2	25.5	25.1	24.2	23.6
Youtube	11.8	9.9	12.8	14.3	13.0	13.5
Cricbuzz	29.2	28.3	25.1	27.8	24.2	24.2
Espncricinfo	25.0	29.0	29.0	41.3	36.4	37.7
TheNews	35.0	27.3	26.9	32.5	25.3	26.3

From Table 2, uBlock Origin demonstrated the most consistent reduction in GPU power consumption across most websites, such as 9gag and Dailymotion, with notable reductions from 25.3 W (without an ad blocker) to 21.5 W and 24.1 W, respectively. Adblock and Adblock Plus generally showed moderate reductions, while uBlock had mixed results, including increased GPU consumption on Espncricinfo (41.3 W). YouTube showed a reduction in GPU power from 11.8 W without an ad blocker to 9.9 W with Adblock, indicating its efficiency for lighter media content.

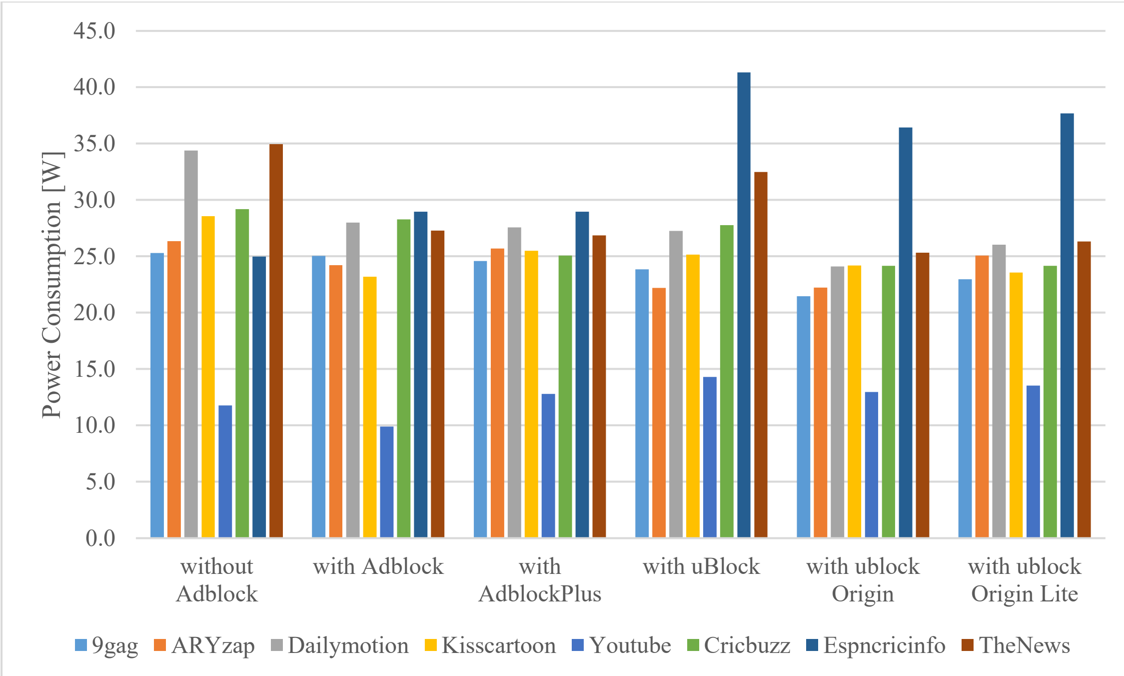

Figure 5.2 Comparision of GPU power Consumption by Add blockers on Windows

Above bar chart is proposed to illustrate the comparative effectiveness of different ad blockers in reducing GPU power consumption across multiple websites.

5.4.3. CPU Power Consumption by Ad Blockers on Ubuntu:

The below table presents CPU power consumption (in watts) across different websites when using various ad blockers, including Adblock, Adblock Plus, uBlock, uBlock Origin, and uBlock Origin Lite, on the Ubuntu operating system. The objective is to compare the effectiveness of these ad blockers in reducing CPU power usage on Ubuntu.

Table 5.3 CPU Power Consumption by Ad Blockers on Ubuntu

Websites	without Adblock	with Adblock	with AdblockPlus	with uBlock	with ublock Origin	with ublock Origin Lite
9gag	20.36585	20.36585	13.60976	13.36585	12.175	10.15
ARYzap	10.83077	12.00833	12.10833	12.26667	12.39167	10.325

Dailymotion	21.84566	12.91489	14.19149	12.55239	11.38298	13
Kisscartoon	12.62069	16.43704	15.68302	15.87925	16.77358	16.21509
Youtube	12.62069	16.43704	15.68302	15.87925	16.77358	16.21509
Cricbuzz	19.55833	13.40833	15.725	13.925	14.68333	13.55833
Espncricinfo	23.53623	22.15942	22.62319	23.5942	21.85507	21.2029
TheNews	12.68333	14.7	13.40833	14.45833	13.44167	14.36667

uBlock Origin Lite and uBlock Origin achieved the lowest CPU power consumption across several websites, notably on 9gag and Dailymotion, reducing the power from 20.37 W (without an ad blocker) to 10.15 W and 11.38 W, respectively. In contrast, Adblock Plus and uBlock showed mixed performance, with some websites (e.g., Espncricinfo) experiencing slightly increased power consumption compared to no ad blocker. This indicates that uBlock Origin Lite was the most energy-efficient option overall on Ubuntu.

