Green coding

Can we make our carbon footprint smaller through coding?

10 June 2022

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This thesis is submitted to the Faculty of Computing at Blekinge Institute of Technology in partial fulfillment of the requirements for the bachelor's degree in software engineering. The thesis is equivalent to 10 weeks of full-time studies.

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Abstract

In this paper, the aim is to research green coding and sustainability within web development. Can environmentally friendly web development make a difference in climate change? In which ways can a web developer code green? And to what extent are programmers today aware of the phrase “green coding”? These are the key questions that will be discussed in the essay.

The goal is to research the current recognition of environmentally friendly coding within the programming community. To give examples of eco-friendly development and research its relevance as a tool for combating climate change. The paper will attempt to answer if it has a significant enough effect on global emissions for society to care about, or explain why such a conclusion is difficult to ascertain.

This study proceeded accordingly when answering the questions. Firstly, a survey was created with questions about green coding and eco-friendly development and then shared with a group of programmers. Secondly, previous studies were collected to see how well their research fit together and what conclusions can be drawn from it. Thirdly, information and data from statistics were collected together with test measurements in order to identify energy-efficient ways of coding and developing.

The results from gathering and comparing sources of energy consumed from data being transferred show that it is difficult to calculate the impact eco-friendly development has on climate change. Some techniques and tools that are preferable when prioritizing energy efficiency are revealed. The results of the survey showed that there is some recognition of the phrase “green coding” among programmers but not widespread and that there is a minority of the respondents who think about saving energy when coding and choosing tools and techniques.

Keywords: green coding, eco-friendly web development, energy efficiency

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1. Introduction

1.1 Background

Humanity is currently facing one of its biggest threats in history, global warming. The situation is so severe that we must consider the climate in all different fields and aspects of our professional and everyday life. Energy accounts for around three-quarters of the total greenhouse gas emissions and more than 80% of our energy comes from fossil fuels [1]. Almost every year in the last decade energy consumption has risen globally. As well as the number of people who are using the internet. In 2021 4.9 billion individuals or 63% of the population were using the internet [2]. Every day we send emails and messages and upload photos on social media, as well as stream videos online, and all of this comes with a small cost. One little Google search hardly makes a difference but Google alone processes more than 60 000 search queries on average every second [3]. Gadgets, the internet, and the systems supporting them account for 3.7 % of the greenhouse emissions in 2019 [4], and this percentage is predicted to double by 2025 [5].

I see these numbers and realize that the IT industry should think green and recognize the carbon footprint it makes. I want to explore if there are ways for me and my fellow programmers and web developers to decrease the energy spent while using the projects we develop. Hopefully, some of it will be covered in this essay.

When coming across the phrase “green coding” i.e., code that is written to produce algorithms that have minimal energy consumption, I wondered if this is something that is used and has an impact in reality. I wanted to research the existence of green initiatives within the web developing community.

There is one green initiative called green software engineering, which is a new field where software practices and architecture, electricity markets, hardware, data center design, and climate science intersect to try and make software engineering more sustainable [6]. This is an interesting initiative that combines several competencies in order to establish a new sort of climate science within the field of software engineering. It strongly underlines the importance of being independent from the industry at large and is being presented as an emerging discipline that aims to inform anyone “building, deploying or managing applications” [6]. Since this initiative concerns software engineering, which includes

programming, it could be thought of as being within the scope of this paper. Within this emerging new discipline, there are several core claims that I will be discussing later in this paper, such as the importance of optimizing applications based on energy efficiency in order to reduce the carbon footprint of our applications. Especially going forward, with all the technological advances, meta worlds, and so on, the people referring to themselves as green software engineers believe that this topic will be an increasingly important one. I will later be discussing whether programmers have a significant ability to reduce energy consumption and by doing so reduce global emissions. Green software engineering does, as I will also do later in this paper, give concrete examples of how to code green, such as optimizing your database and choosing the right programming languages based on energy efficiency. I will be discussing some of these later in this paper and how they should be implemented into everyday use by the programming community.

1.2 Purpose

As more and more people have several devices connected to the internet and are using various applications and websites to a larger degree, the bigger the responsibility in the hands of web developers becomes. Hopefully, the results from this study can give us a larger perspective of how this group of people thinks about the environment when working on projects. This might also tell us something about which direction this industry is leaning toward on this issue.

There is quite a lot of environmental research out there which are all about sustainability strategies and how we can live a green lifestyle that will reduce our carbon footprint. Today, climate change is already a huge topic and it is becoming more and more relevant.

It is surprisingly hard to find much relevant information on sustainable web development and similar topics. When typing in the search words “Green coding” in academic search engines like Google Scholar there is not much relevant material regarding environmentally sustainable coding practices. In my efforts to find specific examples of green coding I have only managed to find a few. This might be because it is a relatively new phrase and phenomenon. I think that there will be a growing number of people searching for studies on green coding and related subjects in the future as sustainability goals are advancing in the tech industry [7]. It is difficult to raise interest, awareness, and discussions with a lack of research and facts, and therefore more research must be done in this area.

In today's climate, it is not a question of whether you should incorporate sustainability in your business or not. Studies show that the most profitable companies are the most sustainable ones [8]. This study and other related ones that educate about eco-friendly and energy-efficient options within web development and programming are important from a business perspective as sustainability and awareness can help companies become more attractive and profitable. Climate change is not going to disappear overnight, and the importance of sustainable companies is probably just going to grow.

In many ways coding is about being efficient and using few lines, as well as creating fast loading times and so on. In this sense, one can argue that good coding is green coding. There is a truth to that, but I think green coding will raise some questions on its own, especially when considering the design process, which may or may not change your project. I think this is what makes this research important, to examine what green code is in comparison to just “good code” and to what extent green code could make a difference. I anticipate that this topic is interesting for many programmers whether you believe in it or not, and hopefully, it will give a broader understanding of the subject and create important discussions about the responsibilities of a developer.

I hope that I will be able to answer the research questions well in this essay, even though I do think that it will be difficult to draw firm conclusions in some areas. But I believe that the topics and analyses which will be covered in this essay will give a meaningful contribution to the ongoing discussion about climate change, as it should be covered in all different fields and professions. As a result of this research, we will have a well-described definition of the concept of green coding, a rough sketch of the awareness or unawareness of the term in the programming community, as well as a guide on how to code green.

1.3 Scope

Global warming and energy pollution are a part of the background of this study and the reason why the phrase green coding has appeared and evolved. It is a very big subject that includes a lot of topics and areas to cover which will not be a part of this essay. To limit the research for this essay the focus will be on the coding itself, the tools that are used in development, and the attitudes of the individual programmers.

