

# Reducing Green House Gas Emissions With Congestion Control

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## 1 Internet energy saving: Why is it important?

By enabling online meetings, replacing snail mail with email, etc., the Internet helps to reduce Green House Gas (GHG) emissions. However, at the same time, the Internet itself needs a significant amount of energy, which translates into GHG emissions, and hence an effect on global warming. Appendix A is an attempt to estimate the magnitude of the Internet’s impact, on the basis of well-known prior studies; it arrives at an approximate range of 0.5% - 1.17% of worldwide GHG contributions, and an approximate global warming impact between 1/7th and 1/3rd of the aviation industry.

While these numbers are dwarfed by, for example, road traffic or energy use in buildings, the absolute amount is still large, and reducing it is important. The Internet offers a particularly interesting opportunity here because, quite different from e.g. the aviation industry, it is possible to achieve an almost immediate worldwide impact by introducing standards and fostering their implementation. Operating System updates, for example, are commonly rolled out to millions of devices within a short time period.

## 2 Why congestion control?

It is extremely common to regard energy consumption as a trade-off, where good performance means high energy usage and vice versa. Such a trade-off is made explicit to the user by smart phones offering a “power saving” mode.

Congestion control is uniquely placed in that regard: when done efficiently, it reduces the Flow Completion Time (FCT), which is a very well accepted congestion control metric [DM06]. A shorter FCT means that transfers finish faster, which translates into *both* a performance gain and longer sleep times for devices, i.e. energy reduction — a win-win, attractive for everyone to permanently enable.

## 3 Is this real?

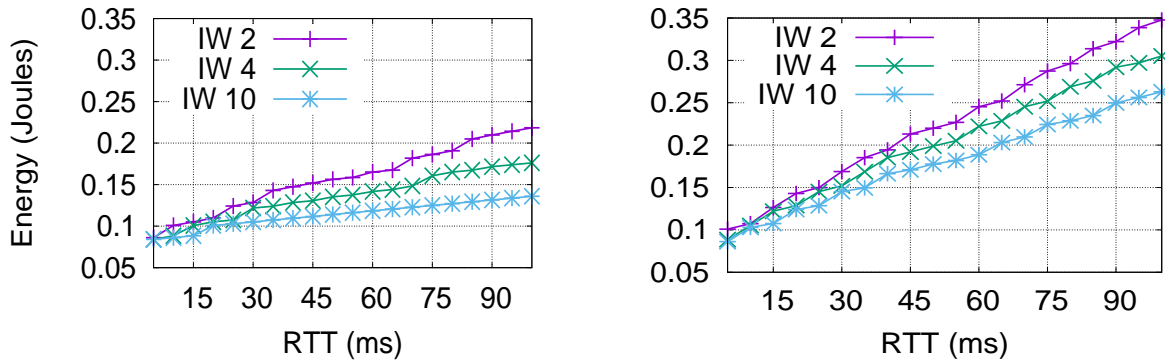


Figure 1: Data transfer energy consumption when transferring 10 (left) and 80 packets (right). Transfers using larger IW values finish faster, and they are more energy efficient.

Yes. Figure 1 shows a result of a test where we fed packet traces from data transfers with different values of TCP’s Initial Window (IW) parameter into EnergyBox [VNTP14], a tool that provides an

estimation of an end hosts’s Wi-Fi power consumption related to a certain traffic pattern. EnergyBox has been validated to achieve 95-99% accuracy, and it has been used by Spotify for quantifying their mobile application’s energy consumption.

The focus on end hosts may seem surprising, but there are in fact good reasons to reduce the energy usage of “last mile” equipment in general; see Section [A.1.3](#) for an elaboration.

## 4 What can we do?

Generally, methods to decrease the FCT can help (e.g., 0-RTT connection setup as in QUIC [[IT21](#)] or TCP Fast Open [[CCRJ14](#)], or increasing the IW when this is appropriate). It is probably useful to go beyond a simple general update of the IW constant, and apply dynamic methods—e.g., the authors of [[NZL<sup>+</sup>19](#)] describe a reinforcement learning based approach to tune the IW, successfully deployed over several years at Baidu. Other ways to decrease the FCT include the re-use of parameters from ongoing connections—e.g., by coupling congestion control [[IWH<sup>+</sup>18](#)] when appropriate, or multiplexing flows over a single connection as with QUIC’s multi-streaming. Such mechanisms can work better when they are applied inside the network (e.g., in proxies) as the multiplexing potential increases.

