Calculating the carbon emissions of Dutch national government websites

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ABSTRACT

In the last few years, the world has become very dependent on the internet and on visiting websites using the internet. A big problem with this is that electricity is consumed each time a user visits and interacts with a website. Considering that most data centres are not running on green electricity, carbon is emitted whenever a user visits and interacts with a website. Motivated by the need to understand the environmental footprint of digital services we investigate the cost of visiting and interacting with websites of the Dutch national government in terms of carbon emissions in this paper. We found that 1103 out of the 1748 websites hosted by the Dutch national government are verified to be green. To estimate the carbon emissions of a typical browsing session we simulated[1] a representative browsing session for 595 websites, where we recorded the amount of traffic produced by this session. Based on this we found that the average CO2 emission for a representative browsing session is 0.015 grams of CO2. On average, the biggest opportunity for improvement was improving the page rendering of the websites.

KEYWORDS

carbon emissions, environmental impact, automation, simulation

1 INTRODUCTION

Over the years, we have become increasingly dependent on the internet. One of the main usages of the internet is visiting websites. We use websites in our daily lives for topics ranging from leisure to obtaining important information. However, there is one big downside to using the internet, which is that it consumes a lot of electricity. As the world we live in is not running on sustainable energy, this means that making use of the internet emits carbon. The current carbon emissions of websites and services account for 1.3% of worldwide emissions[13]. The carbon emissions of websites and services are produced by, among others, data centres and networking infrastructure. Given that the digital industry is still growing, there will be more data centres and the networking infrastructure will continue to grow.

In 2021, the total CO2 emissions of The Netherlands were 143.9 billion kg[8]. Data centres emitted a total of 395.2 million kg CO2[17]. These emissions are causing the world to approach an average global warming of 1.5°C in 2025. To reduce the risks and impact of climate change, it is critical to stay below 2°C above pre-industrial levels[20].

Even though there already exist websites like Ecograder[2] and Website Carbon[9], there has not been any research on simulating actual browsing sessions automatically. There has been research on performing this kind of research manually, however, that is not viable given the scale of the internet. Therefore, it is important to create tooling that can help with automating this kind of research. Given the size of the needed tooling, this paper will only create a small part of it. However, this will provide a starting point that can be expanded upon by further research. This paper aims to provide insights into the carbon emissions of Dutch national government websites, to help reduce them.

In order to do so, this paper aims to address the following research question: *What is the cost of visiting and interacting with the websites of the Dutch national government, in terms of carbon emissions?*

To answer this main research question, we need to find answers to the following sub-questions:

SQ1: What party or parties host the Dutch national government websites? How green are the data centres of these parties? Are there big differences between government departments?

SQ2: What are the carbon emissions of an average browsing session on each Dutch national government website, calculated in an automated way?

To provide additional insight, the following sub-question was also added:

SQ3: What are ways for the Dutch national government to improve upon the carbon footprint of their websites?

This paper is organised as follows. Section 2 will provide a brief overview of previous work related to this research. After that, the methodology is described in Section 3. Following up on the methodology are the results in Section 4, after which the limitations and the results of this paper are discussed in Sections 5 and 6. Finally, the paper is concluded in Section 7.

2 RELATED WORK

Starting with the research most relevant to this, Jeltes[16] researched whether hosting providers located in The Netherlands use renewable energy to host their websites. For this, the hosting locations of the top 1 million most visited domains and the domains hosted by the Dutch government were looked up in the dataset of the Green Web Foundation. Only 29% of the approximately 80,000 domains examined are hosted using renewable energy, and 53.1% of the 1718 Dutch government domains are hosted using renewable energy.

[1]https://gitlab.utwente.nl/s2832461/calculating-the-carbon-emissions-of-dutch-national-government-websites

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Next up, the carbon foorptint of Spanish university websites was investigated[21]. For this, the carbon emission data was obtained from Website Carbon[9]. Next up, the carbon footprint of each Spanish university website was calculated using this data and the number of enrolled students. The findings show that only 17% of the university websites can be considered environmentally friendly.

In their thesis, Fahlström and Persson[15] have shown that there is a significant improvement achievable by making adjustments to websites. Some of the influential items that they changed were the font, video autoplay and colour theme. To show their findings, they compared a website simulating the average of websites they studied to a comparable website they made which incorporated sustainable design principles. Both websites were given to Ecograder[2], where the score improved from 74 to 93.