2. Research questions

This essay will focus on different ways to save energy through coding and what kind of tools and techniques are preferred. The awareness of green coding or eco-friendly web development among programmers will also be examined.

RQ1. To what extent can environmentally friendly web development make a difference in climate change?

The reason for asking this question is to determine if programmers have a significant ability to reduce energy consumption and global emissions. The knowledge that will be gained from the answer to this question could be useful for different actors working with web development, such as individual programmers, companies and organizations. These actors can use this knowledge to make decisions about whether green coding or eco-friendly web development is worthwhile and if it could have a positive difference to their operation and the climate.

RQ2. What are some efficient techniques to code green?

RQ2's goal is to look into some energy-efficient options for web development to gain knowledge and tools for saving energy. I'll go over some energy-efficient techniques for the subjects listed below, which cover a wide range of programming topics but are primarily focused on web development at various levels.

- Programming languages
- Content and Design
- Databases

By exploring these areas in which green solutions can be put into practice, the actors that are interested in using or researching eco-friendly development can get a deeper understanding of how to proceed with the tools currently available.

RQ3. To what extent are programmers aware of green coding?

Information gathered from a group of programmers will show if, and in some cases how, they take the environment into consideration when writing code. In this way, we will find

out if they make conscious decisions about energy efficiency when choosing techniques for their projects.

It can be useful to research how widespread the knowledge and awareness of green coding or eco-friendly development is among programmers because it will give an idea of the current importance and relevance of the subject within the programming community. Actors who are interested in working with sustainable development and exploring the subject further would be helped by knowing the attitudes among programmers. It can help them determine whether there already is a lot of knowledge in the area or if they might need to educate programmers on this topic.

2.1 Objectives

The goal of this essay is to get a good understanding of the subject of green code, what it means, and its presence amongst programmers. By answering the research questions in this essay we will hopefully be able to see in what way eco-friendly development can help make a smaller carbon footprint. The data and information gathered will show how one could evaluate how to code green. The expected outcome of this study is to be able to clarify if the energy consumption from inefficient code has a significant effect on climate change, to display energy-efficient techniques for web development as well as reveal the awareness of green coding among programmers.

3. Research Method

The following methods will be used to answer the research questions: information and data gathered from well-selected literature and statistics together with test measurements, as well as results from a survey directed toward programmers.

3.1 Literature

To collect literature and articles which will be used in this essay I will primarily use BTH's library, Google Scholar and ResearchGate. These search engines will return query matches of literature from all over the world. I will also be using Google search to find more articles and information related to the subject.

There aren't a lot of examples of green coding even though the phrase is becoming more common, so I will use words and phrases like "energy-efficient", "energy-consumption" and "sustainable development" to get more hits and information.

To identify what literature is relevant and usable I will be following some guidelines [9]. As the technology industry is evolving rapidly each year I will try to use material that is published in recent years. If it is older than 5 years I will have to consider this and reflect on the accuracy and relevancy of the material. I want to make sure that I use peer reviewed sources and will examine the purpose of the source so that I can evaluate if the intention of the material is appropriate. When searching for literature I was only looking at English written essays and articles.

3.2 Execution

3.2.1 RQ1

To answer RQ1 I will mostly use statistics and information gathered from research literature. I will analyze them and draw conclusions. I will look for reliable data that can help us understand to what extent eco-friendly development could make a difference in climate change. RQ1 is about understanding what green coding is and why this subject has appeared and become more common. It will give us an understanding of the connection between code and energy consumption.

3.2.2 RQ2

When exploring what green tools and techniques can look like I will be collecting information and measurements from tests and studies. An example of a test is a comparison between different programming languages executing the same task. I will mainly base the results on previous studies. There is not a huge number of examples of green coding, but there is however more research on energy efficiency when it comes to programming languages and other different techniques. I will use the collected data to make a list of examples of energy-efficient techniques to code green. This list will be the answer to RQ2 and will include programming languages, databases, loading time, and content and design.

3.2.3 RQ3

I will be collecting material through a survey for RQ3. The survey will include six questions directed to programmers about green coding and if it is something they can relate to professionally or personally. I intend to reach a broad group of people that are either working professionals, non-professionals, or students. A non-professional would be a person who is neither working with nor studying programming but still is knowledgeable within the subject and is a practicing programmer in some other way. If the person answering the survey is a professional, there will also be a section of questions about their workplace to see if it prioritizes or discusses green coding or environmentally friendly development. I will be publishing the survey for people to answer in different programming groups and forums. I will summarize the results to analyze and see what the awareness and knowledge of green coding are amongst these programmers. I'm using Google forms to create the survey where you can download the answers as a CSV file. Diagrams will also be created for each survey question to summarize and visualize the findings. In some cases, the person answering the survey can leave a written answer or comment which can deepen the understanding of the answers and help analyze the results (see appendix A).

4. Literature Review

Previous research that was used as the main sources in this essay is the following: *Electricity Intensity of Internet Data Transmission: Untangling the Estimates* [12], *Energy Efficiency across Programming Languages* [16], *Analyzing Programming Languages' Energy Consumption: An Empirical Study* [18] and *Improving the energy efficiency of relational and NoSQL databases via query optimizations* [28]. Other main sources are the articles *CO2 emissions on the web* [10], *Operators are committed to drastically reducing the energy consumption of their networks* [13], *The performance cost of custom web fonts, and how to solve it* [19], and statistics from Http archive [9] [24], W3Techs [11], Internet live stats [21] and Think with Google [25].

In the results section for RQ1, the number of energy used per GB of data transferred is discussed where several sources are being used [10] [11] [12] [13] to determine which number seems to be most accurate or relevant when calculating emissions. The different sources all mention the difficulties in finding a definite number and support each other in that manner. They do not always present the same numbers but it does not necessarily mean that they are in conflict but may rather be using different factors and variables.

For energy efficiency among programming languages, primarily two studies are being used, the first is *Energy Efficiency across Programming Languages* [16] and the second within the same area is *Analyzing Programming Languages' Energy Consumption: An Empirical Study* [18]. Both the studies show similar results for energy efficiency across programming languages and support each other's conclusions.

5. Analysis and Results

5.1 RQ1

Results and analysis for research question one, “To what extent can environmentally friendly web development make a difference in climate change?”, will be presented here.

5.1.1 RQ1 results

The average website size has in the past decade grown by 356 % [10]. In 2021 the average web page was 2,205 kB in comparison to 2011 when the average was 484 kB. Danny van Kooten, a self-employed developer, wanted to reduce his carbon footprint and did so by removing 20 kB JavaScript in all his WordPress plugins which combined run on over 2 million websites [11]. By doing so he reduced global emissions by around 59.000 kg CO2 per month according to his measurements, which is like flying from Amsterdam to New York and back 85 times. Not everyone's website has that kind of impact, but it does say something about the significance web development can have on the climate. WordPress is the number one content management system and out of all websites, 40 % are built with it [12]. What if every WordPress plugin developer followed in van Kooten's footsteps, we can only imagine the reduced emissions of CO2 per month. These kinds of measurements are difficult to make, as network conditions can vary greatly.

