Complete life-cycle assessment of the energy/CO2 costs of videoconferencing vs face-to-face meetings

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Abstract—**While video conferencing is often viewed as a greener alternative to physically travelling for face-to-face meetings, it has its own energy and carbon dioxide costs. In this paper we present the first analysis of the total cost of videoconferencing, including network plus videoconferencing equipment operating costs, and lifecycle assessment (LCA) of equipment costs, and compare these costs to the total cost of transport for face-to-face meetings. While the costs of these meeting forms depend on many factors such as distance travelled, meeting duration, and the technologies used, we find that videoconferencing takes at most 6.7% of the energy/carbon of a face-to-face meeting. We analyze the sensitivity of the costs to various factors and consider trends in energy and carbon usage to predict how the comparison might change in the future.**

Keywords- carbon; green communication; greenhouse gases; GHG; teleconferencing; telepresence; remote virtual meetings

I. Introduction

Information and communication technology (ICT) is often seen as an attractive mechanism for reducing our environmental impact. In particular, ICT substitutes physical processes with virtual ones, thus providing a greener alternative to conventional activities. A good example is the increasing use of videoconferencing, which replaces physical travel with transfering information across a network. However, videoconferencing is not entirely green with zero environmental impact. The many devices involved in the capture, processing and transmission of information in a videoconference consume electricity, and the generation of electricity has a considerable carbon footprint. Significant environmental impact also arises from the lifecycle of these devices, including their production, deployment and disposal stages. Depending on the magnitude of these effects, the actual carbon savings of videoconferencing over face-to-face meetings might be reduced or even negated.

This paper presents a comprehensive study to evaluate the actual energy and carbon savings of videoconferencing solutions over face-to-face meetings. The scope of our study includes the operating and lifecycle (embodied) cost of the end terminals, videoconferencing equipment, and network infrastructure. Thus this study provides, to the best of our knowledge, the first holistic estimate of the energy and carbon cost of a videoconference that includes both the direct and embodied energy of all devices involved in videoconferencing.

We also compare the carbon emissions of videoconferencing with those of the common modes of transportation taken by participants to attend meetings. We consider the direct fuel consumption and the lifecycle energy cost of the vehicles and the corresponding transport infrastructure. We also evaluate how varying travel distance and meeting duration affect the overall carbon savings brought about by videoconferencing.

This paper starts (Section II) by reviewing literature that has examined the carbon costs of videoconferences and face-to-face meetings. Because the carbon costs of running videoconferencing equipment arise from electricity consumption, and electricity generation systems (and so corresponding carbon costs) vary radically by geographical location, most of this paper (Sections III-IV) expresses running costs in terms of energy, and we translate these to carbon costs in Section V. Considering energy as the unit for operating costs has the added benefit of facilitating comparison to other lifecycle costs (e.g. manufacture and disposal) which are typically expressed in terms of energy rather than carbon emission, enabling a total lifecycle comparison of the costs of videoconferencing versus face-to-face meetings. In Section III we consider the costs of videoconferencing, covering network operating costs (III.A), videoconferencing terminal operating costs (III.B) and lifecycle analysis of network and terminal equipment (III.C). We then consider the transportation costs of face-to-face meetings in Section IV, and compare the total costs of video conferencing and face-to-face meetings in Section V. In Section VI we extrapolate trends in energy/carbon usage to predict how these costs may change in the future, and offer conclusions in Section VII.

II. Literature Review

Although video conferencing has been commonly advertised as a greener alternative to face-to-face meetings, surprisingly little research has been done in quantifying the actual energy savings and greenhouse gas reductions brought about by video conferences. In this section we review the few papers that have directly considered the carbon costs for videoconferencing, while in subsequent sections we refer to many other papers that provide data about energy and carbon costs of components of the complete meeting ecosystems.