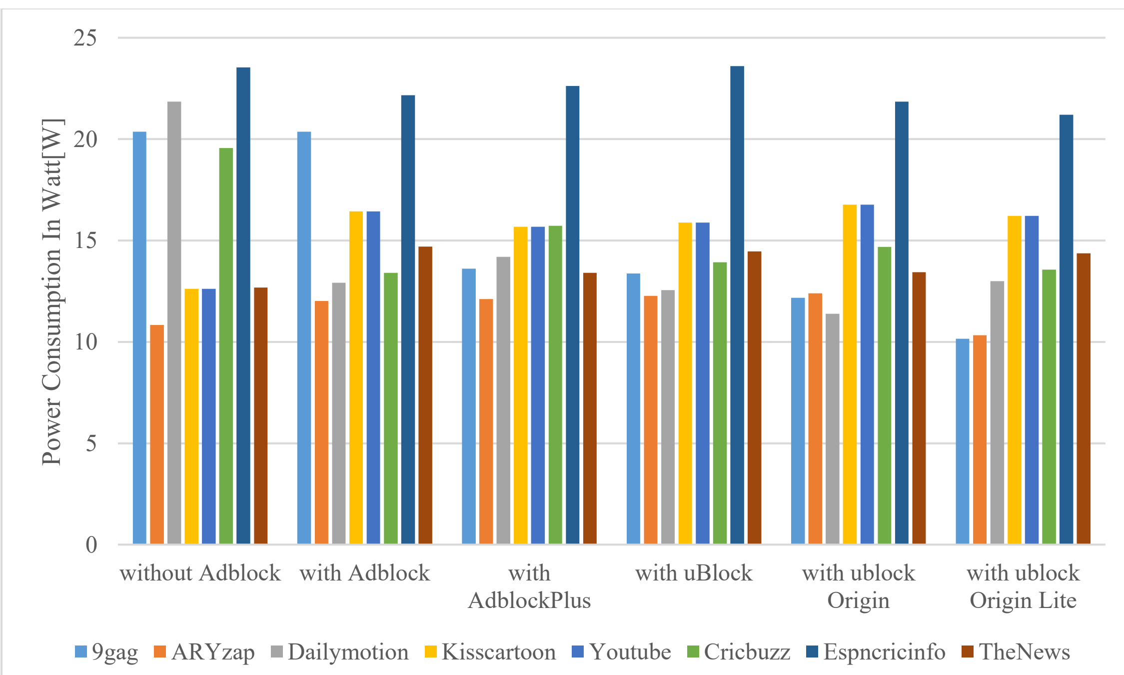

Figure 5.3 Comparison of CPU Power Consumption by Ad blockers on Ubuntu

A stacked bar chart is used to illustrate the comparative effectiveness of different ad blockers in reducing CPU power consumption across multiple websites.

5.4.4. GPU Power Consumption by Ad Blockers on Ubuntu:

This table presents GPU power consumption (in watts) across different websites when using various ad blockers, including Adblock, Adblock Plus, uBlock, uBlock Origin, and uBlock Origin Lite, on the Ubuntu operating system. The objective is to compare the effectiveness of these ad blockers in reducing GPU power usage on Ubuntu.

Table 5.4 GPU Power Consumption by Ad Blockers on Ubuntu

Websites	without Adblock	with Adblock	with AdblockPlus	with uBlock	with ublock Origin	with ublock Origin Lite
9gag	28.24697	15.54487	12.68321	13.96951	13.11368	11.95289
ARYzap	11.46285	17.0395	11.42833	9.560917	9.643083	8.68975
Dailymotion	19.6329	13.51326	8.478333	11.70014	11.39044	14.532
Kisscartoon	12.48525	11.95083	8.859167	11.3735	9.77025	9.95225
Youtube	15.2075	24.37908	23.88533	24.1685	24.80083	24.63283
Cricbuzz	28.932	15.12467	18.04992	13.96042	14.82758	13.6695
Espncricinfo	35.55667	32.83754	33.2113	35.75812	33.97362	33.5758
TheNews	12.3875	16.39342	16.85258	20.1735	16.59958	17.98608

In Table 4**,** uBlock Origin Lite and Adblock Plus demonstrated the most consistent reduction in GPU power consumption for most websites, particularly for 9gag and Kisscartoon, with reductions from 28.25 W (without an ad blocker) to 11.95 W and 8.86 W, respectively**.** ARYzap also showed the lowest GPU power consumption with uBlock Origin Lite at 8.69 W**.** Conversely, YouTube did not show any significant reduction, and GPU power consumption remained similar across all ad blockers.