The task of calculating a website’s emission is not simple, and the numbers for energy used per GB of data transferred differ a lot. In a study from 2017 where the authors tried to wrap their heads around these differences, they reviewed 14 existing papers on the subject where the figures went from 0.004 kWh/GB to 136 kWh/GB [13]. They concluded that the most accurate estimate for electricity used to transmit data through the internet in 2015 was 0.06 kWh/GB. Seeing that was several years ago now, this number might not be accurate today. Another significant factor that needs to be considered here is the importance of system boundaries. The study adjusted the research to simply look at how much energy it takes to send a gigabit of data through a telecom network within a national cable network. This means the study ignores the totality of the system including end-user devices and data centers among others as well as the dissimilarities between cable and mobile networks. To get a more accurate measurement all system boundaries should be used, but that would be

hard to arrange. Mobile networks use more energy per GB transferred than cable networks, but it seems that they are getting faster and more energy-efficient in recent years. At the same time, mobile network use has increased drastically [13]. In 2020 the analyzed markets say that primary energy efficiency was 0.24 kWh/GB in RANs [14]. This number seems to differ in different studies and articles, and you also have to differentiate between 2G, 3G, 4G, and 5G, as there are many differences between them. But it seems that the number goes from around 0.15 kWh/GB to 0.8 kWh/GB in the more recent research. van Kooten, who was previously mentioned, used 0.5 kWh/GB as the average for 3G in his calculations in 2020 [11].

Today there are websites and tools to measure how clean and green your website is, one is called Website Carbon Calculator [15]. They use five key variables to calculate the website's carbon emissions, which are as follows: data transfer over the wire, energy intensity of web data, the energy source used by the data center, website traffic, and carbon intensity of electricity in website traffic. The tool is supposed to give you a rough idea of the CO2 that is produced from the website and its code is available on GitLab for anyone to access [16]. They are clear about what the tool bases its score on and have open access to their code, which shows transparency. Sometimes you need to be able to visualize the kind of negative impact things have to be motivated enough to do something about it, and if there are easy ways to access information, there is not much stopping you. An easy tool like this can play an important role in increasing interest in eco-friendly development, as it makes it possible to quickly see if any improvements can be made when it comes to emissions.

5.1.2 RQ1 analysis

There are examples like the one mentioned above with van Kooten that show that eco-friendly development has an impact on the environment, the difficult thing is to show to what extent. Many variables play into the energy consumption of a website, which makes it hard to see how for example the weight of a page weighs in. But by looking at the numbers that are available and the rapid rise in mobile network use, using sustainable options and making websites lighter can help to some extent. Like with most things, great change comes about through the accumulation of small efforts. The conclusion is that web development makes a difference in climate change but as demonstrated it is difficult to estimate just how

big of a difference, and therefore very hard to determine its significance in reducing greenhouse gas emissions and slowing down global warming.

5.2 RQ2

Results and analysis for research question two, “What are some efficient techniques to code green?”, will be presented here.

When choosing a language, tools, and techniques for a project you probably have some preferences as to their abilities and functions, or maybe you are limited to only a few options. This part of the essay will discuss what techniques might be preferred if your choices are based on energy efficiency.

5.2.1 Programming languages

Previous research has shown that some programming languages have a big impact on energy efficiency, meaning that choosing the right programming language, depending on the project, could make a big difference when it comes to saving energy.

A research group investigated the energy consumption of 27 of the most popular programming languages, updated in 2021 [17]. They did this by using ten different programming problems compiled by the “Computer Language Benchmarks Game” project, dedicated to implementing algorithms in different languages [18]. The study shows different factors that influence energy consumption and that the language running fastest is often but not always the one that consumes the least energy. The overall result shows that the five most efficient languages keep their rank when it comes to execution time where C is the most energy-efficient language as well as the fastest and then comes Rust not far behind, C++ is third, Ada is fourth, and Java is fifth. The most energy-efficient language in the benchmarks is almost always the fastest one but the result shows that no language is consistently better than the others. Meaning that the situation in which the language will be used is a key factor in finding out which language is the most energy-efficient. One benchmark, regex-redux, manipulates strings using regex and shows that interpreted languages were the more energy-efficient option even though they tend not to be very energy-efficient in other scenarios [17].

As an interpreted language needs more time to execute in comparison to compilers, JavaScript is still showing the highest energy efficiency among interpreters compared to Python which is one of the most energy-consuming languages based on this research next to Ruby and Perl. Even though JavaScript still consumes about double the amount of energy compared to Java. If we move over to consider memory, things look a little bit different in a language like Java, which is one of the least energy-consuming languages and also is one of the most memory-consuming languages along with JavaScript among others [17].

Another study also explored the energy efficiency in different interpreted programming languages and compared results in different tasks to show the percentage of increased energy usage while using the inefficient implementation in comparison to the efficient [19]. For example, a test for classes shows that the increased energy usage while using Python is 1616% in comparison to PHP, and another test for insertion-sort shows that the increased energy usage while using Perl is 9430% in comparison to JavaScript. The test shows the most inefficient case in Swift which consumes 12694% more energy in comparison to JavaScript. PHP, JavaScript, and Ruby are shown in the study to be more efficient than Swift, Perl, R, and Python which are shown in the test cases to have the most energy-consuming implementations among the interpreted languages.

5.2.2 Content and Design

When creating a website or application you want it to look attractive and for it to be easy to use. There are many ways to make your website energy-efficient through content and design and at the same time make it more user-friendly, accessible, and performant.

Images can be powerful and serve an important purpose on a website, but they can often lead to heavy pages. Having a lot of images, especially the larger ones, means more energy being spent. There are several tools like TinyPNG and ShortPixel to compress images without visible loss of quality. The pictures at the top of the next page are an example of ShortPixel usage where the image to the left is the original with the size of 8 MB and the picture to the right is optimized to the size of 0.6 MB without any notable visual difference. The use of CSS to rescale images is also common. If the image is instead the scale as you plan to display it you won’t need to use CSS to resize the images, which leads to less redundant code.


When styling your webpage with CSS there are some things to keep in mind to minimize energy use. Choosing the right fonts can raise the appeal of the website but a font file can be as large as 250 KB, and that is only for normal font weight. Using system fonts instead of loading a font file is the preferred option to save energy. If you would like to use a special font for headings, for example, try to stick to one font and think about if it represents your message, ask yourself if it's readable rather than has a cool design. When you choose a web font file format, use WOFF or WOFF2, which compared to TTF and SVG has higher compression methods [20]. By also using a font subsetter [21] to only include characters that will be used on the website, like removing characters from other languages, can minimize the font file further. For example, an original TTF font file went from 298kb to 7kb by using the two techniques previously mentioned [20].