Baliga et al. [1] studied the carbon savings provided by telecommuting as a function of the percentage of reduction in car and air travel. Their work focused on the energy consumed by the network infrastructure, in particular the carbon contribution for different access networks. However, they did not study the energy and carbon contribution of end systems such as videoconferencing equipment and LAN, and also omitted the lifecycle cost of the devices involved. Based on their calculations, they found that telecommuting and teleconferencing does substantially reduce carbon emissions; e.g., a 5% reduction in car travel will save between 50 to 160 $kgCO_2e$ (kilograms of carbon dioxide equivalent) per household, depending on the quality of the video call and the type of access network.

Guldbrandsson and Malmodin [2] studied the life-cycle CO_2 savings of three different videoconferencing setups for a meeting between Stockholm and Dallas. The total active duration of the video conferencing systems is assumed to be 960 hours p.a. and 48 plane trips are assumed to be eliminated per year. For this specific case, they found that using the videoconferencing systems saved roughly 215 ton CO_2e/year, which is about 170 times the annual carbon emission of a videoconferencing system.

Another study by Quack and Oley [3] found that substituting meetings by videoconferencing reduces carbon emissions by up to 90%. They also presented the tradeoffs between distance and the energy cost – longer travel distances leads to increased carbon savings. However, they did not present details of their derivation and intermediate values in terms of the energy and carbon emission for both meeting solutions. This makes it hard to scale their results to estimate the environmental impact for varying meeting dimensions (distance, duration, configuration of end terminals, number of participants and endpoints).

III. VIDEOCONFERENCING ENERGY COST

In this section we assess the energy costs of videoconferencing by examining the contribution of the operating expenses (opex) of the network (Section III.A) and videoconference terminals (Section III.B), as well as the lifecycle costs of network and videoconference equipment (Section III.C).

A. Network operating expenses

Network opex cover the use-phase energy cost of the network infrastructure including all transmission and switching equipment in the Internet. For our purposes, the Internet does not include networking equipment at end sites (e.g. home routers) but includes ISP equipment. We will separately consider networking equipment at end sites because it can be measured using techniques similar to those used to measure the power requirements for other devices at end sites, which will be addressed in Section III.B. A common measure for the network opex is the energy intensity of data transfer, which is the energy cost per gigabyte of data transmission (kWh/GB) [4].

The total active power of the Internet is estimated to be between 43 GW to 72 GW [5]. Also, the global Internet traffic was estimated to be 500 PB per day in 2010 [6]. This is consistent with the value extrapolated from the Minnesota Internet Traffic Studies [7], assuming the growth rate of the Internet data flow is 50% in 2009 [4]. Therefore, the Internet energy intensity is calculated by dividing the operating power of the Internet (Watts) by the Internet data flow (bits per second), as in [4]. The end result is an estimate of the average operating energy intensity of the Internet in 2010 of between 2.17 kWh/GB and 3.61 kWh/GB. Videoconference data rates vary widely (as discussed further in Section V), but typically range between 100 kb/s to 10 Mb/s (or equivalently 0.045 GB/h to 4.5 GB/h), which at around 3 kWh/GB equals 135 W to 13.5 kW to carry video traffic across the Internet.

As a sanity check, we compare our obtained value of the Internet energy intensity to the value estimated in [4]. Taylor and Koomey's analysis of Internet advertising [4] presented 3 separate estimates of the energy intensity - 24.9, 16.3 and 9.4 kWh/GB in year 2006, which were based on different sources. They also found that the Internet energy intensity fell 10-fold between 2000 and 2006. Assuming this trend continues, in 2010 the estimates of energy intensity would be 3.7, 2.4 and 1.4 kWh/GB, which are consistent with our range of estimates.

B. Videoconference terminal operating expenses

Videoconference devices lie at the outer edge of the network, which include the home or office LAN devices (modems, switches and WiFi access points), computers, displays, projectors and videoconferencing specific equipment and peripherals such as CODECs, microphones, sound systems and cameras. Unlike network equipment, the energy consumed by these devices correlates to their operating time rather than data volume. So, we estimate the power consumption of these devices, representing the energy consumption per hour of use.

Current videoconference systems vary widely in terms of their configuration. PC-based videoconferences only require a microphone, speaker, camera, display and a PC. On the other hand, top of the range telepresence systems such as the Cisco TelePresence System 3000 [8] include multiple large displays that can optionally be replaced by projectors, multiple high definition (HD) cameras and a sound system for spatial audio-video, a dedicated CODEC and custom lighting arrays. Therefore, we estimate the power consumption per device separately for a range of devices to enable calculation of the energy consumption of different setups.

