Life Cycle Assessment of Website Development

Working Paper · December 2016

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1. Goal and Scope

1.1 Goal of the Study

A) Project Background

The Internet has been a driving force in connectivity, efficiency and social change since its inception (Kinney, 2000; Gard & Keoleian, 2002). Despite these significant achievements, there is an environmental cost that is often overlooked. There has been little debate on the environmental impacts of the Internet in public thus far; however, there have been many improvements in efficiency and a reduction in impacts per user over time from a hardware perspective. The development of new hardware such as tablets and mobile computing (EPA, 2016), as well as virtualization and load balancing of servers (Koomey, 2008; Jin et al., 2013) has led to the potential for a significant decrease in the impacts of the Internet per user. An increasing volume of users as well as growing content sizes are negating these efficiency gains and fueling a growth in energy usage (CIRA, 2014).

The current meme being spread around the Internet is that "the Internet is Doomed" which references the fact that the average web page is now the size of the original game Doom which was 2.3MB (Finley, 2016). Although the Internet is growing at an ever increasing rate, most companies are not questioning the impact of the infrastructure and communications via the Internet. Practices as simple as responsible web design are not implemented throughout the industry. In fact, the trends tend to be the opposite and many companies are increasing the impact of the Internet such as video and music streaming websites that require significant bandwidth (Hochschorner & Moberg, 2015). The Netflix CEO remarked that "it's almost a human rights violation what they're charging for Internet access in Canada" when the company entered Canada (Obourn, 2015). By Internet access, Mr. Sarandos was referring to bandwidth fees specifically.

The impact on the environment in the case of web design, development and usage, is in the form of energy generation and consumption required to accomplish a function or communicate a message. It is the practices of users, developers and hosting companies and not the infrastructure that are the focus of this study. Many studies have already attempted to calculate the impacts of the Internet infrastructure partially or as a whole (Müller et al., 2013; Koomey, 2008; Mayers et al., 2015; Borggren, 2011; Hochschorner & Moberg, 2015; Gard & Keoleian, 2002). There were multiple studies that compared the Internet as a delivery medium to traditional delivery methods in various industries including music, newspaper and gaming (Gard & Keoleian, 2002; Hochschorner, 2015; Weber et al., 2010). In these reports, sensitivity analysis was critical to reporting results since there are many potential paths and configurations for delivery via the Internet. This study will incorporate sensitivity analysis for various scenarios as well.

A study that examined digital mediums versus offline ones for reading the news, discovered that the impact of the accessing data online varies significantly with time of use and speed of reading and that there is large uncertainty in estimating Internet energy consumption (Reichart, 2002). This means that many assumptions need to be made when creating a virtual LCA that could affect results substantially therefore sensitivity analysis is critical. A study examining the efficiency of music distribution online found that emissions increased notably when file size increased and concluded that file size is a driving factor of emissions from digital products (Weber, Koomey & Matthews, 2010). To add to the complexity of the problem, Schien et al. attempted to determine the energy consumption of online multimedia services but uncovered many variables that strongly affect the impacts. They determined that the connection type such as cable, DSL or 3G networks vary in impacts and that there is a large difference in energy usage from top-down and bottom-up Internet studies (Schien et al., 2013).

Although, the studies discovered many factors that influence the impact of data delivery over the Internet; none examine the practices of building the websites that interact with users. *Schien et al.* used 10 minutes of web browsing as a functional unit for a visitor viewing the news in using different mediums; however, this is not how the Internet functions as there are varying Internet connection speeds. The functional unit should be based on a measure of data transmission and the number of requests. This study will further the analysis of Internet communications by including data transmission as the functional unit. This is a critical part of the usage phase for the whole Internet life cycle as it can have a profound effect on the environmental impacts of users. Designers, developers and hosting companies can control a significant portion of the factors that influence user impact; however, this view is not considered in many development environments or practices. This study will outline some of the practices that can conserve energy and improve the efficiency of a website.

On the "Doomed Internet", many designers and developers create multimedia laden content pages and/or use platforms that are bloated with superfluous features which increase page size, load time and environmental impacts. Page size has increased by over 2000% in the last 16 years (Tech Attitude, 2010; Key CDN, 2016; HTTP Archive, 2016). This is the major aspect of the design and development phase that will be examined.

Another is user device impact. With the development of smaller and more energy efficient devices such as laptops, tablets and smart phones, the ability for developers to minimize user impacts have been significantly increased. One demonstration of this is the practices of building websites to be "mobile first" which reduces the bandwidth requirement of downloading the content (Hernández-Nieto et al., 2015). Another important factor is server distance from the client and information distribution network. These factors are beyond the scope of this study but will be examined briefly in sensitivity analysis.

Although the web is considered a global network, it is interesting that page size is now being disregarded by most designers and developers in developed countries. Other countries still have limited access to the Internet and web pages would become unusable on older modems that are still used in rural areas and other countries like Africa. For example, the load time for an average web page of 2.3MB in 2016 on a 56kbps modem would be 7 minutes (Munyaradzi & al., 2013). This paper will focus on Internet usage in Ontario, Canada; however, readers should be aware of international considerations and that high speed Internet is not available worldwide.

B) Reason for the Study

Most people assume that the Internet and digital products are more environmentally friendly than traditional mediums but that is not necessarily the case (Mayers et al., 2015; Hochschorner & Moberg, 2015; Weber et al., 2010). The purpose of this study is to examine the actual impacts of user interactions with a website and how those impacts can be reduced. Ideally, this would lead to the implementation of more sustainable web development and design practices that significantly reduce the environmental impacts per website interaction. There are also international development considerations since the Internet is global and not all users have equal access to high speed Internet (Munyaradzi & al., 2013). It will also help determine the factors with the largest environmental impact in the web development process.

C) Type of Study

In order to demonstrate the environmental impacts of various web development practices and phases, the study will develop a cradle-to-grave LCA to examine the impacts of the average Canadian web page in 2016.

D) Goal of the Study

The goal of this study is to assess the environmental impacts of web design and development practices in 2016 in Canada. Sensitivity analysis will be used to compare the LCA results to a more useable page size without major functionality loss in sensitivity analysis. For the useable page size, the study will use the value of 100KB recommended by *Munyaradzi & al.* as the maximum page size for African web pages. In essence, the goal of this study is to assess the potential to decrease the impact of Internet without losing the ability to accomplish tasks (ie. finding contact information, placing an order, etc…) as well as to research the development of a new low impact content management system (CMS).

Objectives:

- To compile a detailed life cycle of environmental burdens associated a website
- To use the life cycle inventory data to compare potential environmental impacts from average websites and a low bandwidth alternative
- To identify activities with the highest environmental impact from website development to usage

E) Intended Application of LCA Results

This report is intended to inform readers about the impacts of websites, design principles and the Internet as well as provide information on how to reduce these impacts. It will also be used to inform the development of a new low bandwidth platform.

F) Intended Audience

The intended audience is web development practitioners & researchers, policy makers and Internet users in general.

1.2 Functional Unit

A) Function of Product and Service

The function of the Hypertext Transfer Protocol (HTTP) is to transfer of data (information) over long distances between a user (client) and a publisher (server).

B) Functional Unit

The functional unit is bandwidth. It measures the quantity of information distributed to accomplish a task. The study uses 1GB of transferred data as a functional unit.