The state of knowledge of developers about the carbon footprint of software and how developers currently control the carbon footprint of their software has been identified in research by Lyu[19]. Next to that, they developed an automated carbon footprint reduction tool making use of genetic programming. It turns out that no participant in their survey has a lot of knowledge about the carbon footprint of software, while only some have some knowledge. Next to that, most of their survey participants did not take action to reduce the carbon footprint of their software, only lowering it through resource usage reduction. Their automated carbon reduction tool managed to reduce the quantity of data transferred by around 40%.

The carbon footprint of the top 100 most popular Polish e-shops was analysed by Wasilewski and Kołaczek[23]. To do their calculations, they made use of the assumptions suggested by the Sustainable Web Design community. Data about the website visit was gathered using the Google PageSpeed Insights API. Data about the greenness of the data centre where the website was hosted was obtained from the Green Web Foundation. Finally, they used formulas proposed by the SWD to calculate the carbon footprint of a webpage with a small alteration to include renewable energy sources in powering data centres. They found out that the carbon emitted increases linearly for most e-commerce sites, but that this is not the case for about 10% of the worst sites, where outliers emit a lot more carbon.

Finally, Yordanova[24] modelled web browsing energy intensity data over time and combined it with regional grid carbon intensity data and user traffic to estimate the emissions from different websites. The carbon emissions were calculated using CO2.js[1], whilst adapting the emission for the operational energy intensity. It was found that high-traffic websites with rich media content exhibit higher emissions compared to simpler interfaces.

3 METHODOLOGY

This Section presents the approach used for answering each subquestion listed in Section 1. After all the sub-questions have been answered, the main research question will be answered using the answers obtained from the sub-questions. Figure 1 presents a flow chart depicting the process for answering the three sub-questions.

3.1 On answering SQ1

The first and second parts of SQ1 are answered by making use of the list of websites hosted by the Dutch national government[25]. All URLs listed on this website are visited, which means that sometimes a specific page on the website is visited. The first step was to obtain all IP addresses from the domain name. This was done using the *host* command available on Unix systems. Next up, the MaxMind GeoLite2[6] dataset was used to obtain the location and the Autonomous System information of the hosting party. For this research, the following information in the dataset proved to be relevant:

- IP address to Autonomous System
- Autonomous System to city
- Autonomous System to country

Then, all domains obtained were put in the dataset of the Green Web Foundation[4]. The Green Web Foundation has been verifying whether hosting providers are green since 2006 and publishes a dataset where the greenness of a website can be determined based on the URL. In this dataset, a website is either verified to be green, or not. It should be noted that this dataset might be incomplete, as hosting providers have to verify the greenness of their data centre proactively. When a website is verified, it means that the owner of that website has shown proof to the Green Web Foundation that one of the following cases is true for hosting the website (adapted from the Green Web Foundation[4]):

- The equipment is running on 100% green energy from its own infrastructure, the amount of CO2 emitted by the grid is less than 20g CO2e/kWh or the grid uses over 99% renewable power.
- The hosting provider pays for green energy to cover the non-green energy, the hosting provider purchases environment attribute certificates or has guarantees of origin or the hosting provider directly funds renewable energy projects.
- The hosting provider purchases quality carbon offsets to cover the non-green energy it uses or resells or actively uses a provider that is already in the Green Web Dataset.

The third part of SQ1 was answered based on its first and second parts, and by looking up to which department each URL belongs, which is available in the list of websites from the Dutch national government.

3.2 On answering SQ2

To answer SQ2, the same list of websites hosted by the Dutch national government[25] used to answer SQ1 is used. This means that for some websites, not the homepage but a specific page indicated on the list is visited. On each of these websites, a browsing session is simulated using a Python[12] script[2] running Selenium[11]. Selenium is configured to use the Firefox[10] web driver, where the settings visible in 1 were adjusted in *about:preferences*.

To simulate a browsing session, the following steps were followed:

(1) Load the homepage.
(2) Find search box.

