Can the Internet be greener?

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I. Intro

2015 has been another record-breaking year in terms of global climate indicators: average global temperatures were the highest on record, sea levels rose to a new record high, and measured atmospheric carbon dioxide levels were not only the highest on record, but also showed the largest annual increase observed in the past half century [1]. In light of these and consistent other observations in the past decades, there is no denying that the Earth is getting warmer. If we want to stop this trend, or at least limit its magnitude, actions need to be taken to reduce human emissions of greenhouse gases (among which carbon dioxide is one of the main culprits) that contribute to global warming.

Human greenhouse gas emissions originate in various economic sectors, including agriculture, industry and transport, but the main source of emissions is the energy supply sector [2]. These particular emissions come from burning coal, natural gas, and oil to generate electricity and heat. Figure 1 shows the steady increase in global electricity production from the past years, and how, despite large investments in renewable energy we've seen in recent years, the sector still relies on fossil fuels to source most of its energy. As a logical consequence, greenhouse gas emissions have also been on the rise for this sector.

In order to counter the trend of growing greenhouse gas emissions, the intergovernmental panel on climate change (IPCC), tasked with evaluating the impacts of climate change, recommends "efficiency enhancements and behavioral changes, in order to reduce energy demand compared to baseline scenarios without compromising development" as a key mitigation strategy [2]. This is where information and communications technology (ICT) comes into play. On one hand, ICT can be used as a tool to change users' behaviors towards more sustainable actions (this research area is often referred to as "ICT for Green"). On the other hand, we should limit the carbon footprint of ICT itself, which is already considerable today and expected to keep growing in the coming years (this research area is often referred to as "Green ICT").

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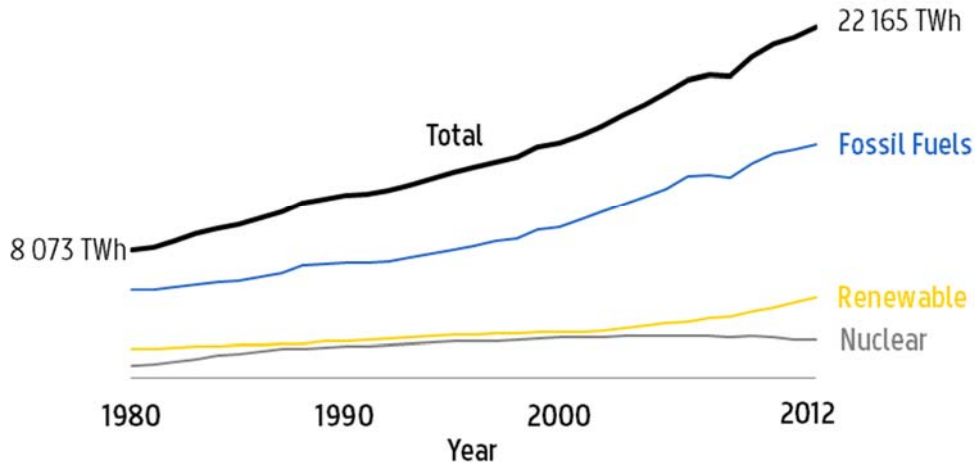

Figure 1: Worldwide electricity generation in the past decades, broken down by energy source [3] (1 TWh = 1 billion kilowatt hours).

II. Internet footprint today

Needless to say, the Internet and associated services (World Wide Web, email, instant messaging Internet Telephony, file hosting and sharing, and so on) are at the heart of the digital economy, and in most regions of the world it has become impossible to imagine contemporary life without them. Billions of devices already have a data connection to the Internet today, and billions more are expected to follow in the coming years.

The data connections for these devices and the services on offer are made possible by a global system of communication networks, that use the Internet protocol suite (TCP/IP) to transmit information across the globe; and by data centers that store and process large amounts of digital information. Because of its sheer size on a global scale, this infrastructure now forms a non-negligible contribution to the human ecological footprint.

