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Perspective

The overlooked environmental footprint of increasing Internet use

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The environmental costs of adopting new technologies and habits are often recognized too late, typically when changing the adopted technologies and behavioral norms is difficult. A similar story may unfold if society continues to blindly transition to an unregulated and environmentally unaudited digital world, a transition path that has been facilitated by the fourth industrial revolution and is now accelerated by the global COVID-19 crisis. The newly developed digital lifestyle has major environmental benefits, including the reduction of travel-related CO2 emissions. Yet, increased Internet use has some hidden environmental impacts that must be uncovered (Fig. 1a) to make the transition to a low-carbon and green economy successful.

The data centers' electricity consumption accounts for 1% of the global energy demand (Masanet et al., 2020), more than the national energy consumption of many countries. Depending on the energy supply mix and use efficiency, Internet traffic contributes differently to negative environmental impacts and climate change. As the number of Internet users increases, the number of online services and applications they use grow. This trend exacerbates the environmental footprint of the Internet, despite the many successful and significant efforts to improve the efficiency of data centers (Masanet et al., 2020) and reduce their reliance on fossil energy. In order to build a sustainable digital world, it is imperative to carefully assess the environmental footprints of the Internet and identify the individual and collective actions that most affect its growth.

There have been a number of studies estimating the carbon footprint of data storage, transmission, and use (Aslan et al., 2018; Malmodin and Lundén, 2018). Given the technological and efficiency improvements in the Internet sector and the changing energy supply portfolios around the world, there is a need to continuously update the previous estimates. Nonetheless, a comprehensive assessment of the environmental cost of Internet use cannot solely rely on the carbon footprint (Ristic et al., 2019). Despite their environmental significance and contribution to climate change, the water and land footprints of data use have not been well studied. To address this gap, one can roughly estimate the three major environmental footprints (i.e., carbon, water, and land footprints) of fixed-line Internet use (i.e., storage and transmission of data via fixed-line Internet) using a simple footprint calculation approach that relies on proxy variables (see Ristic et al. (2015) and Supplementary Material),

Globally, the Internet use has a carbon footprint ranging from 28 to 63 g CO_2 equivalent per gigabyte (GB), while its water and land footprints range from 0.1 to 35 L/GB and 0.7 to 20 cm^2/GB, respectively (Fig. 1b). There have been significant and rapid improvements to the footprints due to technological advances in data center and data

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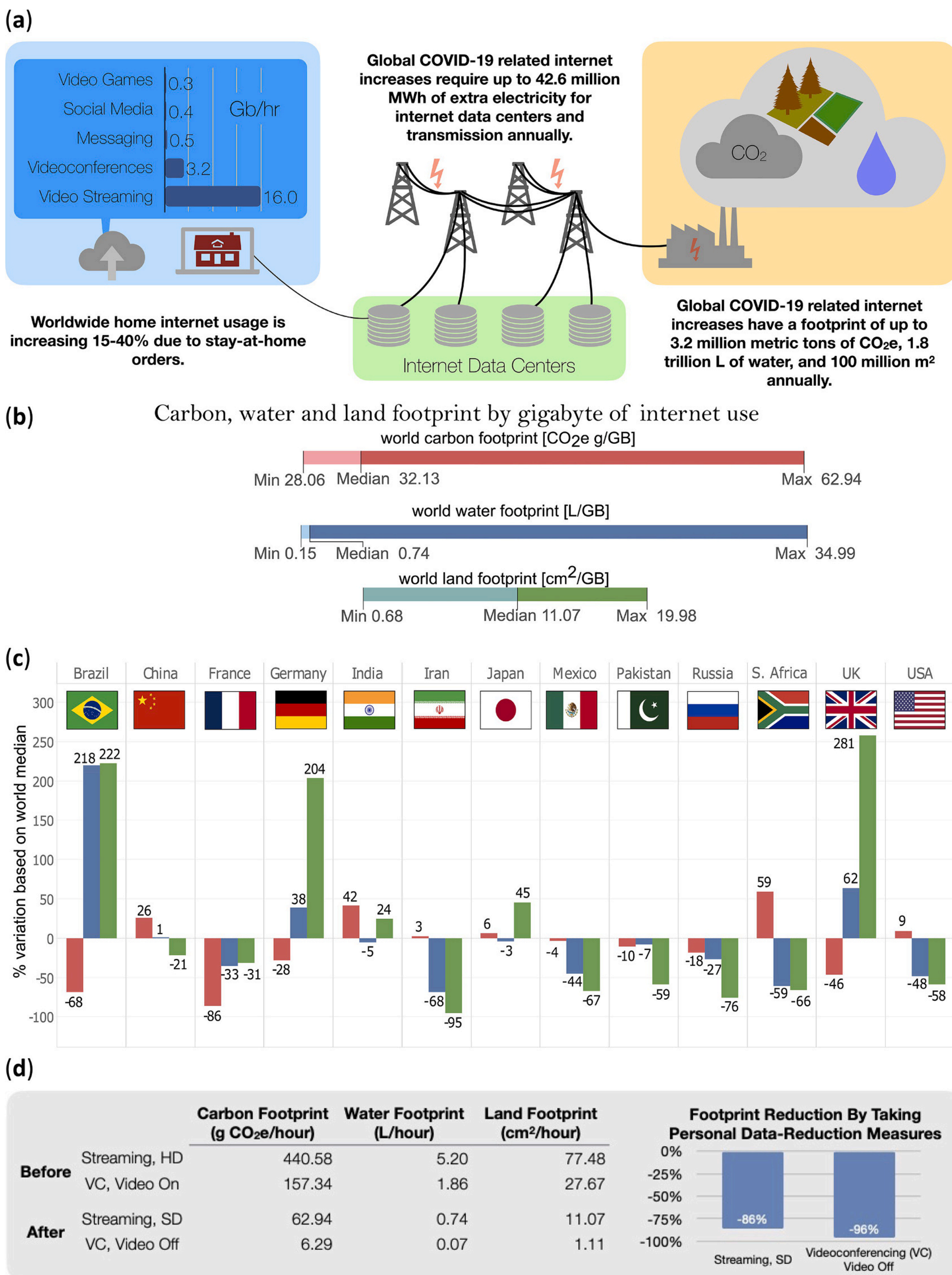