[2]https://gitlab.utwente.nl/s2832461/calculating-the-carbon-emissions-of-dutch-national-government-websites

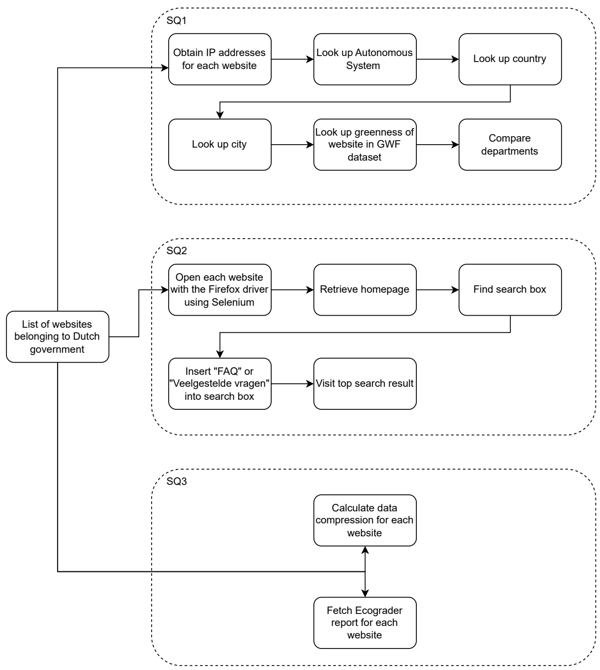

Figure 1: Process for answering all three sub-questions.

Setting	Value
browser.cache.disk.enable	false
browser.cache.memory.enable	false
browser.privatebrowsing.autostart	true
devtools.cache.disabled	true

Table 1: Modified settings for Firefox.

(3) Perform a search query for the word *FAQ*, or, if no results are found, for *Veelgestelde vragen*.
(4) Open the top result that was found by performing the search query.

We chose these steps to represent a small browsing session from a user visiting the website. We assume that the user first visits the homepage and reads that very briefly. After that, we assume that the user will perform a search query, as we assume that users often go to a website looking for a specific piece of information. The choice for searching for *FAQ* and *Veelgestelde vragen* was made based on the expectation that most websites will return a page for this.

For each website, Selenium reopened the Firefox browser. This is done in order to prevent websites from influencing each other's results, which is achieved by configuring the browser to always start in private browsing mode. In addition, caching was disabled to keep the results consistent. When the Python script is run, each website from the list of websites from the Dutch national government is visited. For each website, the homepage is retrieved. In case the homepage loads within 10 seconds, the script attempts to find the search box using different XPATH queries. It should be noted that these were created on a best-effort basis, where the goal was to keep them as generic as possible. This decision was made based on the number of websites that this research takes into account. In case a search box was found, the text *FAQ* was inserted into the search box together with the enter key. If no result is found, Selenium navigates back to the homepage, retrieves the search box again, and inserts the Dutch alternative of *FAQ*, which is *Veelgestelde vragen*. To ensure correctness, the measurements are restarted in case this happens. After searching for the query, the top search result was visited, in case this was found. Once again, the results were obtained using XPATH queries.

During this browsing session, we record the transfer size of each page, the uncompressed size of each page and the URL. It is important to collect both the transfer size and the uncompressed size of each page, as they may differ. The transfer size (TS) and uncompressed size are collected using the PerformanceResource-Timing interface[7], where these properties are called *transferSize* and *decodedBodySize*. Using the data points mentioned above, we calculate the estimated carbon emissions using the methodology of Sustainable Web Design[3]. The carbon emissions are dependent on the operational emissions of the data centre (OP_{DC}), a green hosting factor which can be either 0 when a data centre is not green or 1 when a data centre is green, the operational emissions of the network equipment (OP_N) and the carbon intensity of the grid (CI). The formula used is as follows:

$$\text{Emissions per visit} =$$
$$(OP_{DC} * (1 - \text{Green Hosting Factor}) * TS + OP_N * TS) * CI$$

We altered the original formula to leave out embodied emissions and data caching, as those are not of interest to this research. We are using a number for the operational emissions of data centres from Sustainable Web Design, which is 0.055 kWh/GB. The operational emissions of network equipment are approximately 0, as all three big telecommunication companies in the Netherlands use 100% renewable energy[18]. The network equipment covers the distance between the data centre and the house of the visitor of the website. The carbon intensity of the Dutch grid is 300 gCO2/kWh[22].

3.3 On answering SQ3

To answer SQ3, we make use of the data collected during the answering of SQ1 and SQ2 and use advice from Ecograder[2]. Ecograder is a service which scores web pages based on a variety of performance, efficiency and user experience factors. When a website is queried, Ecograder returns a report. This report includes a general score which takes all other elements in the report together. Next to that, there are a lot of proposals on how to improve the score and therefore the carbon rating of the website. These proposals are split up into three key areas: performance, user experience and green hosting.

