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# Environmental impact assessment of online advertising☆

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ABSTRACT

There are no commonly agreed ways to assess the total energy consumption of the Internet. Estimating the Internet's energy footprint is challenging because of the interconnectedness associated with even seemingly simple aspects of energy consumption.

The first contribution of this paper is a common modular and layered framework, which allows researchers to assess both energy consumption and $CO_2e$ emissions of any Internet service. The framework allows assessing the energy consumption depending on the research scope and specific system boundaries. Further, the proposed framework allows researchers without domain expertise to make such an assessment by using intermediate results as data sources, while analyzing the related uncertainties. The second contribution is an estimate of the energy consumption and $CO_2e$ emissions of online advertising by utilizing our proposed framework. The third contribution is an assessment of the energy consumption of invalid traffic associated with online advertising. The second and third contributions are used to validate the first.

The online advertising ecosystem resides in the core of the Internet, and it is the sole source of funding for many online services. Therefore, it is an essential factor in the analysis of the Internet's energy footprint. As a result, in 2016, online advertising consumed 20–282 TWh of energy. In the same year, the total infrastructure consumption ranged from 791 to 1334 TWh. With extrapolated 2016 input factor values without uncertainties, online advertising consumed 106 TWh of energy and the infrastructure 1059 TWh. With the emission factor of 0.5656 kg $CO_2e$/kWh, we calculated the carbon emissions of online advertising, and found it produces 60 Mt $CO_2e$ (between 12 and 159 Mt of $CO_2e$ when considering uncertainty). The share of fraudulent online advertising traffic was 13.87 Mt of $CO_2e$ emissions (between 2.65 and 36.78 Mt of $CO_2e$ when considering uncertainty).

The global impact of online advertising is multidimensional. Online advertising affects the environment by consuming significant amounts of energy, leading to the production $CO_2e$ emissions. Hundreds of billions of ad dollars are exchanged yearly, placing online advertising in a significant role economically. It has become an important and acknowledged component of the online-bound society, largely due to its integration with the Internet and the amount of revenue generated through it.

## 1. Introduction

In 2013, the total energy usage of the ICT technology industry was estimated to be 1500 TWh (Mills, 2013). The aforementioned total ICT energy usage multiplied by the German electricity mix emission factor of 0.5656 kg $CO_2e$/kWh (Kern et al., 2015), the $CO_2e$ emissions were over 848 million tons. The Internet's share of the global electricity consumption was 10% in 2014 (Mills, 2013): As a reference, the entire global residential space heating in 2014 consumed the same amount (International Energy Agency, 2017a). The expectation is that the emissions will grow to 1.3 billion tons of $CO_2e$ in 2020, attributing to 2.3% of the world's $CO_2e$ emissions (IHS Technology, 2015). Online advertising is a major social and economic driver of the information society. First, up until today, online advertising is associated with funding online search services, map services, and social media, to billions of users. Second, the market volume of online advertising reached

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$72.5B in the US alone in 2016 with an annual growth rate of 22% (PwC, 2017). Third, online advertising represents a source of jobs. For instance, recent studies have estimated that 0.9 M (0.4%) direct and 5.4 M (2.5%) indirect jobs were associated with online advertising in the EU-28 workforce in 2014 (IHS Technology, 2015). Fourth, online advertising represents a fundamental source of income of companies known for their technological innovations, such as Google or Facebook (Google, 2017; Facebook, 2017). Therefore, the sustainable growth of this industry is seen as important.

The continuous increase of digital services such as streaming video, web browsing or data exchange over time has attracted some attention towards the environmental impact of the Internet. Direct environmental impact of digital services results from the energy consumption of devices involved in delivering the service and from the resources consumed to manufacturing and disposing of the devices (Schien and Preist, 2014). The Internet is a collection of over 50,000 independent networks and a large install base of routers (Gupta et al., 2015; Schien and Preist, 2014). The Internet architecture is evolving and changing: tablets and smartphones create new ways to access the Internet on top of desktops and laptops, and clouds and data centers are changing the traditional way of assessing the environmental impact of the Internet (Bull and Kozak, 2014). The key stakeholders on the Internet include more than 300 Tier-2 Internet service providers (ISPs), and tens of Tier-1 ISPs and Internet exchange points (IXPs) providing locations where multiple networks exchange traffic and routes (Gupta et al., 2015).

Malmodin et al. 2007 study found that the ICT sector produced 1.3% of the worldwide $CO_2$ emissions and consumed 3.9% of global energy production. Given the growth of ICT since 2007, this is a growing percentage (Bull and Kozak, 2014). More than 80% of the population in developed countries are heavy Internet users (Ji and Hong, 2016). Estimates of energy intensity, kWh/GB, of the Internet, vary significantly; in literature, we found results ranging from 136 kWh/GB (Koomey et al., 2004) to 0.0064 kWh/GB (Baliga et al., 2011), a factor of more than 21,000. The definition of the Internet is not constant throughout literature. Depending on the study, the Internet as a system might include only networks, while other studies also include data centers and all related equipment. These differences can be considered the main reason for the large variance in published results (Coroama et al., 2015).