Personal Computers (PC): Software-based videoconferencing systems rely on the processing power of a general PC to perform the functions of a CODEC. We estimate the power consumption of current laptop and desktop computers to be 40W and 150W respectively [5].

Display Devices: We consider three display technologies which are commonly used in current PC videoconferencing solutions – plasma display panels, light emitting diode backlit liquid crystal displays (LED-LCDs) and projectors. The active-mode power consumption of plasma and LCD displays generally correlates with their screen area, with additional overhead attributed to non-display components [9], given by:

$$P_{TV}\ on = (\text{Screen Area}) \times P_{Screen} + P_{Basic} \qquad (1)$$

Because videoconferencing systems can differ markedly in screen size, we consider screen area in our power estimation. The average value of P_{Basic} is 20 W [10]. We also estimate P_{Screen} to be 203 W/m^2 for plasma and 172 W/m^2 for LED-LCD, based on data for the average on-mode power and the average screen area of TV displays in 2010 [10]..

Projectors are used as a display device in some videoconferencing systems (e.g., the Cisco TelePresence System 3000 provides an optional projector [8]). We estimate a projector to consume 135 W based on measurements in [11].

CODECs: Some videoconferencing solutions use dedicated hardware for encoding and decoding video, rather than a general purpose PC. Constable [11] performed controlled experiments to measure the actual power consumption of multiple videoconferencing CODECs. He found that newer CODECs generally consume more power (due to their increased versatility), which is contrary to the trend of modern IT equipment where newer equipment consumes less power despite having more computing power [11]. Also, CODEC power consumption tends to be independent of the data rate of the call [11].

In order to obtain the upper and lower bound on the power consumption of CODECs, we present separate estimates for high-end and entry level CODECs. For high-end CODECs, we estimate a power consumption of 80 W, representing the average power consumption among top-of-the-range CODECs from the main manufacturers (Polycom HDX 9000, LifeSize Room 220 and TANDBERG C90) [11]. Likewise, average active power consumption for entry-level CODECs (LifeSize PassPort and TANDBERG C20) tested in [11] is 26 W.

Videoconferencing Peripherals: Although these peripherals have relatively low power consumption, we include them here for completeness. We estimate that cameras consume 9.5 W on average [11], while sound systems take 4.1 W [12]. We also estimate a power consumption of 2.5W for a microphone, based the operating power of a studio quality microphone [13].

Home/Office Network: Here we consider the power consumed by the devices at the edge of the network, including modems, switches and WiFi access points. It is hard to accurately estimate this due to the widely varying size and configuration of home and office networks worldwide. However, 20W is a rough indication of the LAN's power consumption [5].

The left column of Table I. summarizes the power consumption of different devices involved in videoconferencing.

C. *Lifecycle Analysis (LCA) of network and videoconferencing terminal equipment*

The operating energy is only part of the total energy cost. A holistic estimate should consider the entire lifecycle emissions of videoconferencing solutions, including the manufacture, deployment, operation and disposal phases. In this section, we estimate the embodied energy cost involved in videoconferencing. We include the full lifecycle energy consumption for the types of devices where data is available. For the other devices, we use the manufacturing energy cost as a rough estimate of the lifecycle cost, since the manufacturing and operation energy constitutes a major part of the lifecycle cost while the deployment and disposal phases make relatively small contributions. For example, the majority of the studies on consumer electronics evaluated in [14] show that manufacturing and operating energy cost constitutes over 95% of the overall product lifecycle cost.

The lifecycle expenditures should be amortized across active hours of the product lifetime. However, the total operation time of devices varies widely for different organizations, depending on the frequency of usage, duration of meetings and also the total lifetime of the videoconferencing system before being replaced. As such, instead of neglecting the time dimension, we present the total embodied energy (MJ) and the equivalent environmental cost ($kgCO_2e$) over the lifecycle for each type of device, which can later be scaled appropriately to obtain the per hour cost for different videoconferencing setups.