There are also tools like PurgeCSS that analyze the content files and your CSS and remove unused CSS from your project [22]. Be aware that PurgeCSS can't detect things like normalize.css that only shows up in the DOM at runtime, so you can split your styles into different files before running PurgeCSS to avoid a loss that you might need [23]. Using this tool can leave you with a significantly lighter CSS file.

5.2.3 Loading time

When writing this essay there are more than 1.94 billion websites on the internet [24]. The median for the time to interact with a website on mobile devices is 14.4 seconds and mobile visitors are 123% more likely to bounce, meaning leaving your website after only viewing one page, from the website if it takes 10 or more seconds to load in comparison to 1 second [25][26]. If all websites would lighten the unnecessary weight, it most likely will make the loading time faster which will give a better user experience and lower the bounce rate and with that avoidable data transfer.

Google's PageSpeed Insights is a tool where you can easily make measurements for a website including different loading times, for example, "the first contentful paint" and "time to interactive". The tool reports on the performance of a webpage for both desktop and mobile devices [27]. When making these measurements there are also audits divided into opportunities and diagnostics. Opportunities reports on how the page could improve and how much time that would be saved by implementing these improvements. A typical suggestion for improvement could be to reduce unused JavaScript. Diagnostics provides information about how a page follows best practices for web development that in some cases are very specific and would be difficult to detect on your own. Some of the diagnostics show implementations that are too large and add unnecessary load time to the page. The tools will also deliver a performance score that summarizes the overall performance, where a score above 90 is considered good, a score between 50 and 90 would need improvement, and a score below 50 is thought to be poor [27].

Using tools like PageSpeed Insights that explore ways in which a website can improve its performance and shorten its loading time, in ways that will also reduce energy use, is a simple and efficient method to improve your website and make it greener.

5.2.4 GraphQL and Relational and NoSQL databases

In the early 2010s, mobile usage blossomed, which led to a lot of problems for low-power devices and poor networks, and REST APIs had a hard time dealing with that. The main problem with the traditional REST API is that it is slow and requires a lot of hard-coded code. With the increase in mobile usage, there was also an increase in different front-end frameworks and platforms running different types of clients. As REST APIs are relatively inflexible, there was a demand for a more flexible and developer-friendly alternative. It was Facebook that first developed GraphQL for internal use in 2012 and when the source code was then opened up and its stable version released a few years later, things took off immediately [28].

So, what is GraphQL? It is a query language that was designed to be developer-friendly and to improve speed and flexibility for APIs. It allows a client to fetch specific data without retrieving more than what was desired. You can add and remove requests without affecting existing requests, and as a developer, you can build APIs with any methods you want. When developing with GraphQL, schemas are used to describe all possible data that clients can

request. A schema is built with different types of objects that define what kind of objects can be queried and what fields they have. When GraphQL receives these requests, they are validated against the schema before they can be executed. One of the main advantages of GraphQL is that it avoids over-fetching and under-fetching from the API, which is one of the most common problems with REST APIs. Since the only way for a client to fetch data from a REST API is by hitting ENDPOINTS that return fixed data structures, it is difficult to design an API that can provide clients with their precise data needs. Under-fetching means that a specific ENDPOINT does not contain enough information compared to what is needed. The client then needs to make additional requests. It is simply problematic that it takes too large and/or too many requests to retrieve the data rather than what should be necessary which isn't very energy-efficient.

Relational databases allow identifying a piece of data in relation to other data within the database and these kinds of databases are often organized in tables. NoSQL databases do not store their data in relational tables but in other formats. They are document-oriented and are more flexible than relational databases. Different document types are for example graph and key-value.

A study that evaluates the performance and energy efficiency of the relational database MySQL and the NoSQL databases MongoDB and Cassandra, provides evidence that energy optimizations of databases should be considered separately, each according to the facts of the situation [29]. A relational database allows for identifying a piece of data in relation to another piece of data within the database and these kinds of databases are often organized in tables. NoSQL databases do not store their data in relational tables but in other formats. They are document-oriented and are more flexible than relational databases. Different document types are for example graph and key-value.

In the study, they use YCSB benchmarks and 100GB of Twitter data to implement a measurement tool on the NSF-funded marcher system to measure power consumption with and without optimization. The results showed that energy efficiency can be improved significantly without disrupting the performance of the tested databases. It also shows that optimization sometimes increases power consumption and may degrade performance.

For MongoDB, the study shows that using indices can give an increase in speed by 280 times and at the same time reduce power consumption by 40%. When using covered

queries, i.e., queries that can be fulfilled using an index without the need to examine any documents, it can improve performance by 276 times while reducing energy consumption by 45%. It also reveals that ordered queries rather than unordered queries give better performance and are more energy-efficient. Cassandra in comparison to MongoDB does not give as good results in the study's experiments, which could be because of the scalability of Cassandra, as the experimental setup has only two servers, where Cassandra might not shine at its brightest. For MySQL indexing also improves the performance and energy efficiency and avoiding SELECT-command resulted in a 20% gain in energy efficiency.

5.2.5 RQ2 conclusion and analysis

To conclude, there are several approaches to energy-efficient web development and several tools that can facilitate the process. When starting a new project, one should think about and do the research on which programming language is the most efficient for the tasks that will be implemented. The results show that C or Rust are the preferred languages based on energy efficiency but if the options are limited or for some reason those languages do not fit the project, you can still find the most energy efficient language among the suitable ones. There is plenty of research like the ones stated in the results that you can base your choice on. When it comes to databases and APIs, depending on the project, the most energy-efficient way is most likely to use GraphQL and optimize the database by using covered queries, ordered queries, and indices among others depending on the type of database, according to the results. When filling up a new website or application with content and design or just adjusting and improving an already existing project there are many green ways of doing so. One thing that the results emphasize is that you should think twice if an image or a video really is necessary, and the same goes for design features as lighter pages are more energy-efficient. The results show several easy tools in the content and design section as well as in the loading time section that can help expose and sometimes remove redundant code and identify bad practice implementations and inefficient formats for images and font files. Ultimately, there are many tools and ways to enable green web projects and if the will and resources allow, energy can be saved.

5.3 RQ3

Results and analysis for research question three, “To what extent are programmers aware of green coding?”, will be presented here.

Creating and sharing a survey with questions about green coding and eco-friendly web development gave a perspective of the responding programmers' relation to the subject. The survey was shared in different programming communities where any type of programmer was able to answer. The results of the survey will be displayed below with the questions and their results displayed in order of the survey.

