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Carbon footprint of a scientific publication: A case study at Dalian University of Technology, China

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ABSTRACT

Knowledge of the carbon footprint (CF) of a scientific publication can help to guide changes in behavior for mitigating global warming. A knowledge gap, however, still exists in academic circles. We quantified the CF of a publication by parameterizing searches, downloads, reading, and writing in the processes of publication with both direct and indirect emissions covered. We proposed a time-loaded conversion coefficient to transfer indirect emissions to final consumers. A questionnaire survey, certification database of Energy Star, fixed-asset databases specific to our campus, and reviewed life-cycle-assessment studies on both print media and electronic products were integrated with Monte Carlo simulations to quantify uncertainties. The average CF [(CI: 95%), SD] of a scientific publication was 5.44 kg CO_2-equiv. [(1.65, 14.78), 4.97], with 37.65 MJ [(0.00, 71.32), 30.40] of energy consumed. Reading the literature contributed the most, followed by writing and searching. A sensitivity analysis indicated that reading efficiency, the proportion of e-reading, and reference quantity were the most dominant of 52 parameters. Durable media generated a higher CF (4.24 kg CO_2-equiv.) than consumable media (1.35 kg CO_2-equiv.) due to both direct and indirect reasons. Campus policy makers should thus not promote the substitution of e-reading for print reading at the present stage, because their environmental advantages are highly dependent on time-loaded and behavioral factors. By comparison, replacing desktops with laptops is more attractive, by potentially reducing CFs by 50% and the disproportionate consumption of energy.

1. Introduction

Scientific activity can contribute to the mitigation of climate change but also unavoidably consumes energy and emits greenhouse gases (GHGs). For example, flying internationally to meetings on environmental protection can ironically generate a large carbon footprint (CF), scientists thus should be more conscious of climate change than the average citizen due to more frequent flying around the world (Burke, 2011; Gremillet, 2008). Scientific publication to announce technological innovations for reducing climate change is another ironic and important source of CFs. Estimates of the CF of a scientific publication, however, are challenged by the popularity of Information Communication Technology (ICT) products, which is regarded as an opportunity to facilitate sustainable development by dematerialization.

Supported by the development of ICT, electronic media have tended to replace the traditional counterparts in various scientific activities, triggering the interest in the environmental effect from a life-cycle perspective. For researchers in different parts of the world to interact by videoconferencing instead of face-to-face meetings is environmentally favorable to avoid the consumption of fuel spent in travel (Coroama et al., 2012; Dolci et al., 2011). Buying books via the Internet is greener than buying them in traditional bookshops (Borggren et al., 2011), and university digital libraries also conserve energy and reduce CFs relative to their paper-based counterparts (Chowdhury, 2012). The environmental impacts of e-reading supported by ICT and print reading (p-reading) have similarly been compared by life-cycle assessment (LCA), including various media such as tablet-edition magazines (Hischier et al., 2014); on-line, television, and print news (Arushanyan et al., 2014; Hohenthal et al., 2013; Moberg et al., 2010; Reichart and Hischier, 2003); and electronic scholarly journals and books (Gard and Keoleian, 2003; Kozak, 2003). Reports of the relative environmental benefit of e-reading and p-reading, though, have been inconsistent, indicating that identifying a clear environmentally friendly option is not easy,

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due to the variable parameters of user behaviors during usage, such as device lifetime, reading time, and number of readers.

LCAs of the environmental impacts of ICT products have recently been reviewed. Bull and Kozak (2014) reported that current LCA comparisons between ICT and print media were problematic because of the completely different materials and the unique characteristics of the ICT sector. Arushanyan et al. (2014) reviewed the CF indicators used by most studies and highlighted the importance of time-associated user behaviors, such as the time composite of operational modes, service lifetime, and final routes of disposal of ICT devices, "the unique characteristics" suggested by Bull and Kozak (2014). Arushanyan also suggested that user behaviors should be assessed realistically when estimating the environmental impacts of ICT products.

Sophisticated studies of CF generation from various scientific activities supported by both ICT and paper media have been conducted, but few have attempted to quantify the CF embedded in the publication of a scientific paper, which has continuously increased throughout the world. China, with 2.6 million undergraduate degrees awarded annually, is the third largest source of scientific publications (National Science Foundation of National Science Board, 2014) and is being strongly pressured to mitigate the emission of GHGs over the next several decades, although the Green University initiative is being promoted (CGUN, 2011; Xiong, 2013; World Nuclear News, 2014; Yuan, 2013). Our study objectives were thus: (i) to quantify student behaviors in operating ICT devices to produce a scientific publication through a questionnaire survey on the campus of the Dalian University of Technology (DLUT), Dalian, China, (ii) to calculate CF generation and its components from various media, (iii) to compare the differences in the CFs from e-reading and p-reading, and (iv) to develop scenarios of scientific publication for future CF mitigation on campuses.