The term “ecological footprint” refers to a measure of the impact that human activities and products have on the environment. This impact can take various shapes throughout the lifecycle of a product, like pollution associated with mining for raw materials, greenhouse gas emissions following from the energy consumption during manufacturing and usage, or waste creation when broken or obsolete equipment is disposed of.

Most of the existing research on green ICT and green Internet technologies focuses on the associated greenhouse gas emissions, and in many cases this is further narrowed down to an analysis of the use-phase emissions only. This because there is a general consensus that, when considering the full life cycle analysis of Internet equipment, use phase electricity consumption is the largest contributor to the overall greenhouse gas footprint of the Internet [4, 5][2].

[2] This statement holds for the general picture, i.e. averaged over all Internet equipment. It should be noted that for some particular mobile devices with short lifespans (e.g. smartphones) the manufacturing footprint is actually larger than the use phase footprint.

So just how big is this use phase electricity consumption? Our study [5] estimated the following worldwide electricity consumption figures for the year 2012:

- communication networks: 334 TWh
- personal computers (the main device category used to access communication networks): 307 TWh
- data centers (to make data available in the cloud): 268 TWh

Together, these 3 categories have a consumption that amounts to 909 TWh, corresponding to 4.6% of all worldwide electricity. This is not yet accounting for other networked devices such as television sets, set-top boxes (to stream Internet video) and other electronic multimedia devices which would likely consume a similar share on top of the aforementioned value.

As can be seen from the arguments above, the Internet footprint today represents a substantial share in global greenhouse gas emissions.

III. Expected trends

When we want to estimate the impact of ICT on the environment, we are not only interested in the current footprint, but we would also like to assess whether this footprint will increase, remain stable or decrease in the coming years. In such future projections, a variety of drivers come into play:

- *Increasing efficiency*. Internet equipment becomes ever more efficient, leading to a vast increase in the number of bits that can be stored, transported, processed per energy unit spent. Also the manufacturing footprint per sold device (expressed in kg CO_2-equivalent) is typically decreasing from year to year.
- *Increasing volumes and numbers*. On the other hand, the amount of data to be stored, transported or processed is also growing at a fast pace [6]. The number of Internet users worldwide continues to grow, the number of devices per user is growing, etc.
- Many other factors play a role as well: new equipment types can replace old ones (e.g. shift from desktop PCs to laptop PCs to tablets, with much lower electricity consumption per device); changes in the lifetime of devices can reduce or increase the number of new devices to be produced (when lifetime increases or decreases, respectively) and hence reduce or increase the footprint of the manufacturing phase; etc.

Studies based on historical data have shown that in the past decades, the drivers for an increase in power consumption have outweighed the drivers for a decrease in power consumption. For instance our study [5], of which the results are shown in Figure 2, compared the use phase electricity consumption of key Internet equipment in 2007 versus 2012. The results reveal a compound annual growth rate of about 7%. This growth rate is well above the general electricity consumption figures worldwide (about 3%), so the relative share of electricity going to the Internet was clearly growing in the 2007-2012 period.