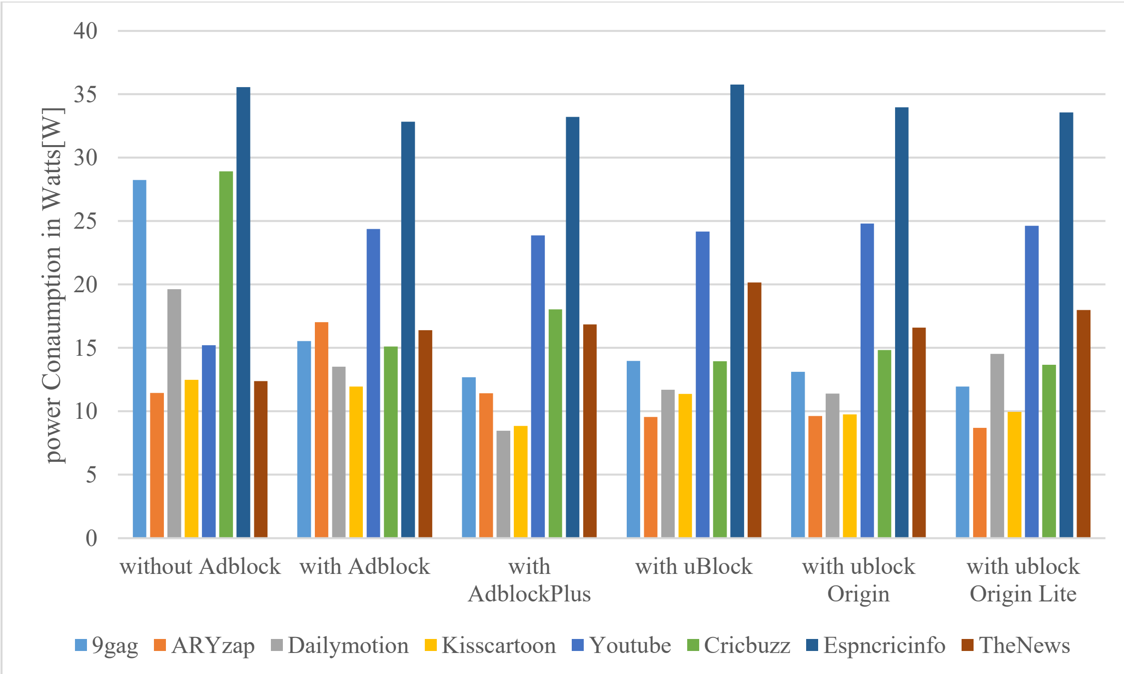

Figure 5.4 Comparison of GPU Power Consumption by Ad blockers on Ubuntu

The graph 4. above provides a visual comparison of the power consumption data across all ad blockers and websites.

5.4.5. Memory Usage by Ad Blockers on Windows (in MBs):

This table 5. below presents the memory usage (in megabytes) for different websites while using various ad blockers, including Adblock, Adblock Plus, uBlock, uBlock Origin, and uBlock Origin Lite, on the Windows operating system. The aim is to compare the effectiveness of these ad blockers in reducing memory usage, which indicates the impact of each ad blocker on system resource efficiency.

Table 5.5 Memory Usage by Ad Blockers on Windows (in MBs):

Websites	without Adblock	with Adblock	with AdblockPlus	with uBlock	with ublock Origin	with ublock Origin Lite
9gag	8106.538	8171.436	8156.769	7886.61	7799.132	7786.368

ARYzap	10592.24	10522.94	10578.93	10497.67	10329.94	10299.97
Dailymotion	11378.77	9039.435	8975.851	8935.417	10452.69	10382.44
Kisscartoon	8014.356	8158.286	8099.026	7699.921	7759.095	7776.5
Youtube	5535.633	5796.438	5879.622	5821.586	10375.21	10342.7
Cricbuzz	8065.493	7958.654	7965.456	7862.528	7902.571	7957.448
Espncricinfo	8372.398	8372.398	8059	7892.362	7858.898	7693.081
TheNews	7975.206	8033.767	8139.765	7880.556	7793.475	7759.271

uBlock Origin and uBlock Origin Lite resulted in the most consistent reduction in memory usage across most websites. For instance, 9gag **s**aw a reduction in memory usage from 8106.54 MB (without an ad blocker) to 7786.37 MB with uBlock Origin Lite**.** Kisscartoon also saw a decrease, with uBlock resulting in the lowest memory usage at 7699.92 MB. Conversely, YouTub**e** exhibited increased memory usage for most ad blockers, with uBlock Origin reaching 10375.21 MB, highlighting potential inefficiencies for multimedia-rich content.