It is also interesting to entertain the thought of energy usage as a *metric* for congestion control, in the same vein as, for example, throughput, delay, packet loss, and fairness. Energy usage is generally tied to the specific hard- and software of a system, but applying it as a metric would require designing a more abstract measure. Perhaps, from measuring multiple systems, we could find a common relationship between the energy use of sending vs. receiving vs. calculation overhead, and maybe such relationships could be represented by a new “energy usage” metric?

We refer to [[CWT<sup>+</sup>22](#)] for a broader discussion of energy saving possibilities in the Internet, including some that are related to congestion control. Further details about the test described in Section [3](#), including an explanation of why these results are still applicable for modern smartphones, are given in [[Wel22](#)], and a brief presentation is also planned for the meeting of the Internet Congestion Congestion Control Research Group (ICCRG) at IETF-115 in London on November 8, 2022.

## A Green House Gas Emissions: the Internet vs. Aviation

In public discourse, air travel has commonly been associated with an activity that should urgently be reduced to help slow down global warming. The impact of the Internet on global warming is much less known, and deserves more attention. It is therefore useful to relate the Green House Gas (GHG) emissions that are caused by the Internet to the aviation industry. Hence, here, we offer some facts about this relationship.

### A.1 Electricity and the Internet

Table 1 is used as the basis for our derivation of Internet GHG emissions in the following subsections. In this section, we use GHG and CO<sub>2</sub> interchangeably, as CO<sub>2</sub> makes up the vast majority of GHG emissions from the energy sector [EPA22].

Line	Fact	Year	Source
1	Power generation: 13 Gt CO <sub>2</sub> , i.e. 38% of energy CO <sub>2</sub>	2018	[IEA19]
2	Energy = 37.6 Gt CO <sub>2</sub> , 75.6% of GHG emissions	2022	[GFV22]
3	Heat & Electricity = 15.8 Gt CO <sub>2</sub> , 31.8% of GHG emissions	2022	[GFV22]
4	USA GHG contribution of electricity: 25%	2019	[EPA22]
5	ICT CO <sub>2</sub> = 2.7%	2020	[LCW19], citing “SMARTer 2030” report
6	ICT CO <sub>2</sub> : between 2.1% and 3.9%	2021	
7	ICT sector = 6% of electricity, telecom = 1.8%	2012	[Wel16], citing [LHV <sup>+</sup> 12]
8	Networks CO <sub>2</sub> share of ICT: 24%	2020	2020 data in Fig. 3 of [FBLW <sup>+</sup> 21]
9	Internet = between 1.1% and 1.9% of electricity	2011	

Table 1: Internet related GHG emissions source data.

#### A.1.1 How much does electricity contribute?

**Lines 1 and 2:** Energy contributes 75.6% of all GHG emissions. Electricity makes up 38% of the CO<sub>2</sub> contribution of energy. Hence, by combining these data from 2018 and 2022, we can derive that electricity contributes 28.7% of the total GHG emissions. **Line 3:** electricity contributes 31.8% of the total. **Line 4:** In the USA, the electricity contribution is 25% of the total. However, in the USA, transport is a much larger contributor to energy than the global average [RRR20], and hence these 25%, while probably too small, can serve as a reasonably reliable lower bound.

**From multiple sources, we arrive at the following lower and upper bounds for the global contribution of electricity to GHG emissions:**

$$MINGHG_{POWER} = 25\%, MAXGHG_{POWER} = 31.8\%$$

#### A.1.2 How much does ICT contribute?

**Lines 5 and 6:** The ICT CO<sub>2</sub> contribution is between 2.1% and 3.9%. From line 7:, ICT constituting 6% of electricity means between a CO<sub>2</sub> contribution between 1.5% (using  $MINGHG_{POWER}$ ) and 1.9% (using  $MAXGHG_{POWER}$ ). Both of these values are significantly below the numbers from lines 5 and 6, but the study underlying table line 7 [LHV<sup>+</sup>12] is also much older than the others (2012). We therefore resort to using this reference only for the relationship between telecommunication and ICT in the following discussion.