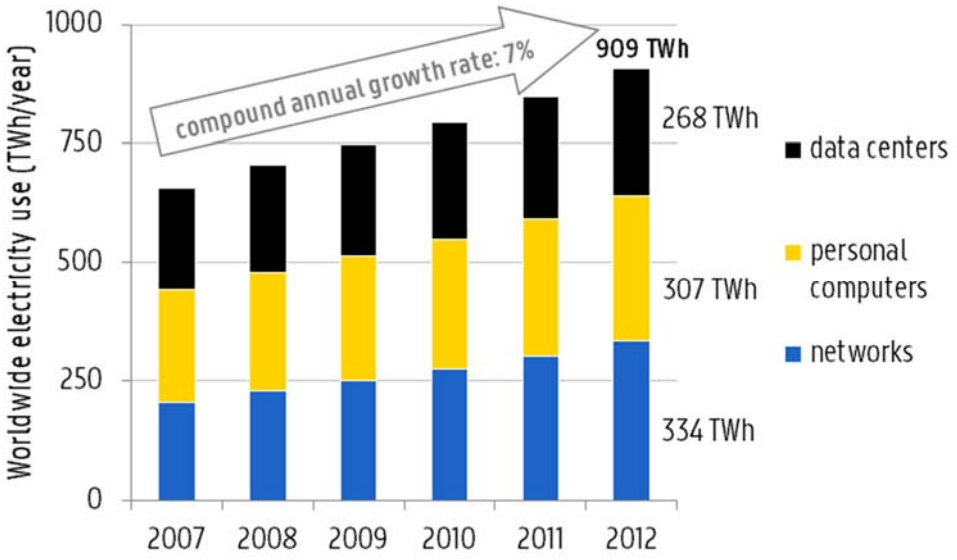

Fig. 2: Worldwide electricity consumption during use phase from 2007 to 2012 for three key Internet equipment categories: communication networks, computers and data centers.

Taking all effects into account, it is very likely that the overall footprint of the Internet will continue to grow for many years to come.

IV. "Internet for Green"

Besides the Internet's own footprint, the Internet also has a large and growing influence on the footprint of other sectors in society. Internet and ICT-solutions can be key enablers to lower the footprint in transportation, manufacturing, building, agriculture, the service and consumer sector and the power generation sector [7]. Extensive studies have been conducted, for instance by major ICT companies, to estimate the potential of these "Internet for Green" solutions. These studies reveal that the abatement potential is multiple times the Internet's own footprint.

However, the word "potential" is key in this context. The abatement potential can be much higher than the real abatement in the future (or even have a different sign in some cases). We illustrate this with an example. Suppose a new video conferencing system is released, consisting of a high-definition life-size screen wall placed in the middle of a meeting table, giving the users of the virtual meeting almost the same look-and-feel as a real face-to-face meeting. This system could be a perfect substitute for international meetings, where formerly some or all of the attendees had to fly in for a meeting that would last only a few hours or days. At first sight, this video conferencing system comes with huge abatement potential: if the system is adopted in many meeting rooms and replaces many face-to-face meetings, as a direct consequence, millions of flights can be avoided each year.

However, the adoption of this video conferencing system will also have indirect effects. As flight travel times and costs are no longer a threshold for these virtual meetings, the number of meetings between remote parties will increase (as distance is no longer a barrier) and result in new collaborations between long-distance partners. At the same time, face-to-face meetings may remain important to create a personal connection between the parties, so ultimately these long-distance partners will still want to meet face-to-face from time to time. This could induce more flights (perhaps spanning longer distances than before) than the initial scenario where people might have

been more reluctant to start a collaboration with a (very) remote partner. So, while the direct consequence of the video conferencing system is a large reduction of flight kilometers, the indirect consequence could actually be a lesser reduction or even an increase of flight kilometers! This is the so-called rebound effect, leading to a real abatement that is much worse than the abatement potential that could be expected from direct effects.

Furthermore, some of the proposed potential benefits rely on assumptions that may not necessarily hold true: "big data" in the form of massive data analysis and feedback to enable better decision-making are often heralded as having the potential to optimize energy efficiency in many aspects of our lives. However, the availability of data in and of itself does not guarantee users will act on this information, nor that they will put energy efficiency first in their decision. A smart car, for example, may inform a user that his driving style is wasteful, but if the user does not act on this information and instead prefers to drive as fast as possible, all the smart functionality did was add to the overall footprint of the product (due to the energy and pollution associated with the electronics for added intelligence).

It is our belief that the real abatement of Internet for Green will be much lower than the estimated abatement potential. Presumably, the Internet's own footprint is in the same order of magnitude as the real abatement that can be expected from future Internet for Green solutions. Therefore, both aspects are important to consider, if we want to optimize the environmental impact of the Internet.