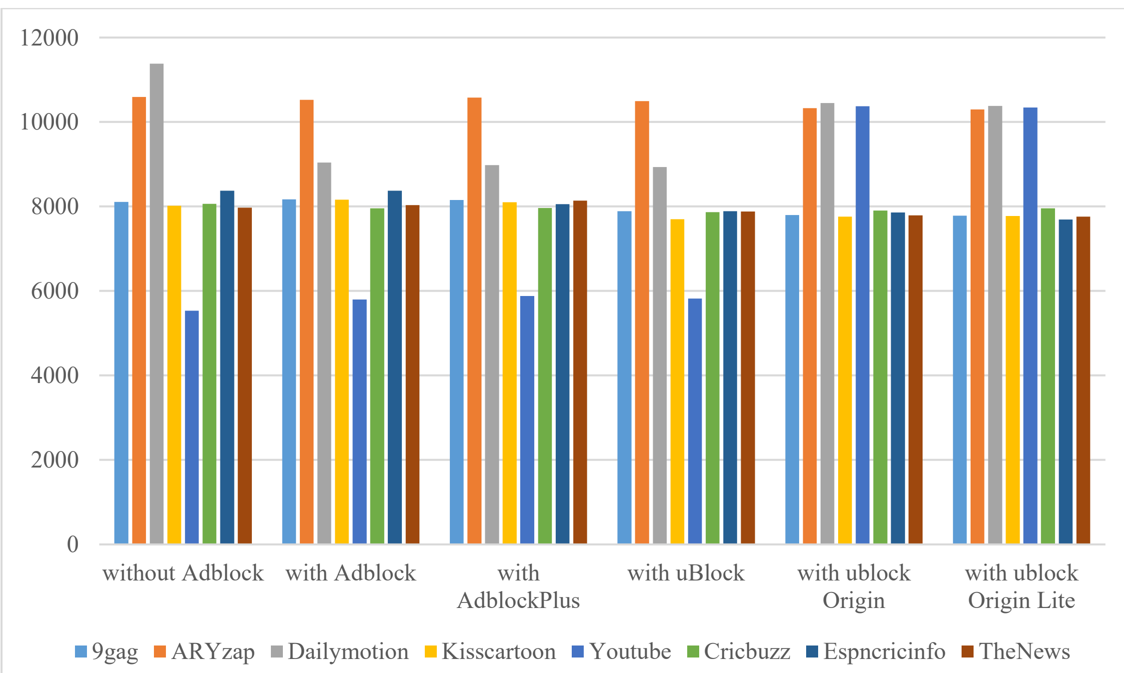

Figure 5.5 Comparison of memory usage by Ad blockers on Windows [MBs]

bar chart has been used to visually compare memory usage for each ad blocker across different websites.

5.4.6. Memory Usage by Ad Blockers on Ubuntu (in MB):

This table presents the memory usage (in megabytes) for different websites while using various ad blockers, including Adblock, Adblock Plus, uBlock, uBlock Origin, and uBlock Origin Lite, on the Ubuntu operating system. The goal is to compare the effectiveness of these ad blockers in reducing memory usage, which provides insight into the system resource efficiency of each ad blocker.

Table 5.6 Memory Usage by Ad Blockers on Ubuntu (in MB):

Websites	without Adblock	with Adblock	with AdblockPlus	with uBlock	with ublock Origin	with ublock Origin Lite
9gag	3248.28	3248.28	3330	3348.32	2876.96	2942.08
ARYzap	3347.077	3341	3516.033	3417.592	3333.267	3277.467
Dailymotion	3552.713	3532.893	3407.667	3187.8	3350.987	3472.947
Kisscartoon	3400.978	3106.45	3129.908	3086.767	3029.767	2960.167
Youtube	3353.459	3641.898	3551.536	3561.985	3561.691	3478.563
Cricbuzz	3611.075	3675.842	3745.183	3675.492	3656.85	3669.558
Espncricinfo	3313.812	3444.348	3864.536	3692.739	3612.638	3128.754
TheNews	3506.458	3658.633	3672.583	3698.392	3714.283	3534.683

From Table 6, uBlock Origin and uBlock Origin Lite demonstrated the lowest memory usage across multiple websites, particularly for 9gag and Kisscartoon, with reductions from 3248.28 MB (without an ad blocker) to 2876.96 MB and 2960.17 MB, respectively. Dailymotion also showed significant reductions with uBlock at 3187.80 MB. In contrast, YouTube and Cricbuzz displayed relatively stable or increased memory usage across all ad blockers, with no major savings observed.