4 RESULTS

4.1 Hosting parties

First, we looked up the Autonomous System (AS) for each URL and therefore for each IP address in the Maxmind[6] dataset. This gives information about the owner of the AS and the AS number.

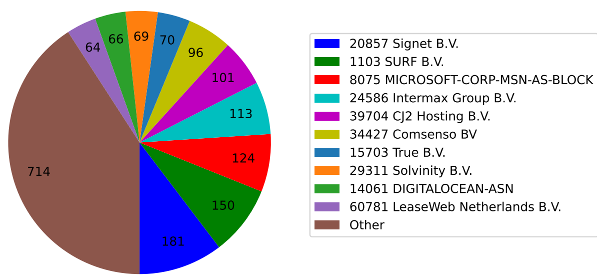

Figure 2: Distribution of Dutch government domains over different Autonomous Systems, showing the number of URLs for each Autonomous System.

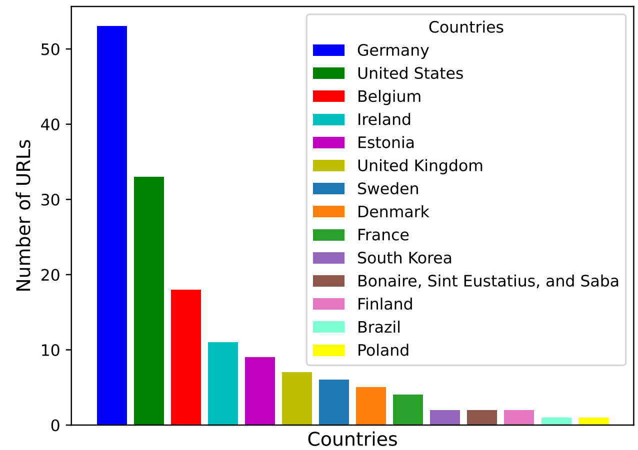

Figure 3: Distribution of Dutch government domains over different countries, excluding the Netherlands.

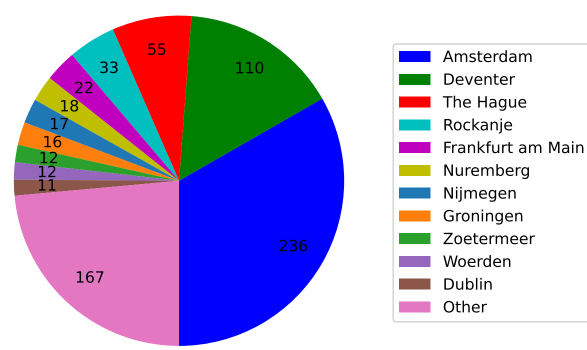

Figure 4: Distribution of Dutch government domains over different cities, excluding unknowns.

The 1748 domains hosted by the Dutch national government are spread out over 100 different AS. Most of the domains of the Dutch national government, 181 in total, are hosted by an AS owned by Signet B.V.. Following closely is SURF B.V., who are hosting 150 domains for the Dutch national government. A full overview can be seen in Figure 2. Interestingly, not all subdomains are hosted in the same AS as their corresponding second-level domain. 263 subdomains are hosted at a different AS than their corresponding second-level domain name, whereas 134 are in the same AS. The AS obtained are spread out over multiple geographical locations. The domains are spread out over 15 different countries, where most are hosted in The Netherlands: 1594. As can be seen in Figure 3 (where the Netherlands has been omitted for readability), Germany hosts the second most domains, followed by the United States. Interestingly, not all websites owned by the Dutch national government are geographically close. There are two websites hosted in South Korea, which are "dutchculturekorea.com" and "dutchdubai.com". Both of these websites belong to the department "Ministerie van Buitenlandse Zaken", or the Ministry of Foreign Affairs. In addition, neither of those domains is verified to be green. Another noteworthy website is "nbso-brazil.com.br", which is owned by "Ministerie van Economische Zaken en Klimaat", or the Ministry of Economic Affairs and Climate. This website is hosted in Brazil and even has the .br top-level domain. This website is not verified to be green, similar to the two websites hosted in South Korea. Making use of the AS to city relation in the dataset, we observed that the AS are spread out over multiple different cities. The dataset does not always provide a city, there are 709 websites of which the location is known. Most of these websites are based in Amsterdam: 236. After that, there are also a lot of domains hosted in Deventer: 110. A full overview can be found in Figure 4, where the websites whose location is unknown have been left out for readability. Using the dataset from the Green Web Foundation[4] we found that 1103 domains are verified to be green, out of 1748. This means that there are 645 URLs hosted by the Dutch government that are not yet verified to be green. Interestingly, the number of URLs for which the Green Web Foundation does not have any information about the hosting party is also 645. The reason for this is that the dataset only includes domains that are verified. If a domain is not verified, it is not in the dataset. It was also noted that there is a difference in greenness for subdomains and their corresponding second-level domain, even for those hosted under the same Autonomous System. As can be seen in Figure 5, 109 subdomains are green where their corresponding second-level domain is also green. However, 25 subdomains are not green while their corresponding second-level domain is green, or the other way around. One possible explanation for this is that the website with the subdomain is simply not verified by the Green Web Foundation.