Fig. 1. (a) The impact of COVID-19 and subsequent stay-at-home orders on global Internet use (e.g., Netflix reported a 16% increase in daily traffic between January and March 2020, while Zoom experienced a tripling of usage following the initial shutdown in the US (see Supplementary Material and the references therein)) and the associated environmental impact. Considering that a number of countries reported at least a 20% increase in Internet usage related to COVID-19 starting in March 2020, the global carbon footprint could grow by as high as 34.3 million t of CO_2e if remote work continues until the end of 2021. This increase in carbon emissions would require a forest twice the size of Portugal to fully sequester all the emitted CO_2e. The associated water footprint is enough to fill 317,200 Olympic size swimming pools and the land footprint is the about size of Los Angeles. (b) Global environmental footprints by gigabyte of fixed-line Internet use (i.e., transmission and storage). (c) Deviation of the environmental footprints of a unit of electricity used for data processing and/or transmission within select countries from the world median environmental footprints of an average unit of generated electricity, calculated based on each country's energy mix. The large ranges of footprint values are mainly attributable to the variation in energy production technologies and efficiencies around the world. The estimated values might underrepresent the footprints in developing economies where the Internet electricity use is higher than the estimates used here. (d) Environmental footprints of specific online activities before and after taking personal data-reduction measures. See Supplementary Material for the main assumptions these estimates rely on as well as the esimated footprints of different application-based online activities.

transmission efficiency levels. For example, Ristic et al. (2015) reported a water footprint of up to 205 L/GB in 2015. This number is estimated to be about 35 L/GB based on current efficiency levels and global energy mix—reflecting nearly a 150% reduction in about five years. Considering the sheer volume of the multi-gigabytes data associated with Internet use, these seemingly smaller footprints are, in fact, exceedingly large. Taking the median carbon footprint for the world (32 g CO_2e/GB), data storage and transmission emits 97 million t of CO_2e a year—roughly equivalent to the annual carbon footprint of Sweden and Finland combined. Similarly, the median global water footprint of Internet use is estimated to be 2.6 trillion L of water, or the equivalent of filling over 1 million Olympic-size swimming pools. Finally, the median land footprint of Internet use is approximately 3400 square kilometers of land, representing the combined size of Mexico City, Rio de Janeiro, and New York City.

Looking at specific countries, some fare better than others in terms of the environmental footprints of an average unit of energy used for processing and transmitting data, due to variations in the energy mix (Fig. 1c). For example, the data processed and/or transmitted in Brazil has a median carbon footprint that is approximately 68% lower than the world median, while in South Africa the carbon footprint of processing and/or transmitting data is 59% higher. Instead, the water footprint of transmitting data in Brazil is 218% higher than the world median (for combined processing and transmitting this number goes down to 210%), while transmitting data in Iran has a water footprint that is 68% lower than the world (65% lower for combined processing and transmitting). These differences highlight the impact of various energy mixes on the overall footprints of Internet use. For example, Brazil obtains nearly 70% of its energy from hydropower, which leads to a higher water footprint, but a lower carbon footprint than other countries. Comparing the differences between countries not only highlights the trade-offs between various sources of energy, but also demonstrates the significance of the simultaneous evaluation of different environmental footprints, rather than unilateral focus on carbon footprint that has been common in the literature. Given that data processing/storage and some part of data transmission do not necessarily occur in the country where the data is being used, this comparison also highlights the trade-offs of placing data centers in different geographic zones around the world as well as the transboundary environmental impacts of Internet use and its environmental justice implications.