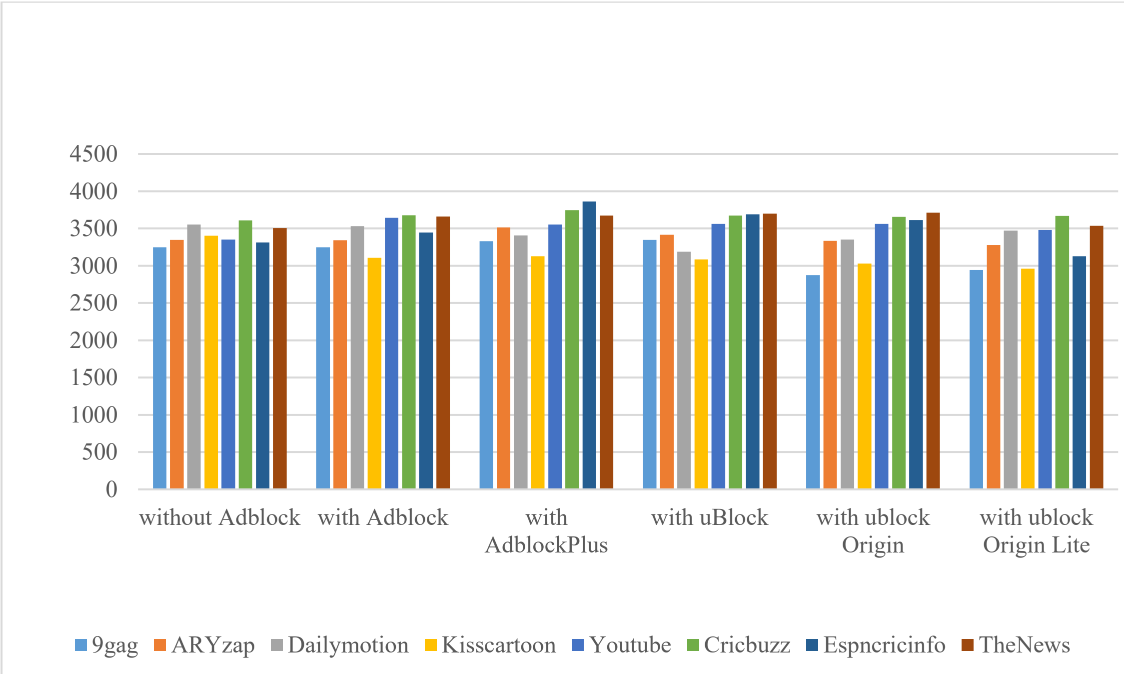

Figure 5.6 Comparison of memory usage by Ad blockers on Ubuntu [MBs]

A stacked bar chart has been employed to illustrate the comparative memory usage of different ad blockers across multiple websites.

The results of this study show that uBlock Origin and uBlock Origin Lite are the most effective ad blockers for reducing CPU and GPU power consumption as well as memory usage across both Windows and Ubuntu. On Windows, uBlock Origin and uBlock Origin Lite reduced CPU power consumption for 9gag by 26.8%, from 11.2 W to 8.2 W, and for Kisscartoon by 26.6%, from 12.4 W to 9.1 W. On Ubuntu, these ad blockers performed even better, reducing CPU power consumption for 9gag by 50.2%, from 20.37 W to 10.15 W, and for Dailymotion by 47.9%, from 21.85 W to 11.38 W.

In terms of GPU power consumption, uBlock Origin and uBlock Origin Lite also achieved significant reductions. On Windows, Dailymotion's GPU consumption decreased by 30%, from

34.4 W to 24.1 W. On Ubuntu, uBlock Origin Lite reduced 9gag's GPU consumption by 57.7%, from 28.25 W to 11.95 W. However, for multimedia-rich websites like YouTube, GPU power consumption increased with most ad blockers, indicating that blocking dynamic video ads can add processing overhead.

For memory usage, uBlock Origin and uBlock Origin Lite consistently reduced consumption. On Windows, Espncricinfo's memory usage decreased by 8.1%, from 8372.40 MB to 7693.08 MB with uBlock Origin Lite. On Ubuntu, Kisscartoon's memory usage dropped by 12.9%, from 3400.98 MB to 2960.17 MB with uBlock Origin Lite. However, for YouTube, memory usage increased significantly, indicating potential inefficiencies in handling complex ad content.

Overall, uBlock Origin and uBlock Origin Lite were the most efficient in reducing power and memory usage, with Ubuntu generally showing better results than Windows. Multimedia-heavy websites, however, presented challenges, often resulting in increased resource usage due to the processing overhead involved in blocking dynamic ads. These results highlight the importance of choosing the right ad blocker based on the type of content and operating system to achieve the best energy efficiency and resource optimization.

5.5. Conclusion and Future Work:

The findings from this study provide valuable insights into the effects of ad blockers on system power consumption in computing environments equipped with AI accelerators. uBlock Origin and uBlock Origin Lite consistently outperformed other ad blockers, resulting in the most substantial reductions in both CPU and GPU power consumption as well as memory usage on both Windows and Ubuntu. On Windows, the CPU power consumption for websites like 9gag was reduced by 26.8% using uBlock Origin. Similarly, GPU power consumption on Ubuntu saw a 57.7% reduction for 9gag using uBlock Origin Lite. These results demonstrate that AI accelerators, when combined with the right ad blockers, can effectively optimize power usage. However, the analysis also highlighted that multimedia-rich websites, such as YouTube, did not experience significant power reductions. Instead, resource usage increased due to the overhead of processing dynamic video content. This suggests that ad blockers introduce additional processing requirements when handling multimedia advertisements, which can lead to inefficiencies.

Overall, the study concludes that uBlock Origin and uBlock Origin Lite are the most effective ad blockers in terms of energy efficiency. Moreover, Ubuntu generally demonstrated better results than Windows, indicating that operating system choice plays a significant role in resource optimization. The results emphasize the need for careful selection of ad blockers based on content type and system architecture to achieve the best energy efficiency. This research has implications for developers of ad-blocking technologies, system manufacturers, and end-users seeking to maximize energy efficiency and system performance.

To build upon the findings of this study, further exploration is warranted across a wider array of hardware configurations to enhance the understanding of ad blockers' impact. Systems equipped with advanced technologies such as next-generation Tensor Processing Units, Neural Processing Units, and emerging architectures like RISC-V could be examined to determine the scalability of energy-saving capabilities in line with evolving hardware. Similarly, the observed differences in energy efficiency between Windows and Ubuntu emphasize the need to investigate additional operating systems, including macOS, ChromeOS, and mobile platforms like Android and iOS, to evaluate their role in optimizing resource consumption across various environments.