For a frame of reference, "With one GB of data you can send/receive 105,000 emails, download more than 200 songs, download about 1½ movies or stream about one hour of Netflix." (Obourn, 2015) or you can view 435 average (2.3MB) web pages.

1.3 System Boundaries

The system boundaries are the development and usage phase for the Hypertext Transfer Protocol (HTTP) web pages over the Internet. This study excludes the manufacturing of hardware as is standard in Internet LCA studies (Schien et al., 2013).

This system has three major activities included:

A) The design and development of a website

It is common practice for developers to create websites locally and upload them to the Internet upon a satisfactory version. This is the assumption adopted for the purpose of this study. The implications are that no bandwidth is used during the manufacturing phase of the website. If the website is developed live on the server, this will increase the impacts of this phase.

B) Transmission of the website data (Bandwidth)

The Internet is used as a transportation medium to send the website information to the user from the hosting server at the user's request. The transmission via the Internet uses significant amounts of energy and infrastructure. Infrastructure; however, is not included in the study as it is considered capital equipment.

C) The client usage of a website

The software and hardware manufacturing required to visit a web page are not included in the study as is common in Internet LCAs. Energy use from the laptop to view the web page is included. The activity boundaries begin with the user landing on a web page to find a specific piece of information or accomplish a specific task (ie. place an order). For simplicity and scale, this study uses 1GB of data transferred (approximately 435 page views of an average web page) as the task and assumes that the user finds what they are looking for immediately. The process ends when the user has located the information and downloaded the pages containing the desired information. The information is then locally stored on the user's computer and uses no bandwidth to view the page. It only uses energy for the laptop to display the page until the user takes an action.

A technical description from the book *Electronic Commerce* outlines the process as follows:

> "Web clients request files from a distant Web server. Using the Internet as the transportation medium, the request is formatted using the HTTP protocol and sent to the server computer. A moment later, when the server receives the request, it retrieves the file containing the web page or other information that the client requested, formats it using the HTTP protocol, and sends it back to the client over the Internet.
>
> When the requested information – a file containing the text and markup tags of a web page, in this instance – arrives at the client computer, the Web browser software determines that the information is an HTML page. It displays the page on the client machine according to the directions defined in the page's HTML code. This same general scenario is carried out repeatedly as the client requests, the server responds and the client displays the result." (Schneider, 2002, p.65)

See figure 1 for the system boundaries diagram.

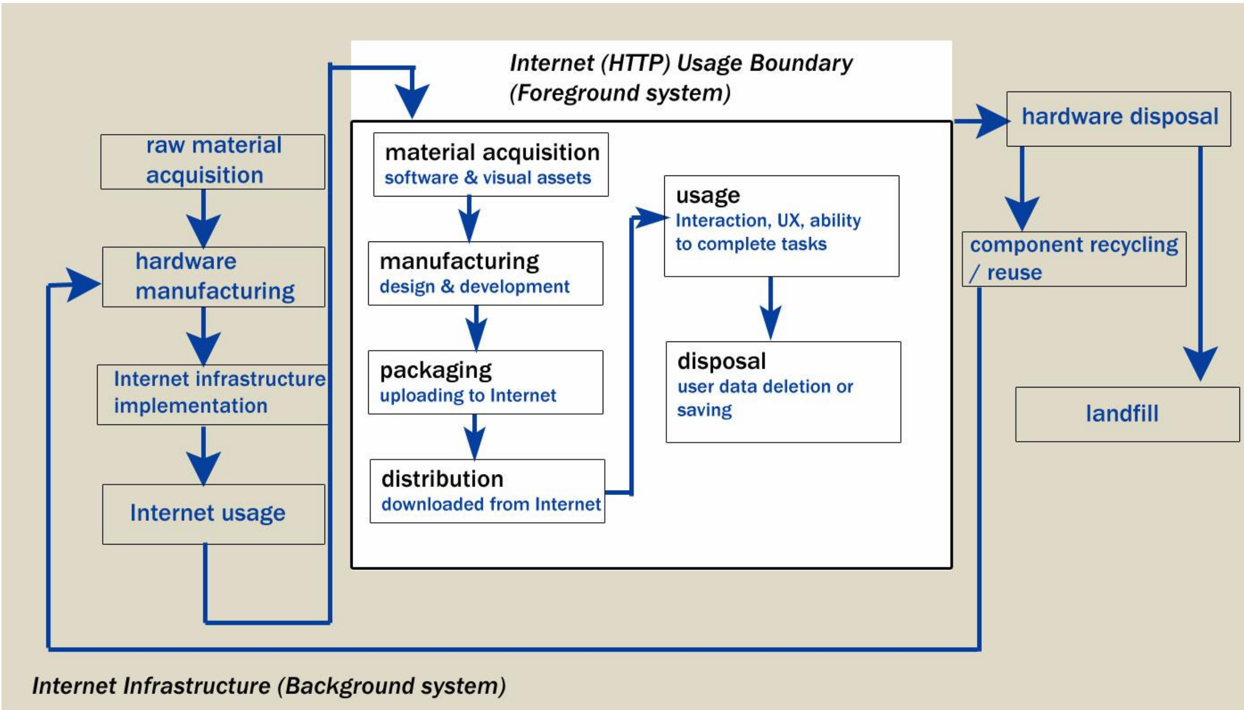


Figure 1 - Foreground and background systems as applied to study concerning Internet HTTP Usage

Geographical boundary is a difficult consideration to make since the Internet is a global infrastructure. It will be assumed that the user is from Ontario, Canada. The use of content delivery networks (CDNs) is an example of how some sites attempt to host their content closer to users (Beal, n.d.; Schien et al., 2013) which eliminates the impact of geographical boundaries for the most part.

Web technologies and efficiency change rapidly and information is often not reliable for long periods of time.

Processes of hardware manufacturing and disposal are not included in the study as their impacts would be negligible due to allocation required over the lifetime of hardware (Mayers et al., 2015; Hochschorner & Moberg, 2015; Weber et al., 2010). Manufacturing and disposal of Internet infrastructure is not included in the system boundary either as this is capital equipment.

“As is standard practice in carbon footprinting, emissions from the manufacture of capital equipment, including vehicles for transport, the construction of facilities used in manufacturing and distribution, and energy used in running offices used for management and administration, are excluded from the study scope (BSI 2011).” (Mayers et al, 2015, p. 405)

There are no co-products in the system.

1.4 Assumptions and limitations

A) The Design and Development of a Website

Web design and graphics design are subjective tasks and there is no set amount of time for design which strongly depends on the developer and technology. The study will use a range of potential development times for a small website according to real web developers from various forums to do sensitivity analysis. This can account for various platforms, experience and language differences. The assumption is made that the developer only posts the information once and is in the same location as the client to simplify the Internet impact calculation. The values used for kwh/GB may change if the users are in different locations. The maintenance and content updates are not included in the calculations. The study also assumes the development phase is done on a local server that does not require the Internet (for the manufacturing and packaging phases). This is common practice in the industry. It is assumed that the websites are developed using a laptop with single display for energy calculating purposes.

B) The Usage of a Website

Sensitivity analysis could be conducted for various devices including desktop, laptop, tablets and smart phones as they have significantly different impacts (EPA, 2016); however, this study focuses on laptops. We assume average Canadian user behaviour and a similar reading time to Reichart at 90 seconds per page. The impact of Internet infrastructure is based on bandwidth used by each web page.