Finally, Figure 6, in which the percentage and absolute number of green and non-green verified websites are shown per department, compares different government departments. We see that most URLs are owned by IenW (Infrastructuur en Waterstaat, Infrastructure and Water Management), where slightly more than half of their websites are verified to be green. An interesting department to look at is EZK (Economische Zaken en Klimaat, Economic Affairs and

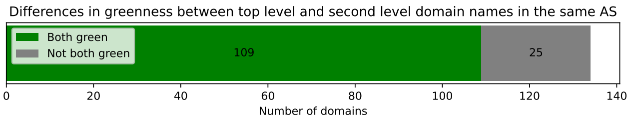

Figure 5: Differences in greenness between 2nd level domain and subdomains, where both are hosted at the same Autonomous System.

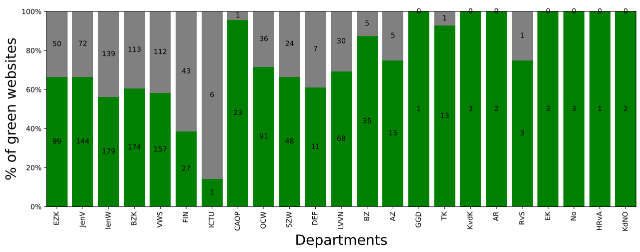

Figure 6: Number of green URLs per government department.

Climate), given that they are the ministry with climate assigned. Nearly two-thirds of their websites are verified to be green.

> *Key insight:*
> In total, there are 1748 websites hosted by the Dutch national government[25]. They are spread out over 100 different Autonomous Systems and in 15 different countries, where the most are hosted in The Netherlands, 1594. 1103 websites are verified to be green by the Green Web Foundation[4]. The department *IenW* has the most websites verified to be green, 179 in total.

4.2 Emissions of browsing session

In order to ensure reproducible results the Python script mentioned in Section 3.2 was executed 5 times, and the average of those 5 runs was used. Next to taking the average of 5 runs, only websites which showed the same characteristics 5 times were taken into account. For example, this means that a website for which a search box is found 4 out of 5 times is not taken into account. Next to that, websites for which the homepage would not load within 10 seconds and some websites with measurement errors were also removed.

There are 595 websites for which the average browsing session could be represented. From these websites, the website that emitted the most CO2 during a browsing session was *projecta44.nl*, where 0.28 grams of CO2 were emitted. The website that emitted the least amount of CO2 is not as easily specified, as 427 websites do not emit any CO2 due to being confirmed green. When we exclude those websites, the website that produces the least amount of CO2 is *iamcdocumentation.eu*, where an average browsing session emitted 0.01 grams of CO2. The average browsing session for these 595 websites emits 0.015 grams of CO2. The average of all websites that do emit CO2 (so excluding websites confirmed to be green) is 0.05 grams of CO2. Comparing this to other things in daily life, this turns out to be a low number. For comparison, a single cup of coffee produces 38 g CO2e (CO2 equivalent)[14], or around 760 times as much. A cup of tea emits less CO2 at 13 g CO2e per cup[14], but still around 260 times more. In Figure 7 the cumulative distribution function of the

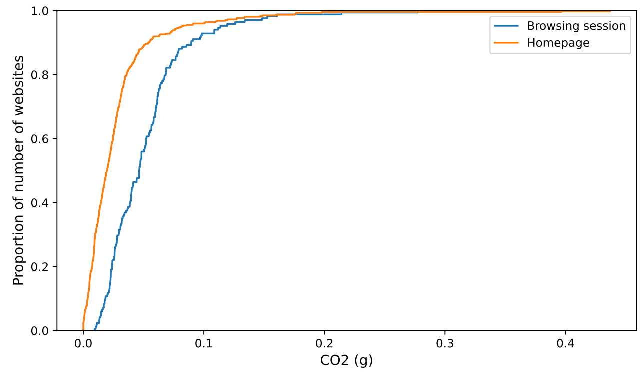

Figure 7: CO2 emitted (g).