5.3.1 Survey results

Question 1

What type of programmer are you?

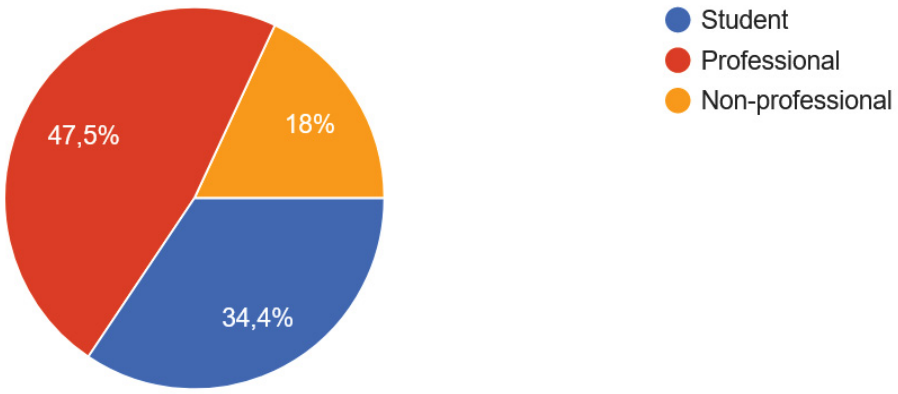

Diagram 1: Question 1

The three response options to the question are displayed in the upper right corner and the results are displayed in the diagram through color and percentage.

The first question in the survey asked the respondent what kind of programmer they are so we can gain some perspective on the awareness or opinion of the specific groups. The total number of programmers that answered the survey is 61, where 29 were professionals, 21 were students and 11 were non-professionals, the diagram above shows the percentage of respondents in each group.

Question 2

Have you ever heard of the phrases "green code" or "green coding"?

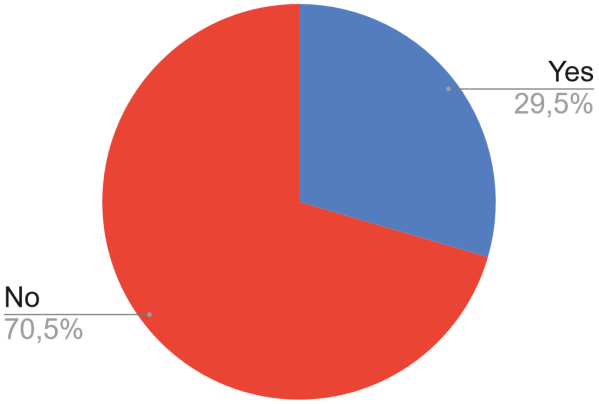

Diagram 2.1: Question 2

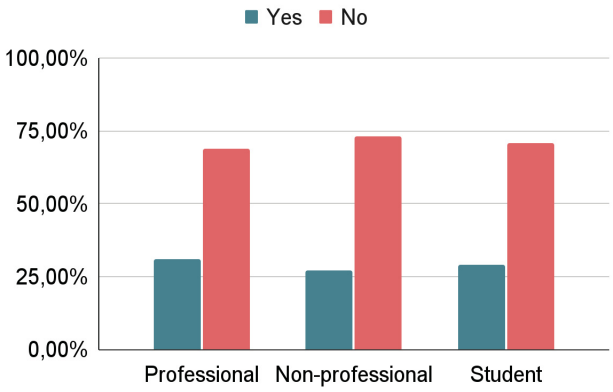

Diagram 2.2: Question 2

The second question asks the respondent if they've ever heard of the phrases green code or green coding with the answer options yes or no. The results in diagram 2.1 show that about 70 percent have never heard of the phrases. Diagram 2.2 which shows the answer statistics for each group, also shows that there is no big difference between the three groups of respondents.

Workplace section

Question 3

Is green coding or eco-friendly development a topic that is discussed at your workplace?

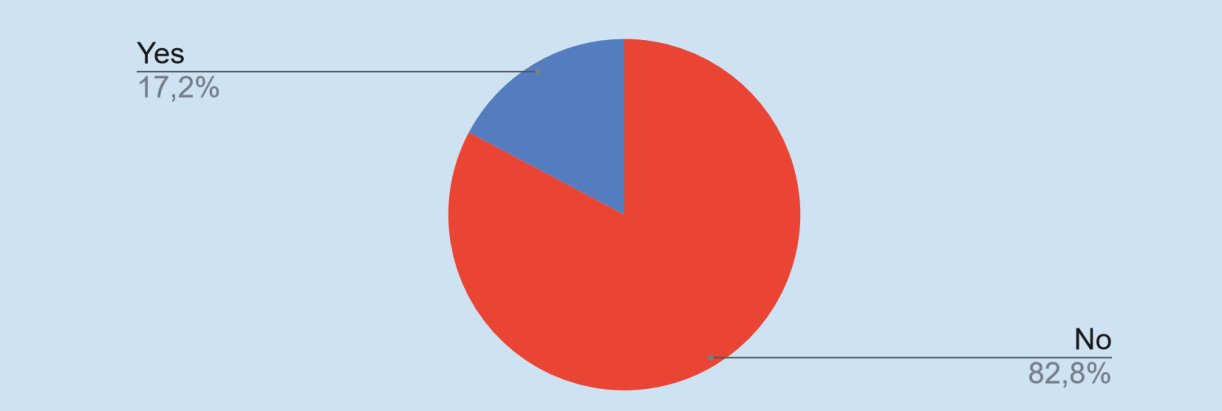

Diagram 3: Question 3

This question from the survey and the following one are about green coding or eco-friendly development in the workplace and were only asked to the respondents from the professional group.

Diagram 3 shows us that of the professional programmers answering the survey, about 17 percent say that green coding or eco-friendly development is something that is discussed at their workplace.

A follow-up optional question was asked for the respondents that answered yes to the previous question, it gave the respondent a chance to mention in what situation green coding or eco-friendly development was mentioned. One respondent mentioned that their company had “energy stars”, in other words, a common goal within the company to reach a certain standard of energy efficiency. Others answered that it was in terms of computing resources and when talking about AWS's focus on green coding.

Question 4

Would you like for the company that you work for to be more climate aware by prioritizing green coding or eco-friendly development higher?