C) Server Location and Hosting

The distance from client to hosting server changes the overall impact of the transfer of data through the Internet infrastructure since it may use more servers for a longer distance. The energy mix of the grid near the server would also change the impacts. A locally hosted server will have a lower impact than a server that is far away since it will connect through fewer servers. For the purpose of this study, the energy requirements from Mayers et al. will be used to estimate Internet infrastructure impacts. The servers used will be volume servers as they are most common (Koomey, 2008). It is also assumed that shared hosting is used since it is common for small websites. Most websites require little in the way of server specialization therefore we will use Koomey's estimate of 186W per server. There are many considerations with regards to servers including hardware, architecture and virtualization that are not included and could be addressed using sensitivity analysis of server power usage ranges.

D) Energy Generation and Impacts

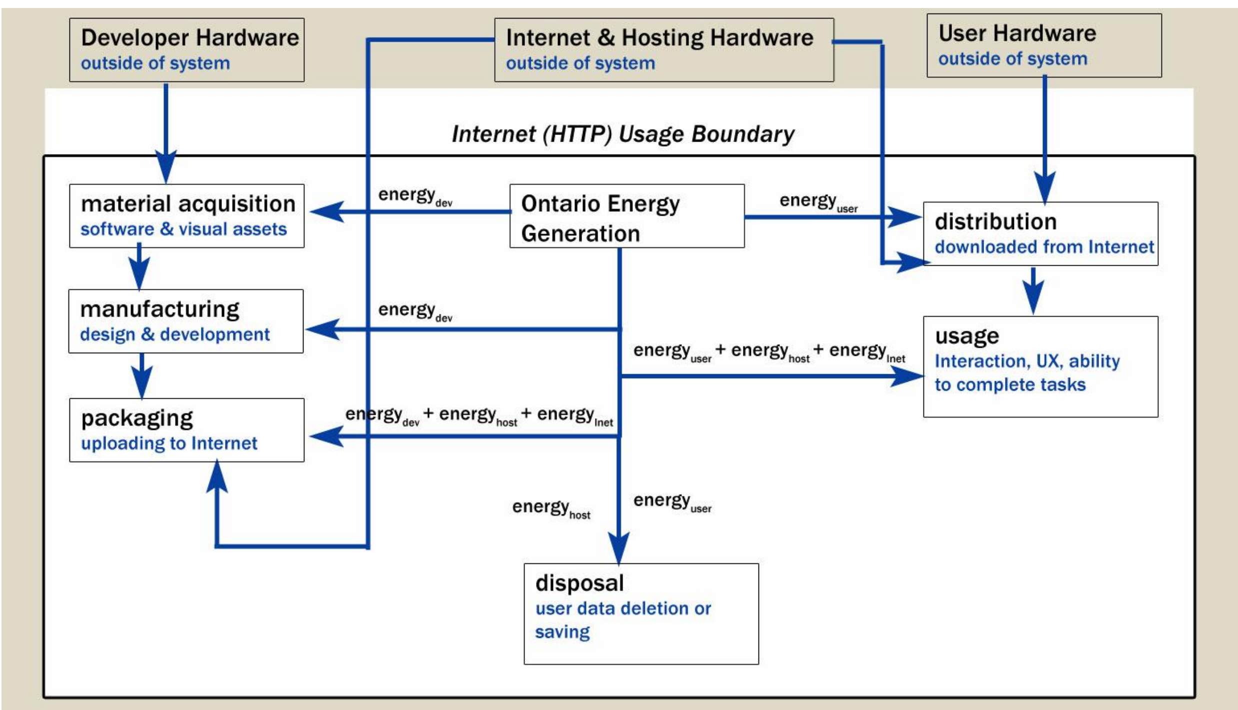
The Ontario energy mix will be used to calculate environmental impacts of the energy required in each activity. The study will assume the Canadian Internet infrastructure has similar energy requirements to that of Sweden.

1.5 Impact categories and impact assessment method

The major impact categories for web design, development and distribution are global warming potential, resource depletion and air pollution from energy generation (IESO, 2016). There are also other human and eco-toxicity impacts that could be included such as radiation and toxicity from the equipment usage and disposal; however, they are beyond the scope of this study and are not typically included in Internet LCAs. The EPS 2000 and Eco-indicator '99 indices will be used to assess the impacts.

The Ontario energy generation mix is primarily composed of nuclear and hydro-electric power (IESO, 2016). The impacts measured by the IESO are GHG emissions and pollution from air contaminants: SOx, NOx and PM2.5 (IESO, 2016). The resource use impacts are also important for energy generation materials such as uranium and natural gas. There is no mention of the impact of nuclear waste disposal but this is a potential impact that could be added.

2. Life Cycle Inventory Analysis



$energy_{dev}$ = hours * laptop energy
$energy_{host}$ = hours * server energy
$energy_{Inet}$ = energy/hr * (bandwidth/modem speed)
$energy_{user}$ = hours * device energy
$energy_{tot\_dev}$ = $energy_{dev}$ + $energy_{host}$ + $energy_{Inet}$
$energy_{tot\_usage}$ = $energy_{tot\_dev\_all}$ + $energy_{user}$ + $energy_{host}$ + $energy_{Inet}$

See appendix A and B for data, energy calculations for development and usage, respectively.

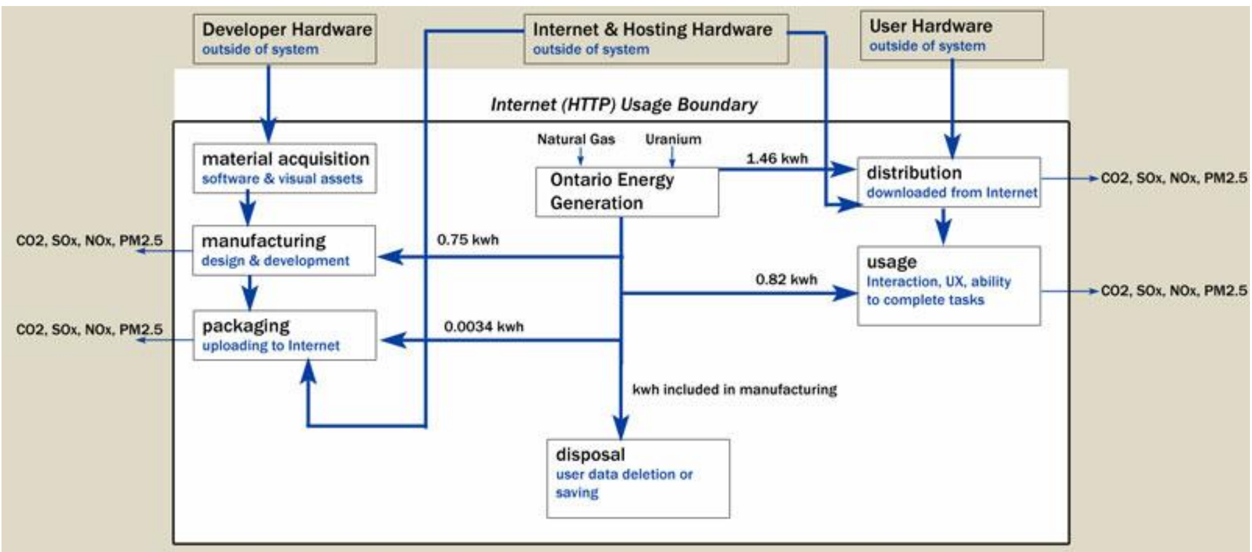
See Excel model for all data and calculations including impacts.