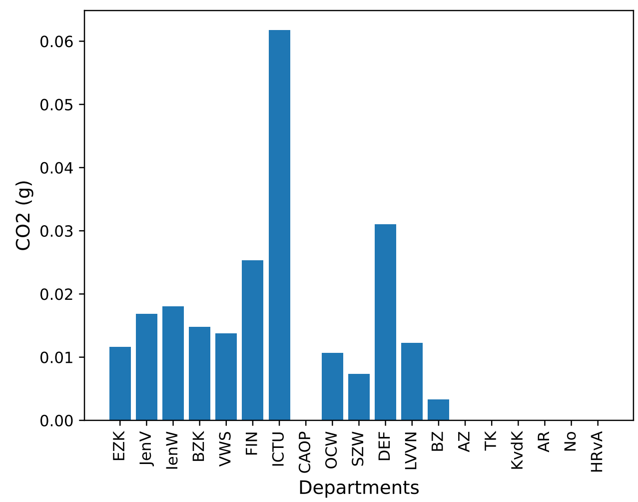

Figure 8: Average CO2 (g) emitted per department.

websites measured by the CO2 output of the represented browsing session can be seen. To keep the graph readable, the websites that were confirmed to be green have been omitted from the graph. Next to that, Figure 8 shows an overview of the average CO2 emission per department. Interestingly, the average of the ICTU, which is a foundation that helps government organisations with challenges related to digitalization[5], is noticeably higher than the average of other departments.

To give a better overview, we have looked at all 1342 websites for which at least the homepage loaded. Data was collected separately for each page, so this does not negatively impact the results for websites which represent the average browsing session. The homepage load that emitted the most CO2 was *themasites.pbl.nl/nature-based-solutions*, which emitted 0.44 grams of CO2. In this group of websites, 870 websites are confirmed to be green. Excluding these websites, we find that the website that emitted the least CO2 is *loc.minbzk.nl*. This website emitted 0.000007 grams of CO2. It should be noted that this URL returned 404 *Not Found*. The website that emitted the least CO2 and loaded successfully (with a 200 response code) is *cost869.alterra.nl*, which emitted 0.00031 grams of

CO2. The average amount of CO2 emitted for opening the homepage of a website is 0.01 grams of CO2, excluding the websites verified to be green results in an average of 0.03 grams of CO2. In Figure 7 the cumulative distribution function of the websites measured by the CO2 output of their homepage can be seen. To keep the graph readable, the websites that were confirmed to be green have been omitted from the graph.

Key insight:
The average CO2 emission for the 595 websites where the average browsing session could be represented is 0.015 grams of CO2, or 0.05 grams of CO2 when websites verified to be green are excluded.

4.3 Possible improvements

After having looked at the CO2 emissions of the websites of the Dutch national government, it was deemed logical to look into ways by which the CO2 emissions could be lowered. First of all, we looked at the transfer size of web pages. This is the main aspect that the CO2 calculations are based on, and therefore a possible easy way to make improvements. Given that it is difficult to give general advice, we chose to look into the different compression ratios used by websites of the Dutch national government. Next to that, Ecograder[2] will give a verdict on the carbon emissions of the websites.

4.3.1 Data compression. Just as in Section 4.2, websites that did not show the same characteristics 5 times, websites for which the homepage would not load and websites with measurement errors were excluded. This means that out of all 1748 websites, 1342 websites will be considered in this Section. From these 1342 websites, the simulations were able to fully represent a browsing session for 595 websites. The average data compression factor of these websites was 2.87. This means that the size transferred over the wire is 2.87 times smaller than the actual data size. However, there are positive and negative outliers in this Section. The website with the lowest data compression ratio was *sophie.oidji.nl*, where the compression ratio was 0.92. This means that there was more data transferred over the wire than the actual size of the webpage. This could have happened due to packets getting lost, or more data being sent over the wire than counted by the browser as being part of the final page. The website with the highest data compression ratio was *bkwi.nl*, which obtained a compression ratio of 30.15. As Figure 9 shows, most websites have a compression ratio between 1 and 5. It can be seen that there are small outliers above 8, where most websites reside between 1 and 5. In Figure 10 the average compression ratio per department can be seen, where we observe that the department *TK*, which is the Tweede Kamer, or the House of Representatives, has no compression on the websites that this research was able to represent a browsing session for. This becomes clear from the compression ratio being 1, meaning that the data transferred is the same as the actual size of the webpage.