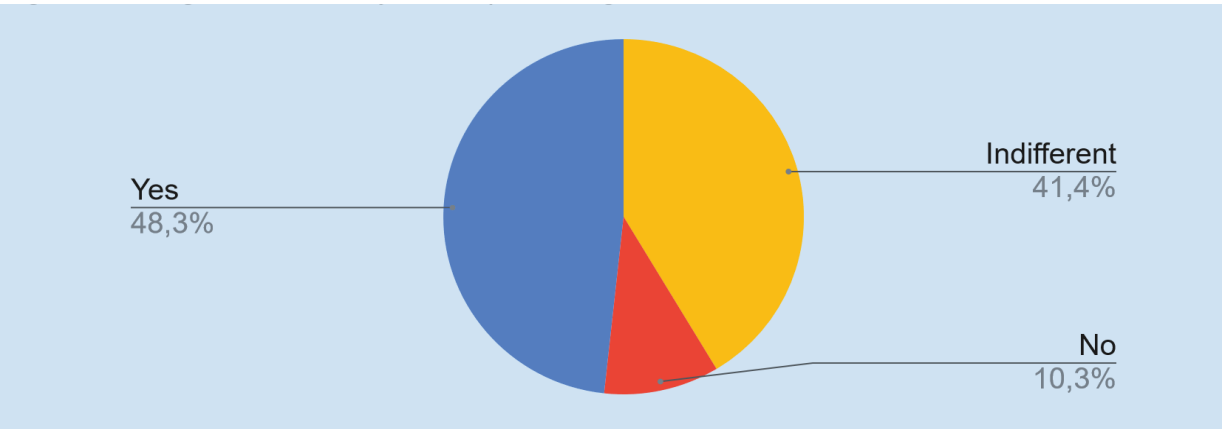

Diagram 4: Question 4

Question 4 asked the respondents if they would like the company that they work for to be more climate aware by prioritizing green coding or eco-friendly development higher, where they had three response options, yes, no, or indifferent. Diagram 4 displays the results of the answers, which shows that the majority answered yes, 41.4 percent were indifferent and 10.3 percent answered no.

Question 5

Do you think that the energy consumption of internet use has a direct and significant effect on global warming that needs to be taken into account?

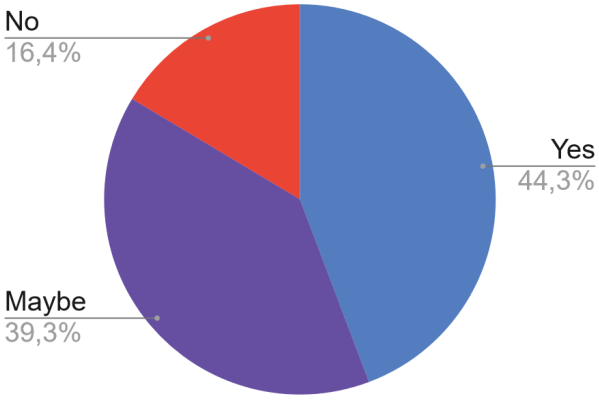

Diagram 5.1: Question 5

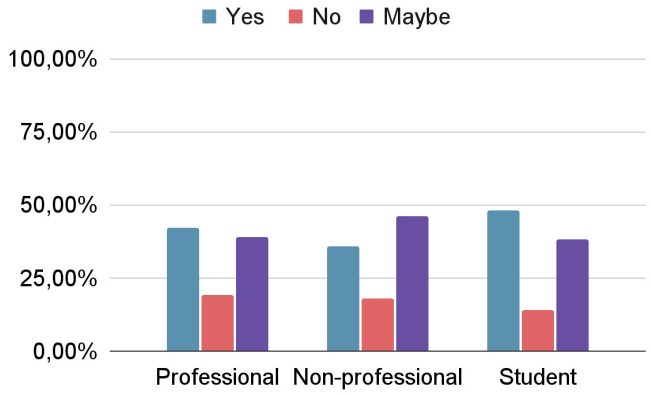

Diagram 5.2: Question 5

Question 5 explores if the respondents think that energy consumption of internet use has a direct and significant effect on global warming that needs to be taken into account. With this question we can get a broader perspective of these individuals' beliefs on the subject as internet use and web development go hand in hand. Diagram 5.2 shows the answer statistic of the three different respondent groups.

Question 6

Do you think about how the code you're writing can save energy when you're creating a program or an application?

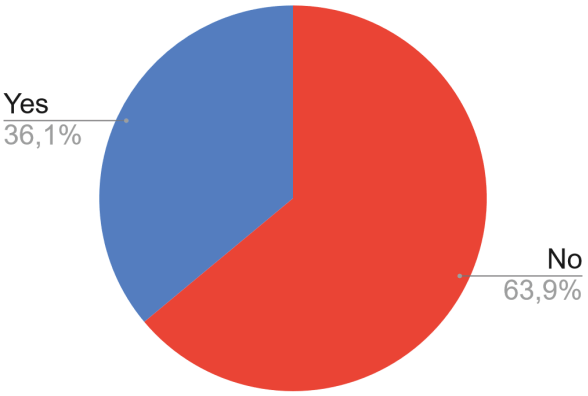

Diagram 6.1: Question 6

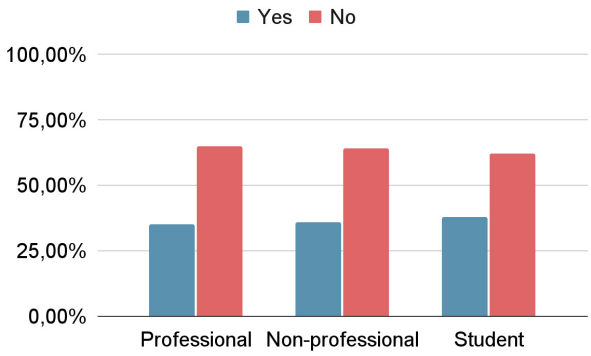

Diagram 6.2: Question 6

Question 6 asks the respondents if their mindset is on saving energy whilst creating a program or application. Diagram 6.1 reveals that 63.9% do not and 36.1% do. Diagram 6.2 reveals the answers from the different respondent groups, which seem to be quite similar.

There was a follow-up question to question 6 which is directed toward the respondents who answered yes to the previous question.