Analyzing a more diverse set of ad blockers, particularly those utilizing innovative techniques such as heuristic-based blocking, AI-driven detection, script filtering, and perceptual ad blocking, would allow for a deeper assessment of their methodologies and effectiveness. Moreover, understanding the implications of aggressive versus conservative ad-blocking settings on energy efficiency could reveal the trade-offs between maximum resource optimization and user experience, providing valuable guidance for developers in refining their algorithms.

Network conditions play a crucial role in determining power consumption, especially during activities like media streaming, where connectivity variations can significantly influence energy use. Testing ad blockers under different network scenarios, such as high-speed Wi-Fi, 4G/5G cellular networks, and limited bandwidth environments, would offer critical insights into their performance in real-world situations. Additionally, optimizing ad-blocking algorithms to handle multimedia content more effectively is essential. Leveraging AI-powered detection methods to reduce processing overhead while exploring pre-processing and caching techniques could enhance the energy efficiency of managing dynamic advertisements.

Emerging technologies such as blockchain and decentralized content delivery networks present new opportunities to complement ad-blocking solutions. Blockchain's potential to improve transparency and efficiency in ad delivery systems could reduce resource demands, while decentralized networks may contribute to creating more sustainable digital ecosystems. Investigating these possibilities could lead to groundbreaking advancements in the field.

To provide a holistic understanding, future studies should integrate power consumption metrics with analyses of network traffic, data usage, and carbon footprints. Such comprehensive evaluations would offer invaluable insights for developers, system architects, and policymakers striving to create more sustainable and efficient digital environments. These efforts would support the development of advanced, user-centric ad-blocking technologies that balance energy efficiency with performance, contributing significantly to global sustainability objectives.

References

[1] Mishra, J. Cha, H. Park, and S. Kim, Artificial Intelligence and Hardware Accelerators. Cham, Switzerland: Springer, 2023.

[2] Y.-H. Chen, T. Krishna, J. S. Emer, and V. Sze, "Eyeriss: An energy-efficient reconfigurable accelerator for deep convolutional neural networks," IEEE J. Solid-State Circuits, vol. 52, no. 1, pp. 127–138, Jan. 2017.

[3] S. Choi, J. Sim, M. Kang, Y. Choi, H. Kim, and L. S. Kim, "An energy-efficient deep convolutional neural network training accelerator for in situ personalization on smart devices," IEEE J. Solid-State Circuits, vol. 55, no. 10, pp. 2691–2702, Oct. 2020.

[4] J. Lee, C. Kim, S. Kang, S. Lee, J. Won, H. Lee, et al., "UNPU: An energy-efficient deep neural network accelerator with fully variable weight bit precision," IEEE J. Solid-State Circuits, vol. 54, no. 1, pp. 173–185, Jan. 2019.

[5] L. Song, X. Qian, H. Li, and Y. Chen, "Pipelayer: A pipelined ReRAM-based accelerator for deep learning," in Proc. IEEE Int. Symp. High Perform. Comput. Archit. (HPCA), 2017, pp. 541–552.

[6] S. K. Cherupally, N. Ramaswamy, J. Juma, Y. Ye, A. V. Yadav, R. Govindan, et al., "In-memory computing for AI accelerators: Challenges and solutions," Semicond. Sci. Technol., vol. 37, no. 3, p. 034001, 2022.

[7] H. Kwon, A. Samajdar, and T. Krishna, "MAERI: Enabling flexible dataflow mapping over DNN accelerators via reconfigurable interconnects," in Proc. 23rd Int. Conf. Archit. Support Program. Lang. Oper. Syst. (ASPLOS), 2018, pp. 461–475.

[8] A. Reuther, P. Michaleas, M. Jones, J. Kepner, S. Samsi, and V. Gadepally, "Survey of machine learning accelerators," in Proc. IEEE High Perform. Extreme Comput. Conf. (HPEC), 2020, pp. 1–12.

[9] Jiang, J. Li, F. Liu, W. Gao, L. Wang, C. Lan, et al., "A systematic study on benchmarking AI inference accelerators," CCF Trans. High Perform. Comput., vol. 4, pp. 87–103, 2022.

[10] M. Capra, B. Bussolino, A. Marchisio, M. Shafique, and G. Masera, "An updated survey of efficient hardware architectures for accelerating deep convolutional neural networks," Future Internet, vol. 12, no. 7, p. 113, Jul. 2020.

[11] M. Capra, B. Bussolino, A. Marchisio, E. Macii, M. Martina, G. Masera, et al., "Hardware and software optimizations for accelerating deep neural networks: Survey of current trends, challenges, and the road ahead," IEEE Trans. Comput., vol. 70, no. 8, pp. 1197–1212, Aug. 2021.

[12] M. R. Azghadi, C. Lammie, J. K. Eshraghian, L. Wang, and O. Kavehei, "Hardware implementation of deep network accelerators towards healthcare and biomedical applications," IEEE Trans. Circuits Syst. I, vol. 67, no. 8, pp. 2626–2637, Aug. 2020.