4.3.2 Ecograder. To gain insight into ways in which the Dutch national government can improve the carbon emissions of their websites, Ecograder[2] was asked to generate a report for each website in the list of websites from the Dutch National Government[25]. See Section 3.3 for more information about what Ecograder does and what is contained in a report. For 1557 websites Ecograder was

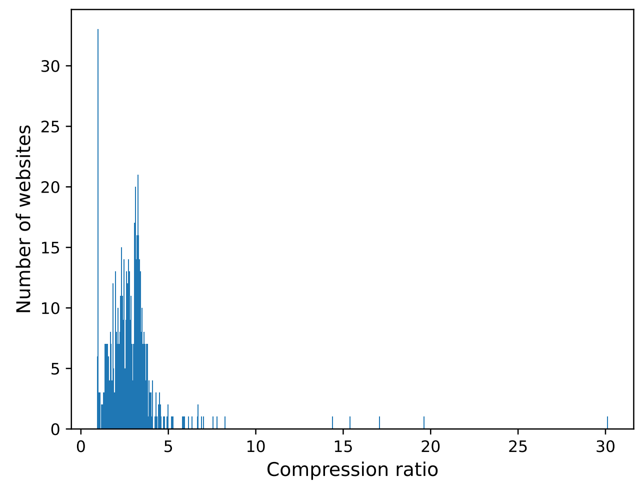

Figure 9: Compression ratios, for websites representing the average browsing session.

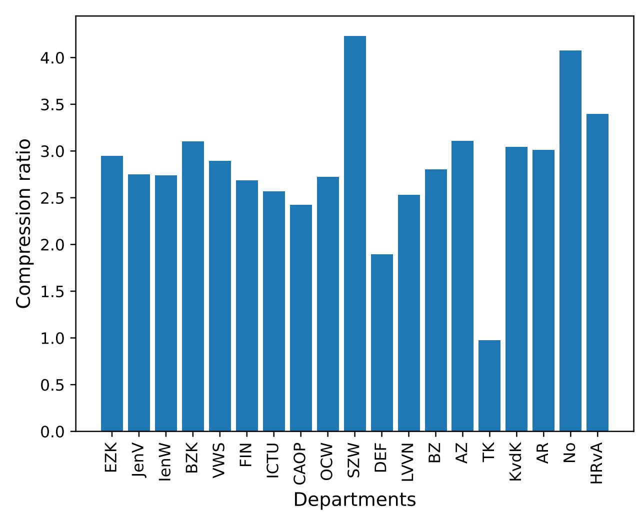

Figure 10: Average compression ratio per department.

able to provide a report. For other websites this was not possible, due to e.g. too many redirects. The average score for all gradable websites from the Dutch National Government is 65. However, some departments score better than others. An overview of the average score per department can be seen in Figure 11, where we see that the department *RvS* (Raad van State) scores relatively lower, and the department *GGD* scores relatively higher. However, this is not the highest-scoring website overall. The highest scoring website overall is *mogin.ndw.nu*, belonging to the Department of Infrastructuur en Waterstaat, or Infrastructure and Water Management, with a score of 99. The highest scoring website per department can be seen in Figure 12. Once again, the department *RvS* (Raad van State) scores the lowest, with many departments having websites reaching close to the maximum score obtainable, which is 100. Table 2 shows an

Item	Score
Improve Page Rendering	48
Remove Unused Code	50
Service static assets with an efficient cache policy	53
Reduce Overall Page Weight	54
Reduce Server Requests	58
Image elements do not have explicit width and height	62

Table 2: Lowest-scoring items, according to Ecograder.

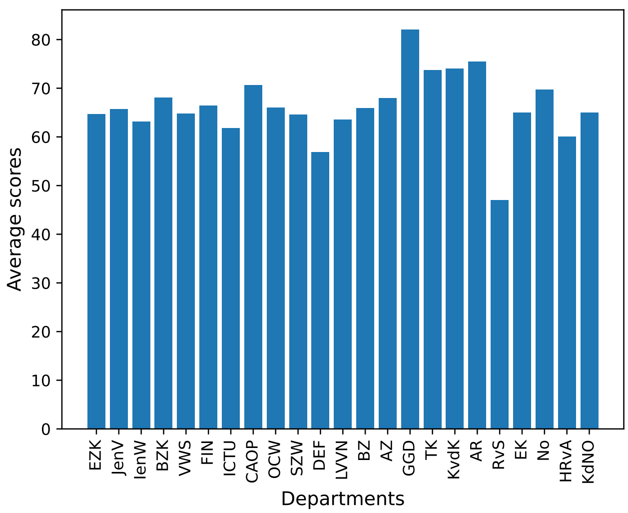

Figure 11: Average Ecograder score per department.