**From lines 5 and 6 in Table 1, we get:**

$$MINGHG_{ICT} = 2.1\%, MAXGHG_{ICT} = 3.9\%$$

#### A.1.3 How much does the Internet contribute?

At this point, things become extremely vague. Limiting the focus to the core and access network, data centers and undersea cables, and not considering embodied energy (the energy used for device production), the authors of [AMKF18] have shown that increasing energy efficiency has led to a decline in energy usage per byte. In two large ISPs, this has offset the exponential growth of Internet traffic, leading to roughly linear energy use in one case and even a slight decline in the other [KM21].

This matches a very recent study, which, using a similar focus, finds that the electricity consumption remained approximately constant from 2015 to 2018 in the networks of 15 telecom network operators with headquarters in Europe, representing operations in 21 European countries, and additionally including their operations in 27 countries overseas [LMBL22].

Importantly, both of these studies exclude enterprise networks and home networks with both Customer Premises Equipment (CPE) (e.g., WiFi access points) and User Equipment (UE) (e.g., laptops). When the focus is broadened, studies differ in various aspects, such as:

- What types of UE are considered? E.g., TVs cost much energy, but are not normally a part of such studies.
- Is CPE considered?
- Is embodied energy considered?
- Are data centers considered? They constitute a large part of the Internet’s energy, yet due to a strong (monetary) incentive, large data centers now quickly move towards operation on sustainable energy. Microsoft, for example, promises to shift to 100 percent supply of renewable energy for all its data centers, buildings, and campuses by 2025.<sup>1</sup>

Here, we consider three studies from Table 1. **Line 8:** 24% of  $MINGHG_{ICT}$  and  $MAXGHG_{ICT}$  means a 0.5% and 0.9% GHG contribution, respectively; this excludes UE and data centers, and it is not clear whether embodied (i.e., device production) energy is considered. **Line 7:** As we stated earlier, this line stands out for its age, and we therefore only use the telecom/ICT relationship from here (30%) instead of the absolute energy numbers. Using  $MINGHG_{ICT}$  and  $MAXGHG_{ICT}$  this yields a GHG contribution between 0.63% and 1.17%, focusing on use phase electricity consumption of telecom operator networks, office networks and customer premises equipment. **Line 9:** between 1.1% and 1.9% of  $MINGHG_{POWER}$  becomes a GHG contribution range from 0.28% to 0.48%, and for  $MAXGHG_{POWER}$ , these values become 0.35% and 0.6%, respectively, i.e. the total range becomes 0.28% – 0.6%. We report about this study despite its age because it is specifically focused on the Internet, and attempts to consider all elements: embedded energy, the core network, CPE, and UE.

GHG %	Embodied	UE	Data centers	Year	Source
0.5 – 0.9	?	N	N	2020	2020 data in Fig. 3 of [FBLW <sup>+</sup> 21]
0.63 – 1.17	N	N	N	2012	[LHV <sup>+</sup> 12]
0.28 – 0.6	Y	Y	Y	2011	[RM11]

Table 2: Three studies on network energy use, with age and coverage. Due to the age of these studies, only the networks/ICT relationship was considered from [LHV<sup>+</sup>12], and we will not further work with the data from [RM11].

From Table 2, we arrive at a range for the Internet’s GHG contribution:

$$MINGHG_{INTERNET} = 0.5\%, MAXGHG_{INTERNET} = 1.17\%$$

## A.2 Aviation

Recent data on the global warming impact of aviation is available from [Rit20]. Here, the analysis is complicated by the fact that *not* only CO<sub>2</sub> plays a role (around 2.5% of global emissions). Warming effects are also caused by other gases that airplanes leave in the atmosphere, including water vapor. The entire impact, called “effective radiative forcing”, accounts for roughly 3.5% of global warming.

## A.3 The Internet vs. Aviation

Putting aviation data from the previous section in relation to  $MINGH_{INTERNET}$  and  $MAXGH_{INTERNET}$ , we can arrive at the following conclusion:

**Considering only CO<sub>2</sub> emissions from airplanes, the Internet’s contribution to global warming is between 1/5th and approximately half of the contribution of the aviation industry.**

<sup>1</sup><https://blogs.microsoft.com/blog/2020/01/16/microsoft-will-be-carbon-negative-by-2030/>

Considering the entire airplane effect of “effective radiative forcing”, the Internet’s contribution to global warming is between 1/7th and 1/3rd of the contribution of the aviation industry.

## A.4 What does this mean?

First, all of the reported numbers are very rough, and to be taken as such — they are ball-park figures that give a “feel” of the magnitude. While they are all small compared to the “bigger picture” (compared to, e.g., road traffic or energy use in buildings [RRR20]), they are nevertheless significant.

