ENVIRONMENTAL IMPACTS OF THE INTERNET: SCOPE, IMPROVEMENTS, AND CHALLENGES

***Jari Arkko*[1], *Nina Lövehagen*[2], *and Pernilla Bergmark*[3]**

[1] *Ericsson Research, Oy LM Ericsson Ab, 02420 Jorvas, Finland (jari.arkko@ericsson.com)*

[2] *Ericsson Research, Ericsson AB, 164 83 Stockholm, Sweden (nina.lovehagen@ericsson.com)*

[3] *Ericsson Research, Ericsson AB, 164 83 Stockholm, Sweden (pernilla.bergmark@ericsson.com)*

1. INTRODUCTION

Climate change is considered the greatest current threat to human health [WHO]. The effects of global warming are already felt, and additional warming will likely increase these effects [IPCC]. All areas of the globe, sections of society, and areas of industry will be impacted.

Information and communications technology (ICT) and the Internet have obvious direct impacts on the environment, for instance using energy and raw materials. But these technologies also have significant indirect impacts in other sectors when using the technology and through their transformative effect on how our societies operate. The levels of effects are referred to as first order effects, second order effects and other effects (also known as third order effects or higher order effects) [ITU L.1410]. Continued attention to how these technologies develop, leveraging the opportunities they enable, mitigating their negative effects, and reducing their energy consumption is important, while at the same time minimize the environmental impact of ICT itself.

The Internet Architecture Board (IAB) has called for a workshop to discuss the Internet's environmental impact. The purpose of the workshop is to "discuss the evolving needs from industry, and to identify areas for improvements and future work", with "the scope is broadly on the entire Internet ecosystem, from the communications to the devices, applications, data centers, etc." [IAB].

This paper is a submission to the IAB workshop. While the scope of what is included in the workshop's definition of the Internet is not fully defined, the related concept of the ICT sector is [ITU-T L.1450]. Focusing on environmental impacts of the sector hence provides a well-defined approximation of Internet and will be the focus of this paper. The goal of the paper is to approach the environmental impact of ICT from a holistic perspective, to understand how ICT can impact and what avenues there are for amplifying its positive effects and mitigating the negative effects.

Throughout this paper, we use examples from mobile communications technology per the authors' background, but many similar examples, issues, and solutions also exist in other aspects of the Internet technology, be it about applications, data centers, and so on.

2. ICT for Sustainability and Sustainable ICT

ICT and the Internet are integral parts of our society. Therefore, the overall impacts of ICT on the environment is complex to derive.

The first high-level observation is that the role that ICT plays in the overall society is important, also for reducing the environmental impacts, as recognized as second-order effects of ICT already in 2001 [OECD]. This could also be referred to as 'ICT for sustainability' as proposed by Hilty and Aebischer [HILTY].

ICT and the Internet can be used to reduce the need for electricity and materials in the society. ICT can also help move to greener energy alternatives, or move to alternative approaches that reduce the need for energy consumption. Various Internet of Things (IoT) technologies can enable optimizations and energy savings in home, industrial, and traffic applications, and can help monitor the state of the environment.

ICT and the Internet further have the ability to replace some physical processes with their electronic equivalents, share information in real-time, and to enable the use of remote resources.

The impact of converting in-person meetings to virtual ones can be significant. For instance, Ong et al. suggests in their 2014 research that, given the conditions of their study, videoconferencing consumes at most 7% of the energy of in-person meetings [ONG]. It has also been suggested that numbers may improve further, considering the rising cost of energy and the growing ease and commoditization of video conferencing capabilities [ECKERT].

The capability for virtual meetings can also be useful in other ways for the society, for instance during the COVID-19 pandemic virtual meetings enabled business, education, and other society's functions to continue to operate despite widespread isolation policies. ICT also enables many professions to perform at least part of their work from home, potentially reducing the amount of energy consumed for commuting. In many cases it may have provided other benefits as well, such as the ability to choose one's location more freely, advantages to local communities and businesses, or reduction in the size of required office spaces. However, such effects may be partially counteracted if people move further away from work when daily commuting is not required or invest in an extra office room in their apartments. This is known as rebound.

However, another aspect of 'ICT for Sustainability' is to keep track of unintended negative impacts from ICT. For instance, ease of the Internet can drive excessive consumerism, where a consumer by more to ease of access and through low-cost e-commerce offerings distributed through ICT.

The second high-level observation is that apart from how ICT can impact other sectors or parts of society, it is of outmost importance for the ICT sector understand the overall situation with respect to the entire ICT sector's impact on the environment. The ICT sector on a high level consists of user devices, networks, and data centers, which all come with an impact across their full lifecycle including raw materials acquisition, production, use and end of life treatment stages. There are numerous factors that influence the impacts, including sometimes factors that counter each other. Negative environmental impacts are for instance energy consumption by networks and data centers, and the embodied carbon emissions related to IT equipment, and the managing of e-waste, recycling and use of raw materials. Addressing these impacts could be referred to as 'Sustainable ICT'.