2.2 Data

The requirements for data quality should be representative of current Internet and website usage. There are limited data sources due to the complexity of the Internet infrastructure and the difficulty in calculating impact so the best available data will be used. Data that is less than 3 years old is recommended and most recent data will be given preference.

Appendix C outlines the data required and the sources used to collect the data.

Appendix D analyzes the data quality based on Weidema and Wesnaes (1996).



3. Life Cycle Impact Assessment

The life cycle impact assessment includes many of the relevant factors but excludes land use impacts which could be significant due to the energy mix including hydro electric and renewable sources. It also excludes the disposal of nuclear waste and the impacts of ionizing radiation from uranium as required data is unavailable.

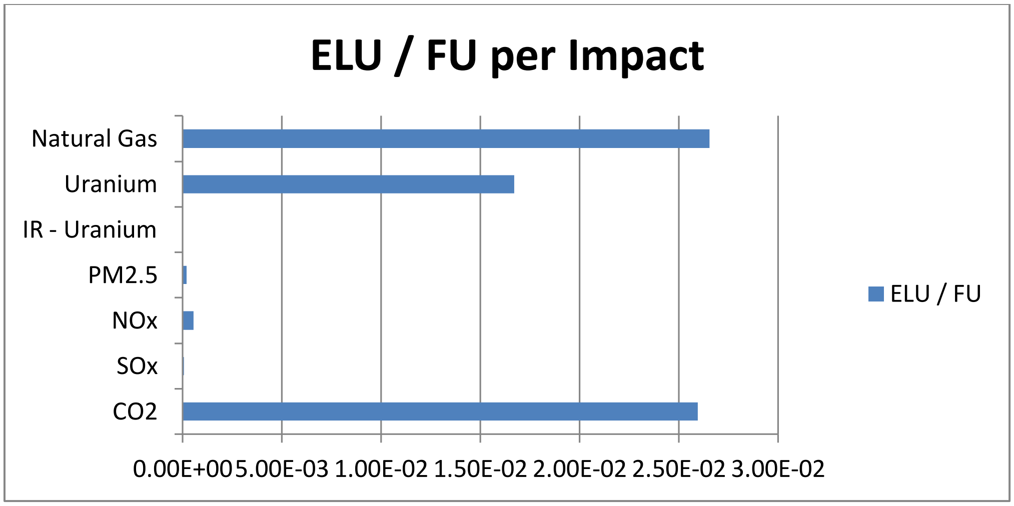


Figure 2 - ELU per Funtional Unit for the Web Development Lifecycle (excluded equipment) using EPS 2000

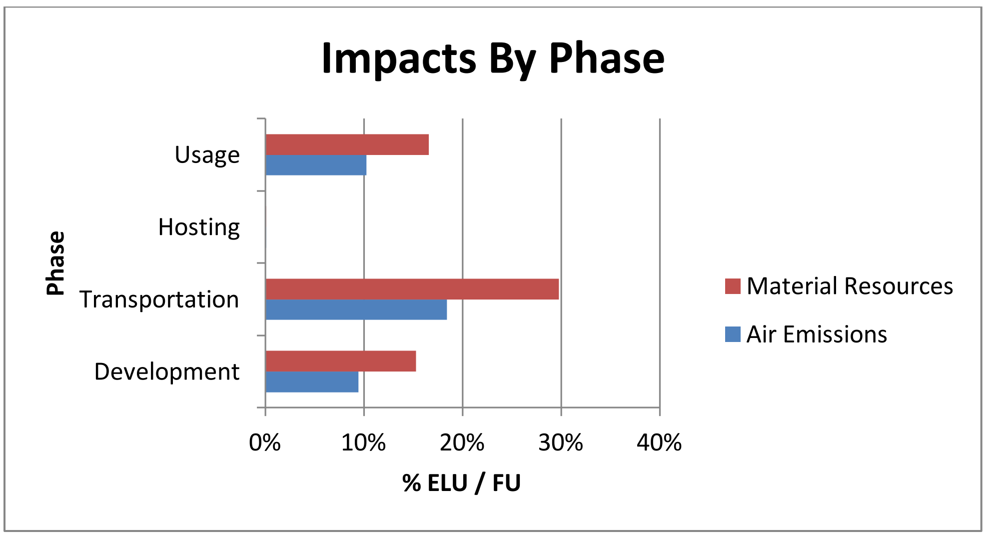


Figure 3 - Impacts by Phase for the Web Development Lifecycle using EPS 2000

3.1 Detailed life cycle of environmental burdens associated with the development and usage of websites

A website life cycle is very different than a traditional product lifecycle. Once the development is completed (product created), it may be re-used multiple times with no additional manufacturing. This means that the usage and transportation phases continue on indefinitely until the site is no longer active. This study analyzes all phases and includes 1 FU of usage and transportation (1 GB of data); however, the usage and transportation phases are likely to include many GBs of data over the lifetime of the website. It is important to remember this fact while analyzing the results.

The results using the EPS 2000 index demonstrate that transportation, the Internet transmission, accounts for approximately 48% of the environmental impacts. The usage and development phases each account for 27% and 25%, respectively; however, this is misleading since the usage phase will continue to grow in impact as usage increases. Also, the development phase impacts could easily change depending on the complexity of the page being developed. These factors will be further analyzed in sensitivity analysis.

The hosting phase appears to be negligible in the study accounting for only 0.2% of impacts; this is due primarily to allocation. Many hosting servers are virtualized and share resources especially for low traffic sites also the server specifications used are not for a high-end server. These impacts could change significantly by changing the hardware and allocation figures. An LCA on the hosting phase could provide much more insight into the impacts of this phase. There are data centre LCAs; however, none were found that could be used to reasonably allocate the impacts for the functional unit of the study.

The main environmental impacts of the website are from energy generation to power hardware. The material resources category accounts for 62% of the impacts due to the Ontario Energy mix which uses mainly nuclear. Natural gas is also included in this impact category but accounts for significantly less energy generation (IESO, 2016). The inclusion of hardware manufacturing, capital equipment and shared infrastructure may change these results; however, there are significant allocation problems for the Internet due to its complex organization, functional variability and redundancy.

3.2 Highest environmental impact from website development life cycle

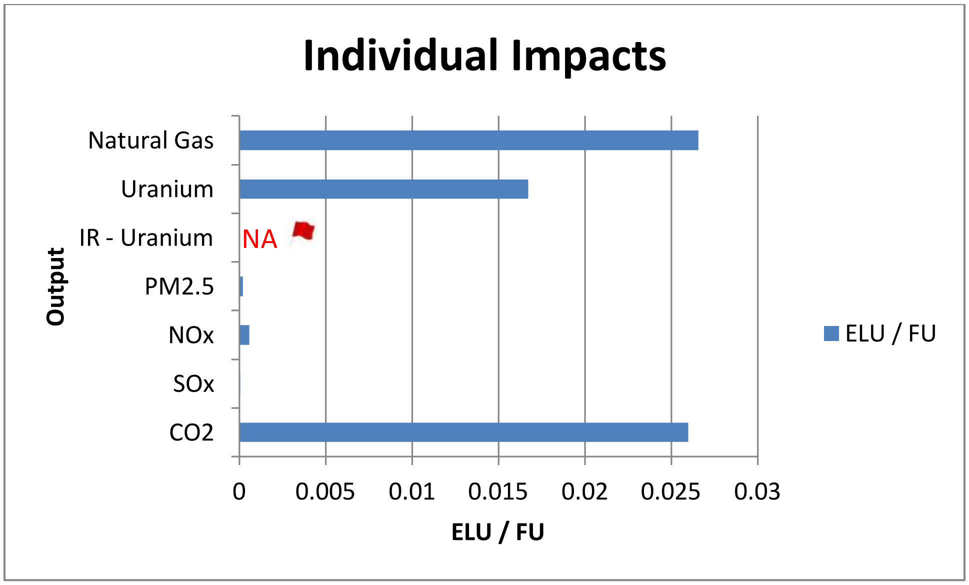
The highest environmental impacts are attributed to the transportation phase using both the EPS 2000 and Eco indicator ’99 indices. The usage phase would be the 2nd highest impact as it will grow with additional FUs of use. This will be examined in sensitivity testing to give additional information on how this phase may vary.