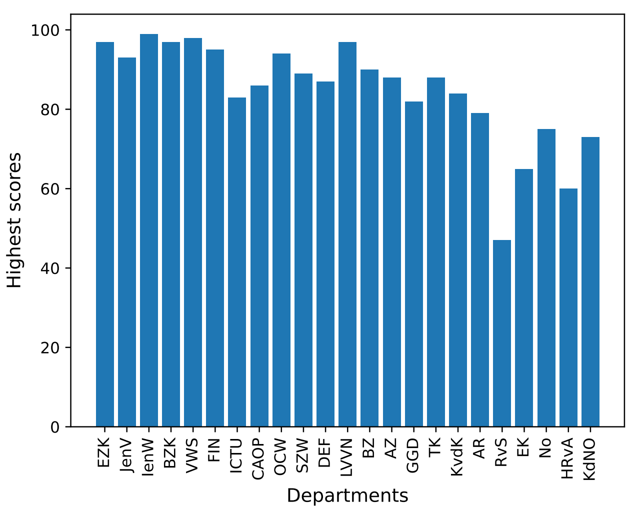

Figure 12: Highest scoring website per department, graded by Ecograder.

overview with items that received the average lowest score. Given that they obtained the lowest scores, they can also be improved upon the most.

Key insight:
The average data compression of the 595 websites where the average browsing session could be represented is 2.87. The average Ecograder[2] score of all websites is 65, where the biggest improvement can be made by improving the page rendering, according to Ecograder.

5 LIMITATIONS

This research is limited by several factors. First of all, our approach was not able to simulate a representable browsing session for each website hosted by the Dutch national government. This is due to the XPATHs used to find the search boxes not being able to find a search box for each website, and due to the XPATHs used to find the result on the webpage not being able to find the correct link on each website. It remains for future research to look into different ways to select such elements on many different websites in an efficient and stable manner. Next to that, this research makes use of the dataset hosted by the Green Web Foundation[4]. To get into this dataset, websites have to be verified proactively by their owners. It is therefore possible that more websites are green while not being in the dataset. Moreover, assumptions were made related to the CO2 calculations. The number used in the formula to transform an amount of data into an amount of energy remains a limitation, as there is no information available about the hardware that each website is running on or the software that is used to run the website. Both of these could heavily influence the amount of power used to handle each browsing session.

6 DISCUSSION

In this Section the results achieved will be discussed. Starting at SQ1, it was interesting to see the different number of websites where the Dutch national government hosts websites, some of which are more expected than others. Next to that, it was positive to see that around two-thirds of the websites hosted by the Dutch national government are verified to be green. Continuing to SQ2, it was interesting to see the difference in CO2 emission per browsing session per department. Finally, for SQ3, there were some interesting outliers in the data compression, with very high compression levels. The results obtained were verified after the initial data collection had been done, but the same results were found. Therefore, it remains for future research to look into why these numbers were reported as such. Next to that, Ecograder[2] provided a different view, as its opinion about the websites is separate from the data collected in this research.

7 CONCLUSION

The main research question of this research is *What is the cost of visiting and interacting with the websites of the Dutch national government, in terms of carbon emissions?* In this research, we were able to find the answer to this question for 595 out of 1748 websites hosted by the Dutch national government. Regarding SQ1, we found that the Dutch national government websites are hosted by 100 different Autonomous systems, where 1103 websites are green, according to data from the Green Web Foundation[4]. Big differences between departments were found, in terms of both the number of websites hosted and the amount of green websites hosted. For SQ2, this research simulated a representative browsing session. It was found that the average for all 595 websites for which a representative browsing session could be simulated was 0.015 grams of CO2. Finally, regarding SQ3, it was found that the Dutch national government can most improve their websites by improving the page rendering, according to Ecograder[2]. Taking the answers to the 3 sub-questions together, the answer to the main research question is that performing an average browsing session at websites of the Dutch national government results in an average carbon emission of 0.015 grams of CO2, based on the 595 websites for which this research was able to simulate a representative browsing session.

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