[13] M. Himeur, B. Bensaali, A. Amira, A. Bourguiba, M. Elhoseny, and F. Karray, "AI-empowered methods for smart energy consumption: A review of load forecasting, anomaly detection, and demand response," Int. J. Precis. Eng. Manuf.-Green Technol., vol. 10, no. 1, pp. 25–45, Jan. 2023.

[14] A. Mirhoseini, A. Goldie, M. Yazgan, J. W. Jiang, E. Songhori, S. Wang, et al., "A graph placement methodology for fast chip design," Nature, vol. 594, pp. 207–212, Jun. 2021.

[15] L. Ke, U. Gupta, B. Y. Cho, D. Brooks, C. Wu, and H. S. Lee, "RecNMP: Accelerating personalized recommendation with near-memory processing," in Proc. ACM/IEEE 47th Annu. Int. Symp. Comput. Archit. (ISCA), 2020, pp. 790–803.

[16] A. Ray, H. Ghasemkhani, and K. N. Kannan, "Ad-blockers, advertisers, and internet: The economic implications of ad-blocker platforms," in Proc. Int. Conf. Inf. Syst. (ICIS), 2017.

[17] B. Datta and L. Madio, "Effects of ad-blockers adoption on digital piracy: A blessing or a curse?," LCII Working Paper 2017-5, 2017.

[18] A. Frik, A. Haviland, and A. Acquisti, "The impact of ad-blockers on consumer behavior: A lab experiment," in Proc. 18th Workshop Econ. Inf. Secur. (WEIS), 2019.

[19] M. Aseri, M. Dawande, and G. Janakiraman, "Ad-blockers: A blessing or a curse?," Inf. Syst. Res., vol. 31, no. 3, pp. 889–908, Sep. 2020.

[20] J. M. Pearce, "Energy conservation with open source ad blockers," Technologies, vol. 8, no. 2, p. 27, Jun. 2020.

[21] N. Heitmann, B. Pirker, and S. Park, "Towards building better mobile web browsers for ad blocking: The energy perspective," in Proc. ACM SIGPLAN Int. Symp. New Ideas, New Paradigms, Reflections Program. Softw. (Onward!), 2020, pp. 80–90.

[22] A. Albasir, K. Naik, and B. Plourde, "Experimental study of energy and bandwidth costs of web advertisements on smartphones," in Proc. 11th IEEE Int. Conf. Mobile Ad Hoc Sens. Syst. (MASS), 2014, pp. 693–698.

Chapter 6. Conclusion and Future Work

6.1. Conclusion

This research comprehensively examined the impact of ad-blockers on power consumption in various web browsing environments, focusing on ARM-based CPUs, AI accelerators, and web browsers with built-in ad-blocking capabilities. The studies revealed that ad-blockers play a significant role in optimizing energy use by reducing the computational overhead associated with processing and displaying online advertisements. For ARM-based systems, which are commonly used in mobile and low-power devices, ad-blockers like uBlock Origin and Brave's built-in ad-blocker have shown to significantly reduce power consumption. These reductions are especially pronounced on multimedia-heavy websites, where the energy demands are high due to the processing of rich media content such as videos and animations. The use of ad-blockers in such scenarios effectively lowers CPU and GPU workload, contributing to longer battery life and enhanced system performance. In systems utilizing AI accelerators, such as Tensor Processing Units (TPUs) and Neural Processing Units (NPUs), ad-blockers have demonstrated further improvements in energy efficiency. AI accelerators handle ad-blocking tasks more efficiently than traditional CPU/GPU combinations, allowing for even greater power savings, particularly when dealing with complex, resource-intensive web content. This highlights the potential of integrating AI-powered solutions into ad-blocking technologies to further enhance energy optimization during web browsing. Additionally, browsers with built-in ad-blockers, such as Brave and Librewolf, were found to be more energy-efficient compared to traditional browsers like Chrome and Firefox that rely on third-party ad-blocking extensions. Built-in ad-blockers, due to their deep integration within the browser architecture, can block ads more efficiently, leading to reductions in CPU and

GPU power consumption by up to 44%. This study underscores the importance of selecting energy-efficient browsers and ad-blocking solutions to not only improve user experience but also to significantly reduce the environmental impact of digital activities by lowering overall power usage. The findings from these four studies collectively demonstrate that the combination of ad-blockers with advanced hardware solutions, including ARM processors and AI accelerators, presents a practical approach to achieving more sustainable and energy-efficient computing practices in the digital age.

6.2. Research Contribution

This thesis provides valuable insights and solutions to the growing problem of power consumption during web browsing, especially in the context of ad-blockers and advanced hardware solutions.

- **Comprehensive Analysis of Ad-Blockers and Their Impact on Power Consumption:**

  The thesis provides an in-depth comparison of widely used ad-blockers, including AdBlock, AdBlock Plus, uBlock, uBlock Origin, and uBlock Origin Lite. It highlights the significant reductions in CPU and GPU usage achieved by ad-blockers like uBlock Origin Lite, particularly on resource-intensive, media-heavy websites. This analysis emphasizes the importance of selecting the appropriate ad-blocker to optimize energy efficiency during web browsing.