Transportation accounts for approximately 50% of the impacts; however, this will increase along with usage over the lifetime of the website. This is more of an estimate using best available data as opposed to a calculation. The information available for Internet assessments is growing; however, there remains a great deal of uncertainty in the calculations for many reasons. The figure used in the study was towards the lower end of the values estimated, at 1.46kwh/GB (Mayers et al, 2015), however; other credible studies found this number to be as high as 7kwh/GB (Taylor & Koomey, 2008; Weber et al., 2010). Scenario analysis will be used to determine the changes this would have on impact estimates.

The usage phase accounts for approximately 27%. This is based on the FU of 1GB of data (or 435 average page views). This value will increase as the website is accessed more often. Development, on the other hand, is unlikely to increase significantly over the product lifetime although it is almost equal to usage phase in the scenario used. In the situation where the website is used for less than 1GB of data transmission over its lifetime, the development phase would have larger impacts than the usage phase with the data used.

3.2.1 Contribution Analysis

The largest impacts are from resource depletion of natural gas and CO_2 emissions. These values would change significantly based on the energy mix of the region or country for which the study is conducted. For the purpose of this study, this is Ontario, Canada. Uncertainty analysis is done below to examine how these impacts would change.



4. Life Cycle Interpretation

4.1 Break-Even Analysis

Comparative LCAs have been done with regards to distributing music, news article and gaming online and offline (Gard & Keoleian, 2002; Hochschorner, 2015; Weber et al., 2010). In the case of web pages, it would be difficult to accomplish this same analysis as there is no suitable offline substitute with the same characteristics. To demonstrate this, use the example of a marketing flyer which could advertise a product much like a web page. The flyer has finite space and no interactivity like a web page. A user can direct their own interaction and select information displayed on a website; however, this is not an option with offline mediums and thus a comparison would have limited value. Furthermore, a website's lifetime may be infinite at this point as some of the first developed websites in the 90s are still useful and usable today (Reilly, 2013).

4.2 Decision Maker Analysis

4.2.1 Hosting

Although hosting appears to be the lowest impact of the web page lifecycle, there are many factors that are excluded in the study that could change these results.

Data centers can have a significant impact and many use a measure called PUE to optimize efficiency (Matt, 2015). There are also eco-labels in place to help users reduce the impacts of hardware such as ROHS (ROHSGuide, n.d.). The hosting server location relative to the user would have an impact as well; however, with the existing data it would be difficult to quantify. The use of CDNs is one way to minimize these additional impacts (Beal, n.d.; Schien et al., 2013). Another option is using a green hosting provider who minimizes their impacts and uses green energy to power their services (HostPapa, n.d.). Localized hosting relative to the average website user would also reduce the impacts of the transportation phase as less hardware would be required.

4.2.2 Usage

The diagram below represents how the impacts of the usage phase change for various devices including laptop, tablets and smart phones as they have significantly different impacts (EPA, 2016). This demonstrates the importance of responsive and mobile first design practices in web development. Due to the energy differences in network types, it would be important to include them for the various devices in the transportation phase as the 3G network used by smart phones is estimated to use approximately 7 times more energy than wired connections (Frick, 2016). There are other design principles that can affect the results of this analysis such as web page colours. Differences in colours require less display energy. Blackle, a modified search engine based on Google, describes how pixels do not have to be lit on LCD screens if the colour is black (Blackle, n.d.). This is only true for certain types of screens, others use less energy when displaying white (Frick, 2016).

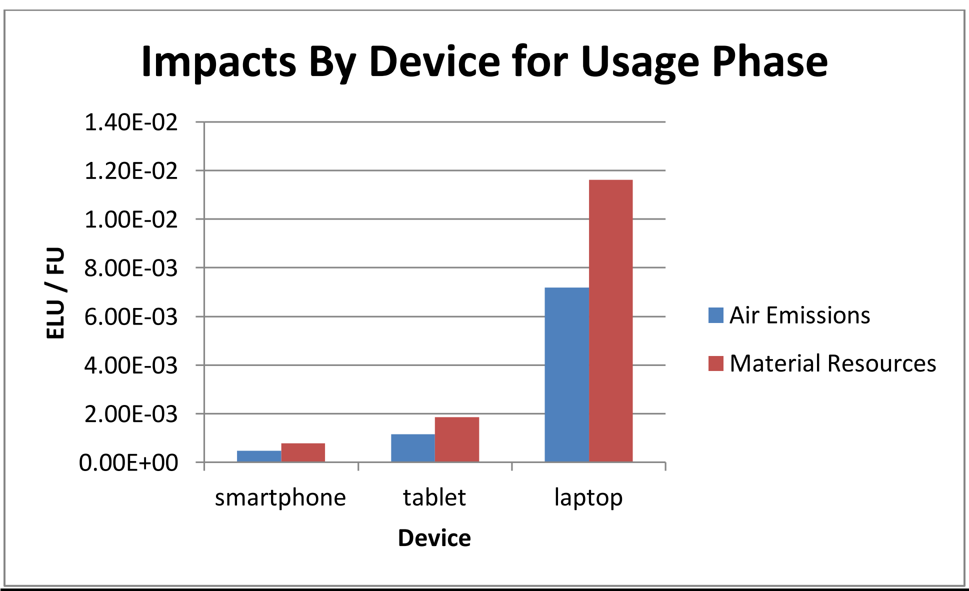


Figure 4 - Impacts by Device for the Usage Phase using EPS 2000

4.3 Uncertainty Analysis

4.3.1 Page Size

In order for this analysis to be representative of the process, it is important to scale the FU from 1GB to 43.5MB for the 100 KB page. This represents the same 435 page loads from the initial study but for the page size recommended by Munyaradzi & al. for African web pages. This factor only impacts the transportation and hosting phase therefore development and usage are omitted from the analysis.