TABLE I. LIFECYCLE AND OPERATING COSTS OF END POINT DEVICES

	Operation	Other Lifecycle Phases		Lifecycle Phases Included^
	Power Consumption (W)	*Embodied Energy (MJ/unit)*	*Carbon Emission ($kgCO_2e$)*	
PC				
Desktop	150	2100*	350	M D O E
Laptop	40	1362	227*	M D O E
Display				
Plasma	203 W/m^2 + 20W	5096 MJ/m^2	849 $kgCO_2e/m^2$*	M D O E
LED-LCD	172 W/m^2 + 20W	3218 MJ/m^2*	536 $kgCO_2e/m^2$	M D O
Projector	135	384*	64	M D O E
CODEC				
High End	80	1120	187	M D O E
Entry Level	26	364	61	M D O E
Video-conf. Peripherals				
Camera	9.5	120	20*	M D O E
Sound System	4.1	374*	62	M
Microphone	2.5	187*	31	M
Home/ Office LAN	20	1000	167*	M

^ M =Manufacture, D=Distribution & Deployment, O=Operation, E=End-of-life (disposal & recycle)

* Value derived from source based on a conversion factor of 0.6 $kgCO_2e/kWh$.

Where data on the embodied energy are not provided, we infer the embodied energy from the carbon emissions by assuming a conversion factor of 0.6 $kgCO_2e/kWh$. This factor is based upon the International Energy Agency's figure on the CO_2 emission arising from the world electricity generation of 0.5 $kgCO_2/kWh$ [15], with an additional 0.1 $kgCO_2e/kWh$ attributed to the fuel supply chain, infrastructure for energy distribution, losses in distribution and waste management [5]. Table I. summarizes our estimates of the embodied energy in the devices commonly used in a videoconference. A column on the carbon emissions is included to show the original value from data sources before our conversion factor is applied. Table II. shows estimates of the Internet's energy intensity.

Personal Computers (PC): We estimate the embodied energy of a desktop PC to be 2100 MJ, derived from Fujitsu's lifecycle assessment of the ESPRIMO E9900 Desktop PC [16], which has a hardware configuration that is common in current office PCs. As for the embodied energy of laptops, a value of 1362 MJ is estimated [17]. Both of these embodied energy estimates for desktop and laptop PCs include all lifecycle phases from cradle-to-grave excluding the use phase.

Display Devices: We derive the embodied energy for the three different display devices included in our scope - plasma [18], LED-LCD [19] and projector [20]. These studies base their assessment on a single screen size (42" for plasma in [18] and 15.4" for LED-LCD in [19]), which does not allow for a fair comparison of the different lifecycle energy for the different display technologies. Therefore, for the purpose of this study, we assume that the embodied energy in plasma and LED-LCD displays scales linearly with respect to the screen area, since a larger display would involve a higher material,

TABLE II. INTERNET LIFECYCLE AND OPERATING COSTS

	Operating Energy Intensity (kWh/GB)	Embodied Energy Intensity (kWh/GB)	Lifecycle Phases Included^
Minimum Estimate	2.17	1.61	M O
Maximum Estimate	3.61	3.33	M O

^ M =Manufacture, O=Operation

transport and waste management energy cost. To this end, we estimate the embodied energy in display devices to be 5096 MJ/m^2 for plasma displays, 3218 MJ/m^2 for LED-LCDs and 384 MJ for projectors.

CODECs: To the best of our knowledge, data on the lifecycle energy of videoconferencing CODECs are not available. Therefore, we estimate this from the embodied energy for desktop PCs, by scaling it according to the ratio between the operating energy of a desktop and a CODEC. The resulting values are 1120 MJ for high end CODECs and 364 MJ for entry level CODECs.

Videoconferencing Peripherals: The lifecycle cost of a camera is estimated to be 120 MJ [21] from the lifecycle assessment of a night camera that has the same form factor as typical videoconferencing cameras. As for the sound system and microphones, we estimate their embodied energy to be 374 MJ and 184 MJ, which were converted from the carbon emission of these devices measured in [2].