- **Evaluation of Built-in Ad-Blockers versus Third-Party Extensions:**

  By comparing built-in ad-blockers in browsers like Brave and Librewolf with third-party extensions commonly used in Chrome, the research demonstrates that built-in ad-blockers are more energy-efficient. Their deeper integration into browser architectures reduces CPU and GPU loads more effectively, resulting in lower power consumption. This finding provides practical recommendations for users to choose browsers with integrated ad-blocking features for enhanced energy savings and improved browsing performance.

- **Impact of Ad-Blockers on ARM-Based CPUs:**

  The study examines the influence of ad-blockers on ARM-based CPUs, which are prevalent in mobile and low-power devices. It reveals that ad-blockers, such as uBlock Origin, can significantly decrease power consumption, thereby extending battery life and enhancing system efficiency. This contribution offers actionable insights for optimizing power usage on ARM-based systems, which is particularly relevant for mobile and embedded environments.

- **Integration of AI Accelerators with Ad-Blockers for Energy Efficiency:**

  A novel contribution of this thesis is the exploration of AI accelerators, including Tensor Processing Units (TPUs) and Neural Processing Units (NPUs), to improve the energy efficiency of ad-blockers. The research shows that AI-accelerated systems can handle ad-blocking tasks more effectively than traditional CPU/GPU setups, leading to significant power savings, especially on resource-heavy websites. This finding underscores the potential of integrating AI hardware with ad-blocking technologies in high-performance computing environments where energy efficiency is critical.

- This solution demonstrates the potential of integrating AI hardware with ad-blockers to improve energy efficiency, particularly in high-performance computing environments where power consumption is a critical concern.

6.3. Future Work

While the current research provides a solid foundation, there are several areas that require further exploration to fully realize the potential of ad-blocking technologies in reducing power consumption. First, deeper integration of artificial intelligence into ad-blockers represents a promising frontier. AI-enhanced ad-blockers could potentially predict and block ads -more efficiently by learning from browsing patterns and content types, leading to even lower power consumption. Additionally, advanced AI models could allow for the dynamic adjustment of ad-blocking intensity based on the type of device or network being used, further optimizing energy use in real-time. Emerging web technologies, such as dynamic and interactive advertisements, present new challenges that need to be addressed in future research. These types of ads are more resource-intensive and may require new approaches to blocking them without negatively affecting user experience or increasing computational load. Future work should focus on how ad-blockers can be adapted to handle these evolving technologies while continuing to reduce power consumption. Furthermore, expanding the scope of this research to different platforms, such as cloud-based services, desktops, and Internet of Things (IoT) devices, would provide a more comprehensive understanding of the scalability and effectiveness of ad-blockers across a wide range of hardware and software environments.

Investigating the use of ad-blockers in data centers, where large-scale ad delivery and processing occur, could reveal significant opportunities for energy savings on a broader scale. In terms of environmental impact, future studies should quantify the long-term benefits of widespread ad-blocker adoption. While the current research shows immediate power savings, future work could calculate the cumulative environmental impact of global ad-blocker usage, including the potential reduction in carbon emissions. Such assessments could provide powerful evidence for promoting the broader adoption of energy-efficient ad-blocking technologies as part of a global sustainability effort. Additionally, user behavior plays a critical role in the effectiveness of ad-blockers. Understanding how users interact with ad-blockers—such as how they select, configure, and use these tools—can inform the development of more intuitive, user-friendly ad-blockers that maximize power savings without requiring complex configurations.

Moreover, further investigation into user education regarding the benefits of ad-blockers, particularly in regions with high energy costs, could drive more widespread adoption of energy-efficient browsing habits. Finally, further optimization of built-in ad-blockers, particularly in browsers like Brave and Librewolf, could be pursued to enhance their energy-saving capabilities even further. Integrating more advanced machine learning models, refining their filtering mechanisms, and ensuring seamless operation across different hardware configurations—such as ARM-based devices and AI-accelerated systems—could lead to the development of even more powerful, energy-efficient web browsing solutions that align with global sustainability goals.

Articles in Refereed Publications

- **KA Khan**, MT. Iqbal, M. Jamil, " Impact of Ad Blockers on Computer Power Consumption while Web Browsing: A Comparative Analysis" Accepted in *European Journal of Electrical and Computer Engineering*, September 2024.
- **KA Khan**, MT. Iqbal, M. Jamil, " The Impact of Built-in Ad-Blockers in Web Browsers on Computer Power Consumption" Accepted in *European Journal of Information Technologies and Computer Science*, October 2024.
- **KA Khan**, MT. Iqbal, M. Jamil, " Computer power consumption while using ad blocker on a system with AI accelerators" Accepted in *European Journal of Information Technologies and Computer Science, October 2024.*

Regional Conference Publications

- **KA Khan**, MT. Iqbal, M. Jamil, " Power Consumption While Using Ad-Blockers on ARM-Based CPU" Accepted in *the 33rd Annual Newfoundland Electrical and Computer Engineering Conference (NECEC), 2024.*