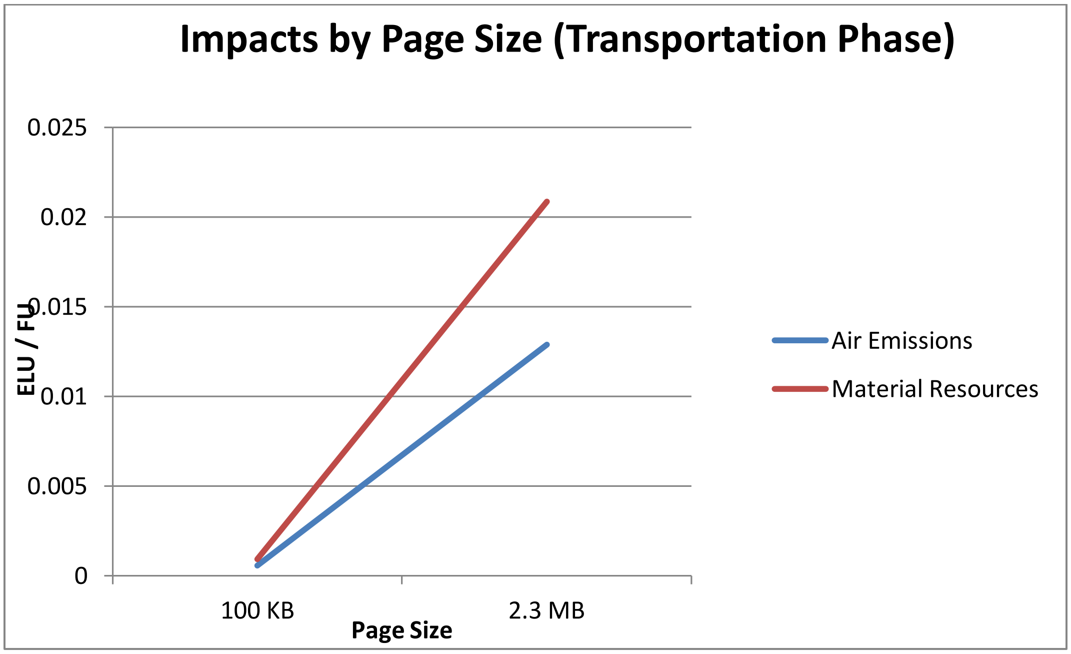


Figure 5 - Impacts by Page Size for Transportation Phase using EPS 2000

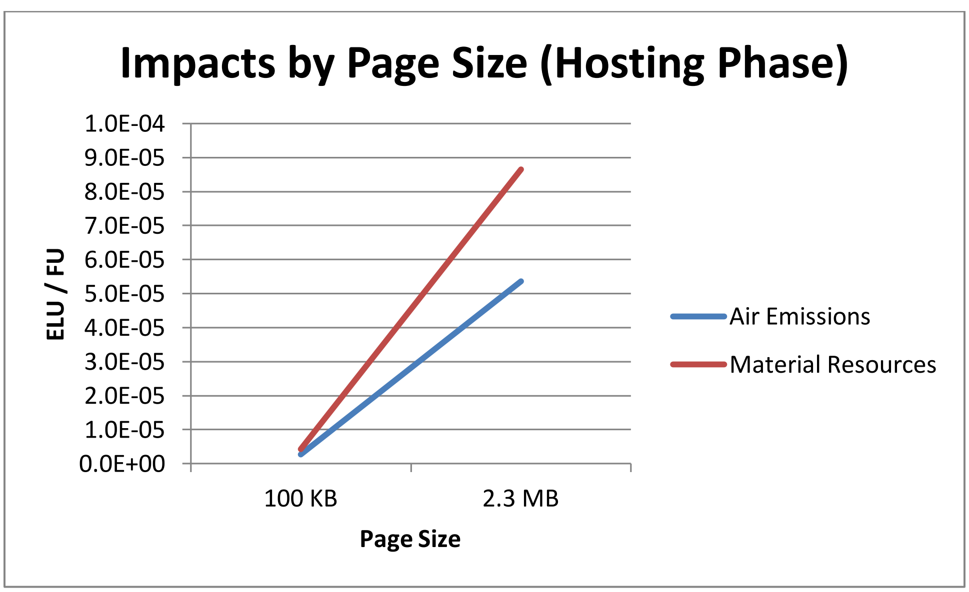
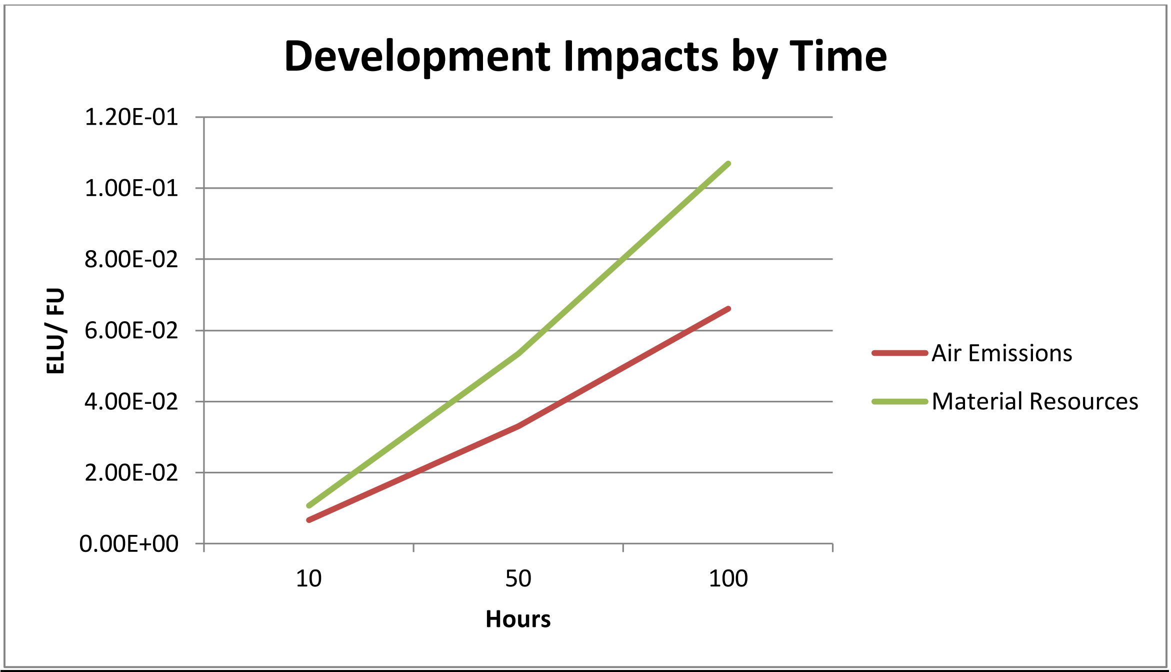


Figure 6 - Impacts by Page Size for Hosting Phase using EPS 2000

These graphs demonstrate a linear relationship which is unlikely; however, there is not enough data available to develop a more accurate analysis at this time.