The impact of digitalization on the global economy is challenging to define. Despite the positive impacts of dematerialization, decarbonization, and demobilization, there is increasing concern about the complexity and uncertainty in the environmental impact assessment (EIA) of ICT (Salahuddin et al., 2016). Another cause of concern is whether services moving online are sustainable development, rather than a burden on the environment. Favorable and adverse environmental impacts can be found on all system levels depending on the depth of causal chains and the time span assumed (Hilty and Page, 2015). The ICT sector is complex, interdependent, contains uncertainties and it is scale-dependent (Bull and Kozak, 2014). As a dynamic industry, it disrupts many other industries. In addition, there is a possible rebound effect; even though the energy intensity of devices has improved, the scale of use has increased at a rate which results to the total increase of energy consumption (Bull and Kozak, 2014).

There is a need for a comprehensive framework for EIA of Internet services. The framework must be modular and support many layers of analysis to overcome the complexity of the Internet. The considerable variability in results in previous studies and level of uncertainties indicate a need for a common framework. Many of the previous studies focus on device level analysis (Andrae and Edler, 2015; Ishii et al., 2015; Lambert et al., 2012) rather than the services on top of them. There are excellent research papers on methodologies of EIA (Morgan, 2017; Jones and Morrison-Saunders, 2017; Bidstrup et al., 2016; Cardenas and Halman, 2016; Leung et al., 2015; Pope et al., 2013) and case studies illustrating some of the Internet's pain points (Aslan et al., 2017; Kern et al., 2015; Whitehead et al., 2015; Whitehead et al., 2014; Bull and Kozak, 2014; Schien and Preist, 2014). The key findings from previous literature can be formed into a general framework for assessing the impact of any Internet service, including online advertising.

This research aims to determine a common framework, utilizing best practices, for assessing the energy consumption and $CO_2e$ emissions part of the EIA of the Internet or a sub-segment of it. The economic and social impacts of the Internet are not in the focus of our research. The second aim is to validate the results by utilizing the determined framework to conduct the EIA of online advertising. The third aim is to approximate the impact of fraudulent online advertising on energy consumption and $CO_2e$ emissions. To the best of our knowledge, this has not been studied previously.

Our research contributes to the ongoing discussion of methodology in the EIA of Internet-related technologies and services. In addition, we contribute an assessment of online advertising energy consumption and $CO_2e$ emissions, to reveal a major consumer of energy for decision makers and regulators. Even with uncertainties taken into account, the energy consumption and $CO_2e$ emissions are substantial.

Section 2 defines the materials and methods that have been used. Section 3 introduces the results and uncertainties. Section 4 discusses the results, and finally, in Section 5, the conclusions are presented.

## 2. Materials and methods

In the following chapters, we present previous knowledge, our framework, and methods used for conducting the EIA of online advertising.

### 2.1. Previous knowledge on methods

In this subsection, we present a short introduction to the main assessment methods and provide the essential concepts required for any impact assessment. Furthermore, we present some research previously conducted on the Internet domain and introduce domain-specific aspects of conducting an impact assessment found in the articles. The aim is to provide solid reasoning and theoretical background for our framework development and avoid known mistakes.

#### 2.1.1. Main assessment methods

There are three main assessments regarding the environment: 1) Life Cycle Assessment (LCA), 2) Impact Assessment (IA), and 3) Environmental Impact Assessment (EIA).

LCA is a systematic and transparent method for assessing environmental impacts associated with the creation, use and disposal of products and systems, from the cradle to the grave (Bull and Kozak, 2014; Ji and Hong, 2016, Whitehead et al., 2015, ETSI Standard, 2015). LCA is at a high level of abstraction (Ji and Hong, 2016). LCA has developed over the last decades, and there are international standards and guidelines written on it. LCA is related to a functional unit. However, different methodological choices can be made based on the aim and the scope of the assessment (Arushanyan et al., 2014). In practice, all LCAs include simplifications. The impacts of the simplifications to the output are not always well-known and explicitly addressed in the studies (Moberg et al., 2014). The six main challenges of LCA are: defining the functional unit, boundary selection, allocation, spatial variation, local environments, and data availability (Bull and Kozak, 2014). There is a need for streamlined tools, which are built on comprehensive and detailed frameworks that can be used by non-experts (Whitehead et al., 2015).

IA is defined as a technical tool for analyzing the consequences of a planned action (Leung et al., 2015; Bond et al., 2018; Bidstrup et al., 2016). IA reflects the positivist theory, or rationalism, implying better data leads to better decisions (Bond et al., 2018). Characteristics of a solid IA include: 1) aiming for the best outcome possible with given resources and constraints, 2) providing given outcome and constraints with the smallest resources, 3) adopting the best procedures, 4) ensures