With the footprint of ICT being estimated to 1,4% of overall carbon emissions [MALMODIN], the impacts that the technology can make are potentially an order of magnitude higher than the energy consumption of the ICT itself.

ICT needs to reduce its carbon emissions by 45% during this decade as stated in normative trajectory for decarbonization of ICT developed by the International Telecommunications Union (ITU), GSM Association (GSMA) and Global Enabling Sustainability Initiative (GESI) in collaboration with the Science-Based Targets Initiative (SBTI) [ITU-T L.1470]. To achieve this, the ICT industry must continue its efforts to reduce its energy consumption or other environmental impacts. The scope of the effort includes:

- Making sure that the electricity consumption is kept within the limits of this trajectory.
- Building end-user devices that last longer and require less energy and other resources.
- Continuing the analysis and reduction of ICT's direct environmental effects and energy consumption.
- Use cleaner energy alternatives to power ICT systems.

At the same time the ICT sector should continue to build the required network capabilities to help the rest of the society address its decarbonization needs. Further it should research – and critically evaluate – in ICT's effects in different areas, both positive and negative.

This is particularly important, given the incredible demand and pace of growth for Internet and communication services. For instance, Ericsson's Mobility Report [ERICSSON-MR] reported that in the last 10 years, the amount of mobile data transmissions has grown 300-fold from 0.25EB to 65EB per month. At the same time the amount of electricity consumed for this has a much more moderate expansion and the increase has been limited to 64% (from 91TWh to 150TWh). Hence there is no correlation between the electricity consumption and the exponential growth in the number of bits sent. With that said there are still much to do to lower to total energy consumption of ICT until 2030.

Not reflected in these numbers is the use of cleaner energy alternatives by the service providers which decouples the development in carbon emissions from the increase in electricity – and from the exponential growth in data. Two authors of this paper participated in a study [LUNDIN] about the use of such alternatives within ETNO operators in Europe, and found the use of cleaner electricity supply growing, leading to overall decrease in carbon emissions. While this study is focusing on European conditions and ETNO members, they illustrate how carbon emissions could perhaps be reduced despite dramatic demand growth in broader settings.

In summary, connectivity is only part of the solution – applications, use cases, the right data sources, devices, analytics, and cloud systems are also required. The overall impacts of ICT on the environment is complex to derive though macro methods may be attempted to give an indication. Whatever we do around the improvements of ICT's environmental impact (including total energy consumption), we cannot compromise on its ability to support other decarbonization efforts. At the same time, helping the decarbonization of other sectors cannot be an excuse for not addressing the carbon emissions of ICT – for our credibility we need to master both. The focus for the ICT industry should be to maximize the value of ICT, mitigate any negative impacts while concentrating on decreasing the impact of ICT itself.

3. Role of Technical Solutions In Improving Energy Consumption

When it comes to ICT there are opportunities for improvements.

As noted in [ERICSSON-MR] and [LUNDIN], there seems to be a weak correlation between traffic growth and energy consumption. There is, however, stronger linkage to covering new geographical areas, increasing number of users, and the adoption of new technology generations.

Technology generations and technical solutions can also have surprisingly large impact on the demand for electricity by networks. There are of course many aspects of technology that can be raised here, from microprocessors to customer chips, edge compute and cloud systems, and Content Delivery Networks (CDNs), streamlined protocols, network architectures, and end-user devices and their power practices.

To provide some mobile-network specific examples, a small change was made from 4G to 5G in how often certain system-level messaging needed to happen. This had a big impact on how easy it is for network equipment to be in power-saving mode. For background, mobile networks typically face very dynamic load patterns, experiencing high time of day variations (night vs. day), user locations (business districts vs. areas of homes), and device or application type differences (smartphones for humans vs. IoT sensors). Given that at least some fraction of the systems supporting users are tied to the user's location, there will be periods where the offered load for a given part of the network is relatively low. This is true for both longer periods such as night hours, but also in many cases at the level of microseconds, even during periods of moderate load there are plenty of small fractions of time when the equipment does not need to receive or transmit anything.

The changes incorporated in the 5G standards allowed equipment to put itself to a "sleep mode" more often or for longer periods of time, for instance, being able to turn off power amplifiers or another circuitry [ERICSSON-5G]. This can cut idle mode power consumption by as much by two thirds.