4.3.2 Development Time

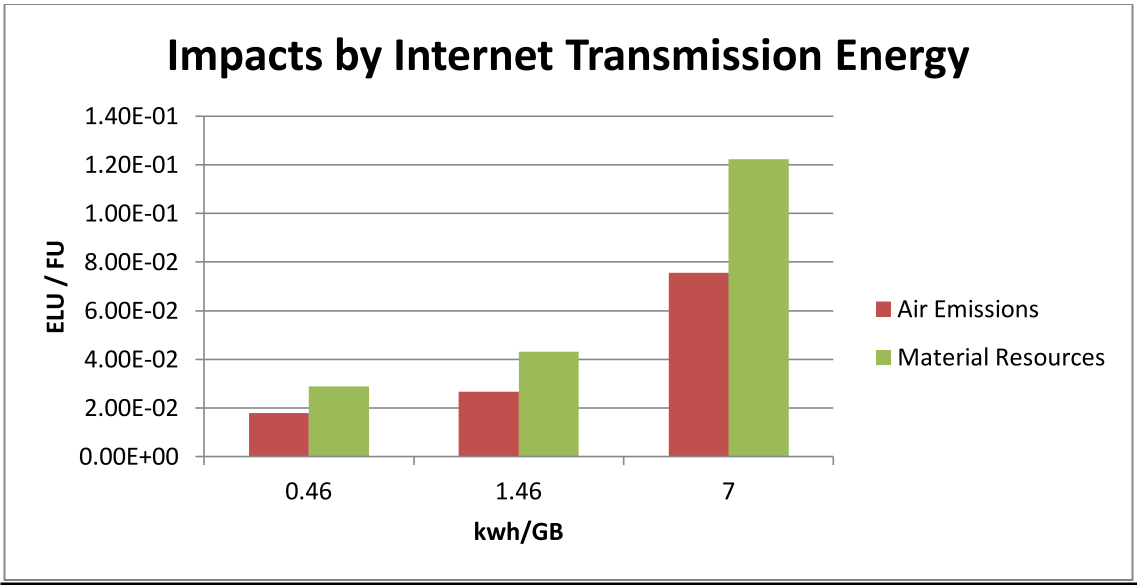
The amount of time required to develop a website is highly variable. In order to determine the potential impacts of the development phase, this analysis assesses the change in impacts in relation to number of development hours.



4.3.3 Internet Transmission Energy Use

There is a great deal of uncertainty with regards to the energy use of the Internet and telephone networks (Reichart, 2002). The study used the figure of 1.46 kwh per GB; however, this analysis explores the possibility that the Internet impacts could be inaccurate. Better figures for this calculation are required to increase the level of certainty.

There are a few important factors that can affect the energy usage calculations for the Internet and would explain the significant differences in various reports. Energy usage varies by type of Internet connection. There are multiple options such as telephone line, cable, fiber optics and wireless towers. The hardware used for the Internet infrastructure is also critical since different servers and technology have different measures of efficiency for the FU (Schien et al., 2013).



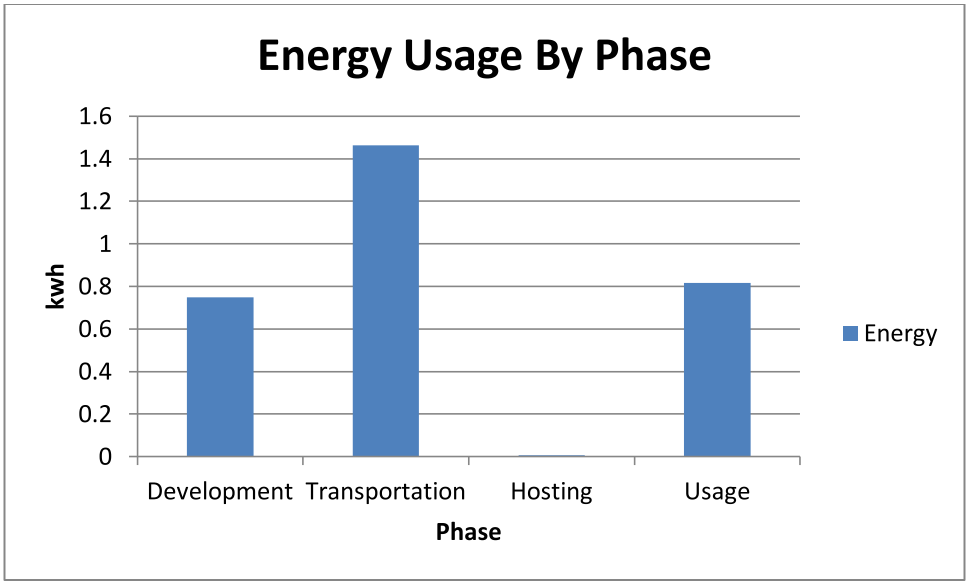
***0.46 kwh/GB (Mayers, 2015)**
***1.46 kwh/GB (Mayers, 2015)**
***7 kwh/GB (Taylor and Koomey, 2008), (Weber et al., 2010)**

4.4 Variation Analysis

4.4.1 Energy use per phase

The environmental impacts of the Internet would vary greatly by region. In order to provide a frame of reference for other regions to use this study, the energy usage per phase is presented below. With this information, the study can be more easily adapted to different energy mixes for other regions.

Phase	Energy Use (kwh)
Development	0.75
Transportation	1.46
Hosting	0.006
Usage	0.816



5. Recommendations

It is very difficult to calculate the impacts of Internet services like websites. There are issues with requesting proprietary information, different routing, varying levels of technology, energy grids and mixes, and hardware allocation challenges. Though it is still possible to get reasonable estimates for most impacts, there is still a high level of uncertainty with figures. This study attempts to use these figures to do sensitivity and scenario analysis for various aspects of the web development lifecycle. There are many conclusions that can be reasonably drawn from the analysis in the study.

The results demonstrated that even using lower estimated kwh/GB figures, web pages have a significant environmental impact. The transportation phase of the study accounted for approximately 50% of the impacts. These figures could be reduced significantly by implementing more responsible design and development procedures. The uncertainty analysis demonstrated that decreasing web page sizes could reduce the impacts of the web page lifecycle tremendously. In my experience as a web developer, the size of web pages has increased significantly without providing additional value to users. Our recommendation would be to maintain page sizes between 200K-400KB when possible. This would create massive reductions in energy consumption for Internet transmission (approximately 475% - 1050% energy reduction). It would also decrease the hardware allocation required for a web page. Media and platform would likely be affected most by these changes, especially images. The hosting phase would also be impacted by the change. Hosting has limitations on the amount of bandwidth a server can handle. By decreasing the amount of bandwidth per page served, the server would be able to handle a significant increase in the number of web pages hosted. This would create hardware efficiencies and reduce the number of servers required for hosting.

Another critical factor to environmental impacts is device energy use during the usage phase. Users should be encouraged to view web pages on mobile devices or tablets when possible. This requires that developers implement responsive design principles to ensure the usability of websites on all devices. Hardware manufacturing allocation would need to be included in a future lifecycle assessment for a more thorough determination.

Although not explored in this study, server location could be an important factor in minimizing the impacts of the Internet. The use of CDNs to store websites and data closer to users demonstrates this; however, there is limited data available to quantify this factor. It is reasonable to assume a local server that is powered by renewable energy would likely be the least impactful configuration.

The analysis of the transportation phase raises questions with regards to other clean technologies such as NEST products that can be programmed via mobile to manage lights and thermostats remotely. Does the use of the Internet negate the energy savings since it uses a significant amount of energy itself? This would need to be explored further to determine whether new efficiency technologies are actually more efficient or if they consume more resources than they save. Using a CLCA would be important for conducting such a study.

Introducing Consequential Life Cycle Assessment (CLCA)

Because a website must use energy and non-renewable sources of materials, websites are inherently unsustainable if indirect impacts are not considered. Therefore CLCAs would be critical to proving a website is sustainable. Although a CLCA would be impossible for a generic web page such as the one in this study, a CLCA for a specific site may be possible. The beauty of the Internet is its diversity of content and ability to create connections across the world. A CLCA of websites could have some impressive indirect impacts. Using existing sites, here are some examples of web pages that produce incredible indirect impacts that would be difficult if not impossible to achieve without the Internet and these websites.