2. Materials and methods

2.1. Functional unit and boundary

The functional unit was defined as one scientific publication by a student. To clarify the functional unit, we defined a student as a typical postgraduate Masters or doctoral candidate at DLUT, who is required to publish at least one scientific paper for graduation. The scope of the analysis was limited to four associated processes – literature searches, downloads, reading, and writing – with the assumption that all literature was read on computer terminals after downloading instead of reading it online. Other processes, such as submission for peer review, publication, and experimentation that could consume experimental materials or power to run electrical apparatuses were all excluded from the analysis to minimize the uncertainty originating from data gaps. In contrast, CFs from reading and writing are more complicated, because they depend highly on reading patterns (i.e. p-reading or e-reading), device power parameters, and individual use behaviors.

2.2. Questionnaire survey

To characterize the average behavior of users, we randomly selected 600 postgraduate students for a questionnaire survey that included 19 questions associated with all requirements for reading literature, search volume, search hit rate, bit quantity downloaded, time required to read and write, and student behaviors for operating electronic devices. After carefully reviewing the collected questionnaires, we selected 502 valid respondents for further analysis. The questionnaire is provided in Table A.1 of Appendix A.

2.3. CF components

The total CF was composed of both direct and indirect components. A direct component is the emission of carbon when power is consumed to run electronic devices, and an indirect component is the emission of carbon along the chains of device provision from an LCA perspective that usually includes extraction of raw materials, processing (production of components), assembly, and transportation. The media were separated into durable devices or consumable media due to their differences in contribution to the generation of direct and indirect CFs. Durable devices with long service lives, including control units (desktop computers without the displays), laptops, displays, and laser printers, are responsible for both direct and indirect CF generation. Consumable media include printer cartridges and paper and generate only indirect CFs. P-reading requires printers, paper, and cartridges, and e-reading and writing require laptops or desktop computers composed of a control unit plus a liquid crystal display (LCD) or a cathode-ray-tube (CRT) display. The CF components and flowchart of the study are illustrated in Fig. 1.

2.4. Searching and downloading

Network devices in data centers are the major sources of direct CFs by the consumption of power during literature searches and downloads. The generation of CFs for literature searching is determined by the power efficiency of the data center, total search volume, and hit rate. The survey (question 2 in Table A.1) indicated that Google Scholar played a dominant role in campus literature searches (52%), followed by Elsevier (21%), Springer (16%), and Ei village (11%). The power consumption of the Google data center was used to calculate the direct CF of searching. The emission factor per search, however, is disputed, ranging between 0.20 g CO_2 reported by Google (Google blog, 2009) to 7.0 g CO_2 widely reported in the Web. We used the average of 3.6 g CO_2 with the range as the uncertainty. The embedded CFs for downloading were highly dependent on bit quantity transmitted through the Internet, estimated at 0.28 Wh MB^{-1} (Hischier et al., 2013). The power consumption (E_1) and CF generation (CF_1) from literature searches were calculated as:

$$E_1 = E_g \times (\alpha \cdot N_g) \quad (1)$$

$$CF_1 = G_g \times \left(\frac{N_g}{\alpha}\right) \quad (2)$$

where E_g is the power consumption of 0.0003 kWh for per Google search, G_g is the CF factor for the average of 3.6 g CO_2-equiv. and ranging from 0.2 to 7.0 g, N_g is the overall literature search volume to find all target items, and α is the search hit rate for each search. N_g and α were surveyed by questions 3 and 4 in Table A.1 (see Supplementary data).

The power consumption (E_2) and carbon footprint (CF_2) for downloading target literature were determined by the transmitted bit quantity through the Internet and were calculated as:

$$E_2 = E_d \times C \times N_r \quad (3)$$

$$CF_2 = \frac{ef \times E_2}{1000} \quad (4)$$

where E_d (0.28 Wh MB^{-1}) is the power consumption to transmit one MB of data (Hischier et al., 2013), C is the bit quantity for one paper with an average of 0.56 MB and a range of 0.12–1.00 MB, N_r is the total number of papers read to produce one publication (question 5 in Table A.1), and ef is the GHG emission factor from the Chinese power grid equal to 1.05 kg CO_2-equiv. kWh^{-1}.