Question 7

Do you take energy consumption into consideration when you're choosing tools and techniques for a project? (For example programming language, architecture, or framework)

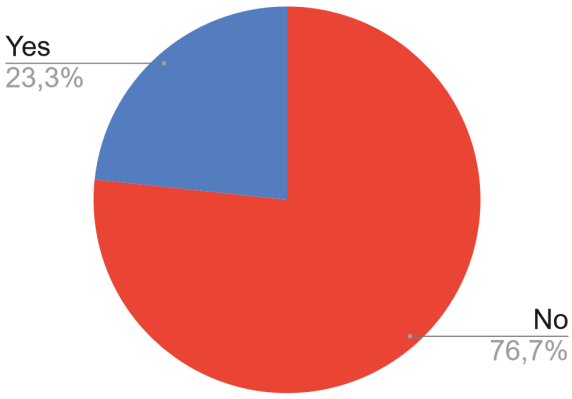

Diagram 7.1: Question 7

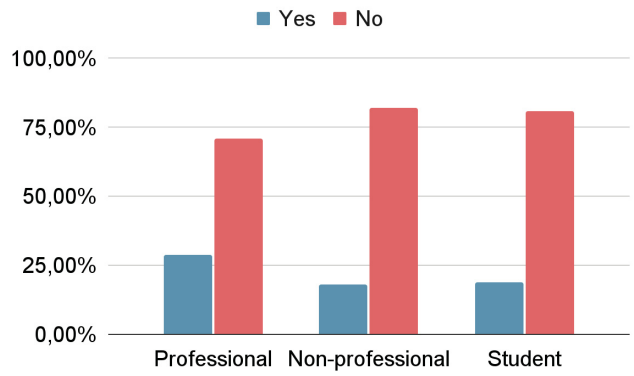

Diagram 7.2: Question 7

Question 7 is connected to question 6 and focuses on the choice of tools for a project. The question asks the respondents if they consider energy consumption when choosing tools and techniques for a project, for example language, architecture, or framework. Diagram 7.1, similarly to diagram 6.1, shows that the large majority answered no. Almost one-quarter of the respondents answered yes. Diagram 7.2 displays the response statistics of the three respondents groups which shows that the professional groups have a higher percentage of yeses in comparison to students and non-professionals.

Comments

At the end of the survey the respondents had the option to leave a comment about the subject which many did. A summary of the comments that were submitted is as follows. Several comments indicated that they haven't heard about green coding before but found it

interesting and wanted to learn more about the concept. Others seemed to be more skeptical of the idea of green coding by leaving comments like “This sounds like something someone who doesn’t write code would come up with” and “People really believe this stuff? Why can't people just do their own research instead of believing everything that the government says”. There were also many comments saying they believe that standard software engineering practices and optimization are already compatible with green coding. And others thought that green coding and eco-friendly development just aren't significant enough to make any kind of difference to the environment, calling them “useless”.

5.3.2 Survey analysis

From the survey results and specifically question 2, diagram 2.1, we can see that green coding as a phrase is not a widely known term. About 70% of the respondents answered no to the question “Have you ever heard of the phrases ‘green code’ or ‘green coding’?”.

Question 2 \ Question 5	Yes	No	Maybe	Total
Yes	12	1	5	18
No	15	9	19	43
Total	27	10	24	61

Question 2: Have you ever heard of the phrases "green code" or "green coding" before?
Question 5: Do you think that the energy consumption of internet use has a direct and significant effect on global warming that needs to be taken into account?

Table 1: The contingency table presents the number of responses to the different answer options for question 2 and question 5.

Of the 30% that answered yes to question 2, two thirds also answered yes to question number 5 which asks if they think that “energy consumption of internet use has a direct and significant effect on global warming that needs to be taken into account”. The majority of the rest answered maybe and only one person answered no, see table 1. The group of respondents that answered no to question 2 seemed to be more unsure about question 5 where the majority answered maybe, one third answered yes and about one fifth answered no, see table 1. It might be possible that the respondents who have heard of the phrase

"green coding" before also have been more exposed to discussions about climate change and its relation to the field and have more knowledge about the subject. This could have led them to be more convinced that the energy consumption of internet use has a negative effect on the climate which needs to be taken into account. It is possible to speculate that learning more about green code will lead you to answer yes to question 5 rather than no or maybe, but it could also mean that people who are more climate aware seek knowledge on how to be green in their field of occupation.

When looking at the results from the workplace section i.e, questions 3 and 4, we can see that more than 80% answered that green coding or eco-friendly development is not a topic of discussion in their workplace, see diagram 3. We can also see that almost half of the professional respondents want their company to prioritize green coding or eco-friendly development higher whilst around 40% are indifferent and only 10% said no, see diagram 4. By looking at these numbers it is possible to establish a lack of environmental thinking in the coding department at these companies, at least according to the employees answering this survey. As discussed previously in this essay, under the heading "purpose", there is a positive business aspect to sustainable companies, and as 90% of the respondents desire or are indifferent to their place of work being more climate aware, we can imagine a positive outcome for a company that prioritizes eco-friendly development higher. There is also a possibility that these companies, for different reasons, have made an active decision in not prioritizing green coding or eco-friendly development.

Question 5 / Question 6	Yes	No	Maybe	Total
Yes	16	1	5	22
No	11	9	19	39
Total	27	10	24	61

Question 5: Do you think that the energy consumption of internet use has a direct and significant effect on global warming that needs to be taken into account?
Question 6: Do you think about how the code you're writing can save energy when you're creating a program or an application?

Table 2: The contingency table presents the number of responses to the different answer options for question 5 and question 6.

About three quarters of the respondents that answered yes to question 6, which asks if the respondent thinks about how they can save energy when writing code for a program or application, also answered yes to question 5, see table 2. Question 5 asks the respondent for their view on internet use's effect on global warming and if they think that it is something worth considering.

Question 7 \ Question 5	Yes	No	Maybe	Total
Yes	12	2	1	15
No	15	8	23	43
Total	27	10	24	61

Question 5: Do you think that the energy consumption of internet use has a direct and significant effect on global warming that needs to be taken into account?
Question 7: Do you take energy consumption into consideration when you're choosing tools and techniques for a project? (For example programming language, architecture, or framework)

Table 3: The contingency table presents the number of responses to the different answer options for question 5 and question 7.

Four fifths of the respondents that answered yes to question 7, which asked if they consider energy consumption when choosing tools and techniques for a project, also answered yes to question 5, see table 3. This indicates that the programmers that make an effort in saving energy when choosing tools and writing code, also believe that internet use has a negative impact on the environment that is worth considering,

There was only one person that answered no to question 5 and also answered yes to questions 6 and 7. This respondent added the following in the comment section to question 6: ”I am an embedded developer, so power consumption is a big problem for us. We generally use low power peripherals/sensors and try to minimize the power consumption.”. This comment describes that saving energy is an important part of their work assignments which is not linked to environmental thinking but rather other interests.

When the survey was distributed in various groups and forums to encourage programmers to respond, it often generated a discussion about what "green coding" is and the participants'

opinions on the subject. It did not go unnoticed that many programmers felt attacked by the topic, one going so far as to call it gaslighting and claiming that there is no point in spending time on green coding and that all the focus should be on the big companies responsible for the big pollution. Other participants in the discussion stressed that a single individual will never create any meaningful change against big corporate pollution and that it will take a huge global movement to undo the damage that has already been done. It is important to point out that several people also expressed the importance of living clean and green in every way possible even if it might not make a huge change and would be really happy to work for companies that put time into creating green projects. These discussions and opinions that were raised align with the comments that were submitted at the end of the survey. Looking at the comments and survey results as a whole, it is clear that there is a wide range of opinions, which is not surprising given that global warming is a polarizing issue that arouses strong feelings in many people while others are completely unconcerned.