1. **Kiva** (https://www.kiva.org/)
   a. Micro-finance for developing countries funding by anyone around the world
2. **Google** (http://www.google.ca)
   a. Search engine that indexes information and makes it easy to find for users
   b. The indirect impacts would be impossible to measure with any accuracy since the education provided to users could be on a diversity of subjects
3. **Change.org**
   a. Activist website that connects people with causes and allows them to sign petition and stay informed on current initiatives
4. **Banking Websites**
   a. E-transfers allow users to send money with only an email address reducing all the physical impacts of currency minting
5. **Bitcoin**
   a. Pseudo-currency that is country independent and requires no exchange

b. Has been used in black market transactions which is an indirect impact (Greenberg, 2013)

These are only a few examples of web pages and what their major indirect impacts would be. Attempting to quantify these impacts would be extremely difficult. The complexity of the Internet and its ability to create change around the world likely puts it beyond the scope of any CLCA and therefore would require choosing a specific website for a study. For that reason, it is not possible to demonstrate what the boundaries of a CLCA would be for the product in this study. It is possible to draw the conclusion that using CLCA would be an important factor to offset the impacts of a web page and indicate whether it is sustainable or not.

Appendix A - Developer Inventory Analysis

	Average Web Page	Africa Recommended Page Size
Page size	2.3MB[1]	100KB[2]
Pages Viewed	435 pages	435 pages
Energy Use of Laptop	75W[3] =0.075 kwh	75W[3]
Download Energy Use (Internet)	1.46kwh/GB[4]	1.46kwh/GB[4]
Development Time	10 hrs	10 hrs
Average Canadian Internet Speed	16.6 Mbps	16.6 Mbps
Internet Infrastructure Energy Usage *($Energy_{Inet}$)*		
Total Data Uploaded / Bandwidth	=page size * number of pages =2.3 MB	=100 KB
Total Energy Used	=upload energy use * total bandwidth =0.003358 kwh	=0.000146 kwh
Laptop Energy Usage *($Energy_{dev}$)*		
Total Energy Use for Development	=dev. time * laptop energy (kwh) =0.75 kwh	=0.75 kwh
Total Energy Usage	**0.753358 kwh**	**0.750146 kwh**

1. (Finley, 2016)
2. (Munyaradzi & al., 2013)
3. (Energuide, n.d.)
4. (Mayers et al., 2015)
5. (Koomey, 2008)

Appendix B - User Inventory Analysis

	Average Web Page	Africa Recommended Page Size
Page size	2.3MB[1]	100KB[2]
Energy Use of Laptop	75W[4] =0.075 kwh	75W[4]
Download Energy Use (Internet)	1.46kwh/GB[6]	1.46kwh/GB[6]
Time on Page	90 secs[3]	90 secs[3]
Internet Infrastructure Energy Usage *($Energy_{Inet}$)*		
number of pages viewed	435	435
Total Bandwidth Used	=page size*number of pages =1GB	=0.043GB
Total Energy Used	=download energy use * total bandwidth =1.46 kwh	=0.063 kwh
Laptop Energy Usage *($Energy_{user}$)*		
AVG number of pages viewed per month	435	435
Total Time on Pages	10.875 hrs	10.875 hrs
Total Energy Use for Displaying Pages	=total time on pages * laptop energy use (kwh) =0.816 kwh	=0.816 kwh
Total Energy Usage Range	**2.28 kwh**	**0.879 kwh**

1. (Finley, 2016)
2. (Munyaradzi & al., 2013)
3. (Reichart, 2002)
4. (Energuide, n.d.)
5. (CBC, 2015)
6. (Mayers et al., 2015)
7. (Koomey, 2008)

Appendix C – Data Requirements

Data Required	Data	Sources
Hardware and software used for development, graphics design and visual elements 1. average development time for a website 2. needs to be converted into energy required	**1. Design and Development Time** o **Low:** 10 hours o **High:** 100 hours **2. Energy usage for a laptop** o A laptop uses considerably less: between 50 and 100 W per hour that it is on, depending on the model o The average of 75W is used **3. Energy usage for other devices** • Smartphone (5W) • Tablet (12W) **Assumptions:** o Web design and graphics design are subjective tasks and there is not set amount of time for design which strongly depends on the developer. o The study will use a range of potential development times for a small website.	**Website Development Sources:** 1. (Sitepoint, 2012) 2. (Graphics Design Forum, 2007) 3. (Meyer, 2014) **Energy of Laptop Sources:** 1. (Energuide, n.d.) 2. (Stone, n.d.) 3. (Helman, 2013) 4. (Cryer, n.d.) 5. (Brown, 2015) **Energy of Other Devices Sources:** 1. (Energuide, n.d.) 2. (Courtney, 2015)
Ontario Energy Mix 3. Impacts per KWH	**3.** Impacts per KWH **a. CO2 Equivalents** i. 3MT (megatons) for 34.36 TWh (tera watt hours) ii. 3,000,000,000,000 (grams)/34,360,000 (KWH) 1. $8.73 * 10^4$ g/kwh **b. Air Contaminants (attributed to smog)** i. SOx (166 T) 1. 166,000,000 (grams)/ 34,360,000 a. 4.83 g/kwh ii. NOx (3177 T) 1. 3,177,000,000/34,360,000 a. 92.46g/kwh	**Sources:** 1. (IESO, 2016)

	iii. $P_{M2.5}$ (67 T) **1.** 67,000,000 grams / 34,360,000 **a.** 1.94 g/kwh	
Size of the average bytes per page 4. File size is equal to bandwidth required	○ **Average web page in 2016:** 2.3MB (Finley, 2016) ○ **Proposed by Study:** 100KB (Munyaradzi & al., 2013)	**Sources:** **1.** (Munyaradzi & al., 2013) **2.** (HTTP Archive, 2016) **3.** (Pinto, 2015) **4.** (Dorsey, 2015)
Impact of Uploading to Internet (Internet Backbone Impact) 5. GHG emissions per GB upload	○ 0.46-1.46 kwh/GB [Sweden] **Assumptions:** ○ Potential mediums: phone (RJ), cable, fiberOP, wireless ○ Assumes the Canadian Internet infrastructure has a similar energy requirement to Sweden's	**Sources:** ○ (Müller et al., 2013) ○ (Mayers et al., 2015)
Impact of Hosting Server 6. Energy required to keep a website online	○ Volume server: 186W (US) ○ Shared hosting **Assumptions:** ○ Assume shared hosting since it is sufficient for most websites ○ Assume volume servers as they are most common ○ There are many considerations with regards to servers including hardware, architecture and virtualization ○ Most websites require little in the way of server specialization therefore we will use Koomey's estimate of 186W	**Sources:** 1. (Koomey, 2008) 2. (Matt, 2015) 3. (Jin et al., 2013) 4. (Zera, 2013) 5. (Chheda et al., 2009)
Impact of Downloading from Internet (Internet Backbone Impact) 8. GHG emissions per GB	**See impact of uploading**	**NA**

upload		
Average page size by year 9. Average page size information by year	1990 4 KB 1993 14.1 KB 2000 100 KB 2003 94 KB 2010 702 KB 2011 780 KB 2012 1097 KB 2014 1850 KB 2016 2332 KB	**<u>Sources:</u>** **1.** (Munyaradzi & al., 2013) **2.** (HTTP Archive, 2016) **3.** (Pinto, 2015) **4.** (Dorsey, 2015) **5.** (Key CDN, 2016)
User data on server 10. Size of a single database record	○ **Included in Hosting Impact**	
User data on client computer 11. Average size of cookies or saved data	○ **Included in Usage Impact**	

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