V. How to lower the Internet's footprint

To reduce the ecological footprint of the Internet, many **research** initiatives in the past years (e.g. the GreenTouch initiative [8]) have pointed out useful directions for the future. With respect to the communication networks footprint for instance, large savings can be obtained by making careful use of wireless networks (since they are inherently less power efficient than wired networks), by introducing sleep modes during off-peak hours, by building equipment with power consumption more proportional to the load, by avoiding large power losses due to equipment doubling for recovery reasons, etc. [9]. Next to these initiatives, further research on Green ICT in industry and academics will be crucial. Novel hardware solutions, software optimizations and clean-slate network protocols have to be designed, in order to drastically lower the Internet's future footprint without sacrificing service quality and quality-of-experience for the user. While many funding stimuli for this Green ICT research were started 5 to 10 years ago, an unfortunate decline in stimuli is noticed in recent years. A reactivation of well-focused research funds is urgently needed.

To steer these focused research initiatives in the good direction, **more holistic models** for the Internet's footprint need to be constructed. The Internet is a complex infrastructure combining a vast number of devices and smaller networks, with a variety of stakeholders with different interests. This makes it hard and challenging to build a holistic model. Nevertheless, such a model is crucial as a guiding compass for research initiatives and other measures to alleviate the Internet's footprint. It will avoid short-sighted solutions that lower the footprint of a system at the expense of a higher footprint for components external to the system boundaries. Too many of these solutions today are branded as "green" while in fact they are not[3].

[3] For instance a new sensor network system can be deployed, measuring the temperature and humidity at many locations in a building. This provides extra information to the occupant of the building and may lead to a more refined control of the HVAC system. However, the extra power consumed by the sensor network itself

Despite the good intentions of the research community, their footprint-reducing solutions may remain hollow phrases when there is no external driving force behind them. One possible driving force could come from **regulations and policies**. The sale of energy-hungry versions of a device or application could be forbidden on the market, and the limitations could become gradually stricter from year to year, to stimulate energy-saving product lines. Next to a plain prohibition, also clear energy labels in ICT shops (comparable to energy consumption labels on household appliances) could be quite informative to allow the customer to make a footprint-friendly decision.

The ultimate driving force to lower the footprint (not only for the Internet but for society as a whole) is a **worldwide environmental taxation system**, often referred to as "carbon tax" [10, 11]. While it is considered too revolutionary for many of today's politicians and policy makers, it is our firm belief that this is the best intrinsic solution to avoid the catastrophic effects of climate change, and it should be introduced as soon as possible. In such a system, the environmental consequences of a product should be translated in a tax added to the product price. The tax should correspond to the real societal cost to reverse the environmental consequences of this product. This will lead to a taxation high enough to steer the potential buyer in making a well-founded decision and towards a preference for environmentally friendly products.

Without a doubt, introducing such a global environmental taxation system is challenging. To keep the complexity under control, the tax should be raised as close to the source as possible, preferably at the mining or extraction of the raw material (e.g. oil, coal, gas). This way, the tax will trickle down automatically in the further steps of the production process and eventually in the final product. To stimulate also positive environmental effects in some specific cases (e.g. carbon capture and storage at power plants), a negative tax or bonus can be included. The taxation system should be introduced worldwide and simultaneously, to avoid unfair competition between countries, raw materials, etc. The taxation system can concentrate on GHG emissions, but can also be extended to take other environmental threats like for instance rare material depletion or ecosystem damage into account.

VI. Conclusions

As motivated in the preceding paragraphs, the answer to the question "Can the Internet be greener?" is a firm "yes". Despite various efforts in the last decade, there is still a lot of potential to make the Internet more energy efficient in the coming years. For this to happen, several factors will be crucial, such as a critical examination of ideas and proposals (Is a new solution really as green as it is presented?) and societal driving forces to stimulate green solutions.

VII. References

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and the energy for the manufacturing of the sensor network are often neglected in the environmental assessment of the sensor network system.

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