To summarize, in the analysis connections between the responses to question 5, asking the respondent for their view on internet use's effect on global warming and if they think that it is something worth considering, and the responses to several other survey questions have been discussed. The analysis of table 1 leads to speculation about programmers who have heard of green coding previously. The interplay and possible causal relationships between previous knowledge of green coding and the belief that internet use has a significant effect on climate change are presented. In the analysis of tables 2 and 3, a meaningful connection is made between programmers that try to save energy when choosing tools and writing code, and programmers that believe that internet use hurts the environment. The analysis of the results of the workplace section suggests that the coding department at the companies where the respondents work might lack environmental thinking. The great majority of the respondents want to or would not be negative towards a push within their own companies to prioritize eco-friendly development. This suggests that a company would not face any significant pushback from their employees if they made such a push, which could be beneficial from a business perspective. The analysis also states that green coding is a topic that gives rise to discussions and opinions among programmers.

6. Conclusion

The results for the three research questions presented in Chapter 5 have given us knowledge about how green code and environmentally friendly development can affect climate change, some effective techniques to code green, as well as the extent of programmers' awareness of green coding.

When looking at the results for RQ1 we can see a clear example where making lighter web pages lead to reduced emissions. It also discussed thorough tools that calculate how clean your website is. We also find that a lighter webpage in fact reduces emissions, but that it is difficult to calculate to what extent and how big the impact is on climate change.

In the results for RQ2, we learn that C and Rust are the most energy-efficient programming languages according to several studies. We also find out that interpreted languages PHP and JavaScript seem to be more efficient than Swift, Perl, R, and Python which are shown in the test cases to have the most energy-consuming implementations among the interpreted languages. The results under the heading Content and design show us that reducing image size and choosing the right formats can help us avoid heavy pages. We can do the same thing with font files and remove redundant CSS code. A connection between loading times and energy efficiency is also presented as well as ways to measure a web page’s loading times. We learn about an easy tool called PageSpeed Insights that makes suggestions on how to improve your website and that reports how much time that you can save by implementing the suggestions. It also exposes issues like redundant code and inefficient structures. The RQ2 result section also provides us with knowledge about GraphQL which is a query language that allows a client to fetch specific data without retrieving more than what was desired. GraphQL solves the problems with traditional REST APIs where it sometimes takes large and/or too many requests to retrieve the data rather than what should be necessary which isn’t very energy-efficient.

The survey result shows that the phrases “green code” and “green coding” are not well-known expressions, but there is however around 30% of the respondents that recognized the terms. We learn that the majority of the professional respondents' workplaces do not discuss environmentally friendly development, while a large proportion of the respondents would have liked it to be a higher priority. A little more than a third of all respondents said they think about how their code can save energy when they develop and a

little less than a quarter said they take energy consumption as a factor when choosing tools and techniques for a project.

7. Validity Threats

As you can read in the results section, 61 individuals responded to the survey in this study. Although it is a widespread group, in other words not just one university, class, or company answering, it is still not a very large group. A much larger group, for example 1000 people or more, would have been preferable in order to make more reliable findings from the results. The risk of using too small of a group when drawing conclusions for a much larger group as a whole is that the results might not be a good representation. If you added one or two zeros to the number of people who answered the survey the percentage of the different answers might turn out to be the same, but it is not possible to know without doing it. And even if it is a good representation, it is hard to prove without a large number. On the other hand, one could argue that 61 respondents justify you to draw if not firm then at least some conclusions. The reader of this essay should not forget the size of the group and the validity threats it poses when relying on the information and conclusions drawn in this essay. Especially considering questions 3 and 4 in the workplace section, due to them only being answered by the professional respondents who numbered 29 people.

Another issue that also is discussed in the results section for RQ1 is that the numbers for energy used per GB of data transferred seem to vary from different sources depending on what different variables are taken into account. People that have a green agenda with their research might use the higher numbers that are presented whilst others use the lower in order to advance their own opinions. It is difficult to know which numbers, in reality, represent energy used per GB of data transferred. When using these sources that are difficult to verify it is important to be suspicious of the data presented. Supposedly one has to decide if they rather overestimate the effect data transfer has on carbon emission or underestimate it. By overestimating it you will probably at least have a lighter and faster website if nothing else.

8. Future Work

When it comes to the possibility of following up and developing the study and the topic further, there are several ways to go. One interesting and significant path would be to get in touch with a company whose web applications have a lot of traffic and work with optimizing energy efficiency similar to what van Kooten did with his WordPress plugins [10]. Working with a company with a lot of potential for improvement when it comes to energy consumption could help us visualize what kind of impact that sort of strategy could have on a broader scale.

Another idea for further work on the study would have been to try to develop clear examples of green coding, i.e. developing algorithms that have minimal energy consumption. It would be wise and more doable with a larger group of people who have different lines of expertise to create good examples and to ensure that all factors are taken into account.

It would also be good to work on getting a significantly larger group to respond to the survey in order to get a more accurate picture of the awareness and views of this group of people. It could be interesting to evolve the survey to go deeper into some topics, for example, what the respondent prioritizes when coding and what it would take for them to value energy efficiency higher. The survey could also be repeated after a good amount of time to see how the results differ and explore if phrases like green coding simply were a trend or if environmental awareness has made its way into the world of programming on a larger scale.

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10. Annexes

Appendix A. Survey questions

* Mandatory

1. What type of programmer are you? *
    - student
    - professional
    - non-professional
2. Have you ever heard of the phrases "green code" or "green coding"? *
    - yes
    - no
3. Is green coding or eco-friendly developing a topic that is discussed at your workplace? * (If the respondent is a professional)
    - yes
    - no
4. If the answer above is yes, feel free to mention a situation when it is discussed.
    - written answer
5. Would you like for the company that you work for to be more climate aware by prioritizing green coding or eco-friendly development higher? * (If the respondent is a professional)
    - yes
    - no
    - indifferent
6. Do you think that the energy consumption of internet use has a direct and significant effect on global warming that needs to be taken into account? *
    - yes
    - no
    - maybe
7. Do you think about how the code you're writing can save energy when you're creating a program or an application? *
    - yes

- no

8. If the answer above is yes, feel free to elaborate in what way.
    - written answer
9. Do you consider energy consumption when you're choosing tools and techniques for a project? (For example programming language, architecture, or framework). *
    - yes
    - no
10. If you would like to add anything else about the subject please leave a comment here.
    - written answer