Not all changes need to relate to standards, of course. Implementation changes can also have a significant impact. New features in microprocessors to enable faster transition to and from "microsleep" modes can for instance enable network nodes to utilize much reduced power consumption modes without impacting latency or other characteristics for the traffic passing through them [ERICSSON-PP].

These are just examples from our areas of experiences. There are, however, broader aspects that we wish to highlight:

- Even small technical details can have significant effects on power consumption.

- Technical solutions can involve either implementations or standards or both. For instance, in some situations it is sufficient that a standard does not unnecessarily constrain the use of the best implementation strategies. In other situations, a standard might need to support the necessary information transfer and control capabilities to enable the use of the optimal strategies.

- Solutions for improved power efficiency can depend highly on circumstances. Not all situations allow specific actions to provide a significant benefit. For instance, a cloud system that typically always has more tasks to execute when one task completes would not necessarily benefit from arrangements relating to sleep mechanisms.

In other situations, optimizing systems for low utilization situations is important for the overall electricity need. In yet other cases, flexibility is important to enable supporting both low utilization and and maximum load situations.

- Given the different situations, there is large demand for better understanding where energy is consumed, and what parts of systems, networks, and data centers consume the highest amount of energy. Addressing these areas should be a high priority, whereas improvements in other areas might not even have a noticeable effect. For instance, we know that in mobile networks, the radio networks are the biggest contributor to energy consumption.

- There is a need for other actions beyond adopting cleaner energy sources. All energy sources are limited and have environmental costs. It is important to both conserve and use the best sources of energy. Conservation enables us to, for instance, leave more of the clean energy resources for areas of society where reductions are not as easy.

4. Directions for Improvements

As discussed above, there are many potential areas where improvements could be made, and some of these have potentially significant impacts. Exactly where to begin to move forward depends on who you are (e.g. researcher, manufacturer, operator, internet service provider, government, non-governmental organization, or standardization organization).

However, in this paper we wish to highlight these areas in particular:

- Measurements, data, and increased understanding of the issues. Understanding where energy is consumed in terms of the end-to-end process is our key concern. What is the fraction consumed by devices, access networks, transit networks, cloud systems, applications, and data centers? What parts of the industry consume what kind of energy? How do different regions compare? Where is cleaner energy in use, and to what extent?

  While there is a lot of data about many different aspects of this, we have found there to be limitations in the data. For instance, data may only be available for some regions, some numbers are based on models rather than measurements, real-time data is not available, data from different sources may not agree, and so on.

  Better information would enable far better research on the issues and be a firmer basis for improvements.

- Transparency and interfaces. There is a lot of interest in the industry for ensuring that the different actors understand and improve their environmental impacts and energy consumption. Given the high complexity of most fields in terms of how supply chains and services connect different parties together, it would be beneficial to understand how one actor’s service is impacted by their supplier’s service. While information about a supplier’s energy consumption can be tracked today, that is largely an opaque and often manual process. Could open interfaces, standards, and real-time information flows enable us to track energy consumption in a more granular manner? Would more information about current status, for instance of energy availability, also enable making better choices at every level?

- Zero-energy devices. Energy harvesting and other technologies can enable a class of devices to operate without batteries or a mains connection. This is beneficial for reducing power needs and reduced need to arrange a power connection or change the batteries periodically. Reduction in the use of batteries can also eliminate some of the potential e-waste.

- Clean energy. Continued increase in use of clean energy for operator networks would decrease the carbon footprint of the ICT sector. Also increased use of clean energy throughout the life cycle, and by putting demand and focusing on the supply chain would further decrease the carbon footprint.

- Materials efficiency and circularity. Increase the attention on materials efficiency and circularity in technology and systems development is key and deserves to be considered alongside energy performance and other characteristics. Materials efficiency goes far beyond the choice of materials and impacts such, for instance, modularization, durability and traceability.

- Decommission old networks. By replacing and decommission old networks when new are available the energy consumption of the networks can be significantly reduced.

- Prolong the lifetime of devices. The impact from the production part of the lifecycle (a k a embodied emission) of user devices can be reduced by prolonging the lifetime of the devices by for instance facilitating exchange of spare parts and keep updating the software to function in a secure and trustful way.

Recommendations for both policy makers and the private sector are provided in the report from International Energy Agency [IEA]. These recommendations include, for instance, improved data collection, clean energy procurement, research on improved next generation computing and communications technologies, and data center waste heat utilization.

5. Role of Standards Organizations and Research Communities

It should be recognized that many potential improvements are outside the scope of standards and research. For instance, implementation improvements, energy sourcing decisions, materials choices and other business decisions are typically within the domain of companies operating systems or building products.