Different from large industries such as aviation, the Internet offers the possibility to have an immediate *global* impact via a change of standards. There are many examples of ideas that were developed by small research groups or even individuals, and were quite quickly deployed in the major Operating Systems, with a direct effect on millions of devices all over the world.

**Due to its potential for impact at a global scale, energy-saving Internet research focused on standards can cause a very significant global reduction of GHG emissions.**

As a side point, we stress that our analysis does *not* conclude that video conferencing would be almost as harmful as flying (or that, conversely, flying would equate 3 – 7 video conferences). Generally, the number of people flying is much smaller than the users of the Internet, and thus, the per-person CO<sub>2</sub> footprint of an individual flight is much higher [Rit20]. Regarding meetings, there is ample evidence that videoconferencing is better for the planet; e.g., the authors of [OMS14] find that videoconferencing takes at most 7% of the energy/carbon of an in-person meeting. Such per-person or per-meeting analyses are entirely different in scope.

## A.5 Misinformation

Plenty of misinformation has been published regarding the Internet’s energy use, often exaggerating it. This can be quite harmful: it reduces the credibility of proper analyses, and it makes efforts to reduce the Internet’s energy seem questionable [KM21]. The present document is intended to place the real energy usage into a more realistic range, hopefully contributing to a better understanding of the issue and the value of improving things.

Some notable examples of misinformation are:

- “The energy used in our digital consumption collectively emits the equivalent amount of carbon as the entire airline industry.”<sup>2</sup> — according to our analysis, this is almost certainly an exaggeration.
- “Perhaps unsurprisingly, the footprint of an email also varies dramatically, from 0.3g CO<sub>2</sub>e for a spam email to 4g (0.14oz) CO<sub>2</sub>e for a regular email and 50g (1.7oz) CO<sub>2</sub>e for one with a photo or hefty attachment, according to Mike Berners-Lee, a fellow at Lancaster University who researches carbon footprints. These figures, however, were crunched by Berners-Lee 10 years ago. Charlotte Freitag, a carbon footprint expert at Small World Consulting, the company founded by Berners-Lee, says the impact of emailing may have gone up.” — this statement appeared in a BBC article from March 2020.<sup>3</sup> A later blog post<sup>4</sup> states: “With new data in hand, Berners-Lee estimates that an individual email can be anywhere from 0.03g CO<sub>2</sub>e to 26g CO<sub>2</sub>e.”. Finally, another BBC article<sup>5</sup> states: “Mike Berners-Lee, a respected professor on the topic whose research was used in the Ovo Energy work, told the Financial Times it was based on ‘back-of-the-envelope’ maths from 2010 – and while useful to start conversations, there were bigger questions.”
- “A typical office worker sends and receives around 140 emails per day, which, over the course of a year, creates as much CO<sub>2</sub> as flying from London to Bruges or watching 955 movies.”<sup>6</sup> — here, the numbers simply do not add up. An average email size may be about 75 KB<sup>7</sup>, which means that the amount of data over a year becomes 3.65 GB. A Netflix movie, for example, can

<sup>2</sup><https://www.climateimpact.com/news-insights/insights/infographic-carbon-footprint-internet/>

<sup>3</sup><https://www.bbc.com/future/article/20200305-why-your-internet-habits-are-not-as-clean-as-you-think>

<sup>4</sup><https://sedna.com/blog/the-carbon-footprint-of-carbon-copies-how-does-email-affect-the-environment/>

<sup>5</sup><https://www.bbc.com/news/technology-55002423>

<sup>6</sup><https://www.cwjobs.co.uk/insights/environmental-impact-of-emails/>

<sup>7</sup><https://www.lifewire.com/what-is-the-average-size-of-an-email-message-1171208>

be between around 0.3 GB and 7 GB per hour in size<sup>8</sup>, depending on the chosen quality. Being “friendly” towards the calculation would mean to assume only 1.5 hours per movie and using the lowest quality in this range, which then means 8 movies instead of 955.

In the examples above, we have quoted online media both as a source of misinformation and to refute it; since the information is contradictory, either one of the sources contains misinformation. More examples are available in the slides<sup>9</sup> from Jonathan Koomey’s keynote speech at the IEEE iTherm 2021 conference.

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<sup>8</sup><https://www.buckeyebroadband.com/support/internet/how-much-data-does-streaming-netflix-use>

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