Society at large should recognize the power of collective action in reducing the environmental footprint of the Internet to avoid paving an irreversible path to an unsustainable digital world. Large-scale adoption of environmentally responsible online behavior by many individuals is vital for combating climate change and promoting sustainability. Making Internet users aware of the costs of online actions and benefits of making small behavioral changes (through information campaigns, behavioral nudges, etc.) is the first step toward promoting sustainable digital behavior. Small actions such as turning off video during a virtual meeting, reducing the quality of streaming services, decreasing gaming time, limiting time on social media, deleting emails and unncessary content on the cloud-based storage services, or unsubscribing from email lists can significantly reduce the environmental footprints of Internet use (Fig. 1d and Supplementary Material).

A common streaming service requires 7 GB per hour of streaming in high video quality (Ultra HD or 4k) (see Supplementary Material), having a carbon footprint of 441 g CO_2e/hr (global median). Streaming videos at this quality for four hours a day would result in a monthly carbon footprint of 53 kg CO_2e However, by lowering the video quality from HD to standard, the monthly footprint would drop to 2.5 kg CO_2e, saving the emissions of driving a car from Baltimore to Philadelphia (150 km). If 70 million streaming subscribers were to lower the video quality of their streaming services, there would be a monthly reduction in 3.5 million t of CO_2e—the equivalent of eliminating 1.7 million t of coal, or approximately 6% of the total monthly coal consumption in the US. Similarly, a standard videoconferencing service uses about 2.5 GB/hr (see Supplementary Material) and has a carbon footprint of 157 g CO_2e/hr. If one were to have 15 1-hour meetings a week, their monthly carbon footprint would be 9.4 kg CO_2e. Simply turning off the video, however, would reduce the monthly emissions to 377 g CO_2e. This would save the emissions of charging a smart phone each night for over 3 years (1151 days). If 1 million videoconference users were to make this change, they would collectively reduce emissions by 9023 t of CO_2e in one month, the equivalent emissions of powering a town of 36,000 people for one month via coal.

In terms of the water footprint, lowering the video quality on streaming services would lead to a reduction in 53.2 million L per 100,000 users per month, enough water to grow over 185 t of potatoes. Likewise, turning off the video during conference calls would save 10.7 million L per 100,000 users per month, the water needed to produce approximately 53.5 t of tomatoes. Finally, reducing the video quality from HD to standard lowers the monthly land footprint by 1.2 million m^2 per 1.5 million users, the size of the National Mall in Washington D.C. By limiting conference calls to voice-only, there would be a land area saving of 239,000 m^2 per 1.5 million users, roughly the size of St. James Park in London.

A key stakeholder in the effort to reduce the Internet's environmental footprint are service providers (e.g., cloud-based storage/computation) and 'over-the-top' application-based companies (e.g., streaming and videoconferencing). Many service providers and data centers continue to work towards improving the efficiency of their operations and reducing the environmental footprint of their energy use portfolios (with a main focus on carbon footprint reductions). Companies must continue to work towards limiting the environmental footprint of their products (e.g., not offering high-definition video quality without users' consent) in addition to reducing the energy and environmental footprint of data processing and transmission. As the nature of many provider-side footprint reduction changes are in contrast with providing improved features and 'quality of service', it is unlikely that in the absence of reputational damage and the risk of losing customers/profits, providers will take voluntary actions to reduce their product's footprint. This calls for campaigns to raise awareness, as well as policy solutions to achieve a reduction in the environmental footprint of the Internet and preventing the irreversible development of unsustainable digital products, norms, and habits.

Policymakers can enact regulations, requiring full transparency on the footprint of digital products and the proactive measures taken by service providers to curb or reduce their environmental impacts. This would ultimately allow for consumers to make decisions on what products and companies they choose, creating market competition to 'go green'. As Internet access increases globally, it is important to be cognizant of the energy generation sources that power it and work to transition to renewable energy sources that have lower environmental footprints.

We advocate for an increased focus on studying the environmental footprint of the Internet and the pros and cons of increased Internet use. High resolution estimates of Internet environmental footprints and projections of future growth that rely on improved data availability and footprinting methodologies are required to achieve a sustainable digital future. The availability and knowledge of such estimates are vital for service providers to reduce their footprints and minimize reputational risk, for policymakers and regulators to enact change, and for consumers to adopt eco-friendly digital habits.

Supplementary Material

Supplementary Material includes the Internet environmental footprint analysis modeling file with all data inputs, assumptions, methodological notes, discussion of uncertainties, sources, and results (including country-specific calculations and estimated footprints of various online activities and applications).

Author contributions

K.M. conceptualized the work. D.M-S., B.R., R.O., and M.A. acquired, analyzed, and interpreted the data. B.R. and D.M-S. created the graphics. R.O., K.M., R.N., D.M-S., B.R., and M.A. contributed to the writing and editing of the paper. K.M and R.N. supervised the work.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Supplementary materials

Supplementary material associated with this article can be found, in the online version, at doi:10.1016/j.resconrec.2020.105389.

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