This does not mean that others, like standards organizations and research communities, cannot contribute. Helpful improvements can, for instance, be the following activities in standards organizations and open-source projects:

- Building protocol interfaces, software APIs, and data access mechanisms for better access to information on how system components operate with regards to energy consumption.
- High performance software designs, and ability to optimize software performance for different situations.

Nevertheless, in launching these types of activities, it is important to have a good understanding of what issues are relevant and where improvements are most fruitful. For this reason, assessment standards like those developed by ITU-T SG5 and ETSI EE EEPS are important to identify and follow up on environmental characteristics and energy performance.

In research communities, collaboration in finding relevant data sources, organizing common data pools, and tooling is an important base for improved understanding of this area. Subsequent analysis activities and critical reviews of the methods provide the valuable results for the standards efforts, open-source improvements as well as the implementation efforts within private enterprises.

6. Conclusions

While the IAB workshop call was specifically on the environmental impacts of the Internet, this paper has focused on the impacts from ICT as a broader and more well-defined topic, and provided examples from mobile networking which is a narrower topic. This focus was partly driven by what information the authors were aware of, but arguably it is difficult to distinguish the roles of the Internet from other aspects of ICT – particularly when ICT equipment is almost universally connected via the Internet technologies.

The paper's contribution is two-fold: first, it provides pointers to analysis and information. And second, we wanted to highlight

- The complex nature of ICT including positive as well as negative impacts across three orders of effects
- The role of ICT in helping other efforts related to environmental impacts
- The opportunities in making ICT itself reduce its environmental footprint via technology
- The role of standards and research organizations

Acknowledgments

The authors would like to thank colleagues across the industry for fruitful discussions and contributions in this area. In particular, we wish to acknowledge the contributions of Ylva Jading, Lars Eggert, Colin Perkins, Mike Mattera, Rich Salz, Luis M. Contreras, Toerless Eckert, Kit Brown, Jiri Novotny, Daniel Migault, and Mirja Kühlewind.

References

[CTIA] "5G Connectivity: A Key Enabling Technology in Meeting America's Climate Change Goals". Accenture & CTIA, 2022.

[ECKERT] Eckert, T.; et al. "IETF and Energy – An Overview". Internet Draft (Work in Progress), IETF, July 2022.

[ERICSSON-CACC] "Connectivity and Climate Change". Ericsson, 2021.

[ERICSSON-MR] "Ericsson Mobility Report". Ericsson, November 2021.

[ERICSSON-PP] Johansson, L.; Holmberg, P.; Skog, R.; "Energy-efficient packet processing in 5G mobile systems". Ericsson Review, June 2022.

[ERICSSON-5G] Frenger, P.; "5G energy consumption: what's the impact of 5G in real networks?". Ericsson, October 2021.

[HILTY] Hilty, L.M., Aebischer, B. (2015). ICT for Sustainability: An Emerging Research Field. In: Hilty, L., Aebischer, B. (eds) ICT Innovations for Sustainability. Advances in Intelligent Systems and Computing, vol 310. Springer, Cham. https://doi.org/10.1007/978-3-319-09228-7_1

[IAB] "IAB Workshop on Environmental Impact of Internet Applications and Systems". IAB, 2022.

[IEA] "Data Centres and Data Transmission Networks", IEA, Paris October 2022.

[IPCC] Arias, Paola A.; Bellouin, Nicolas; Coppola, Erika; Jones, Richard G.; et al. "Technical Summary". 2021.

[ITU-T L.1450] "Methodologies for the assessment of the environmental impact of the information and communication technology sector". ITU-T recommendation L.1450, September 2018.

[ITU-T L.1470] "Greenhouse gas emissions trajectories for the information and communication technology sector compatible with the UNFCCC Paris Agreement". ITU-T recommendation L.1470, January 2020

[LUNDEN] Lunden, D.; Malmodin, J.; Bergmark, P.; Lövehagen, N.; "Electricity Consumption and Operational Carbon Emissions of European Telecom Network Operators". Sustainability 2022, 14(5), 2637; https://doi.org/10.3390/su14052637.

[MALMODIN] Malmodin, J.; Lunden, D.; " The Energy and Carbon Footprint of the Global ICT and E&M Sectors 2010–2015". Sustainability 2018, 10(9), 3027; https://doi.org/10.3390/su10093027".

[OECD] OECD 2001 Berkhout, Frans and Hertin, Julia (2001), Impacts of information and communication technologies on environmental sustainability: Speculations and evidence. Report to the OECD, Brighton, 21.

[ONG] Ong, D., Moors, T., and V. Sivaraman, "Comparison of the energy, carbon and time costs of videoconferencing and in-person meetings", DOI 10.1016/j.comcom.2014.02.009, 2014.

[WHO] "WHO calls for urgent action to protect health from climate change – Sign the call". World Health Organization. November 2015.