Home/Office Network: The LAN is estimated to have an embodied energy of 1000 MJ [5]. Note that this value represents the average aggregated embodied energy of all devices in a LAN instead of the embodied energy of a single LAN device.

Internet: The low and high estimates of the Internet's energy intensity are summarized in Table II, which are 1.61 and 3.33 kWh/GB respectively. This is obtained by dividing the Internet's embodied power of 33.2 GW (minimum) and 70.7 GW (maximum) [5] by the global Internet traffic in 2010 of 500 PB per day [6], which is similar to the method used previously in Section III.A.

IV. FACE-TO-FACE MEETING COSTS

A. Transportation costs

The transportation used to get participants physically together significantly contributes to the carbon footprint of face-to-face meetings. To this end, we evaluate the energy consumption and carbon emission of the transportation here to enable a comparison of the difference in environmental impact between a virtual meeting via videoconferencing and a physical meeting. We evaluate three common modes of transportation, which are plane, train and private car. Since the distance travelled affects the energy consumption (and the carbon emission) of transportation, the measurement unit for transportation is the energy involved in ferrying 1 passenger over the distance of 1 kilometer (kWh/pkm).

The estimated energy costs for transportation are summarized in the left column of Table III. Our estimates are mainly based on research by Lenzen [22]. That study considered both the direct energy from the fuel and electricity consumption, as well as the indirect emissions from the production of fuel, vehicle lifecycle, generation of electricity, maintenance cost and

TABLE III. WHOLE LIFECYCLE (INC. OPERATING) COSTS OF TRANSPORT

	Lenzen [22]		**DEFRA** [23]
	Lifecycle[a] Energy (MJ/pkm)	***Lifecycle[a] Carbon Emission ($kgCO_2e$/pkm)***	***Lifecycle[b] Carbon Emission ($kgCO_2e$/pkm)***
Plane (International)	3.1	0.25	0.13
Plane (Domestic)	5.7	0.49	0.20
Train	1.9	0.17	0.06
Private Car	4.4	0.34	0.24

a. Includes lifecycle for fuel, vehicle and corresponding transportation infrastructure

b. Includes lifecycle for fuel only

the construction of related infrastructure (roads, railways, stations, airports etc.).

The UK Department for Environment, Food and Rural Affairs (DEFRA) also provides data on the energy and carbon emission for different modes of transport [23]. Unlike Lenzen's study which considered the embodied energy in the vehicle and infrastructure, DEFRA only included the direct emissions and the lifecycle impact of fuel that arise from fuel extraction, refinement, storage and transportation. However, we include data from DEFRA here as a check on the lower bounds of the transportation energy to increase the reliability of our data. As DEFRA presented results in terms of the carbon emission rather than the energy consumption, we include the figures on carbon emission from both studies in Table III.

V. TOTAL COST COMPARISON

In this section we compare videoconferences and physical meetings in terms of energy consumption and carbon footprint (including both the operation and embodied cost). As highlighted previously, current videoconferencing solutions have widely varying configuration using different types and number of devices. Besides, the meeting duration, meeting frequency and replacement time-span of the devices are different for different users. Therefore, we consider two different configurations - a high-end telepresence setup and a laptop-based videoconference - to obtain an upper and lower bound estimate of the energy and carbon expenditures. For the conversion of energy into the equivalent carbon emissions, we applied a conversion factor of 0.6 $kgCO_2e/kWh$ as described in Section III.C.

Upper Bound: The high-end telepresence system evaluated is assumed to consist of 3 65-inch plasma screen, 3 HD cameras, 3 microphones, a sound system and a CODEC at each endpoint, using the Cisco TelePresence System 3000 as a model [8]. The system is assumed to be used 5 hours per business day (representing the average utilization of Cisco TelePresence solutions worldwide [24]), with 260 business days p.a, and an active lifespan of 4 years.

We first calculate the operating energy involved per hour of active use. Based on the average telepresence bandwidth of 7 Mbps [8] and an upper bound value of the network energy intensity of 3.61 kWh/GB, the network opex is estimated to be 11.4 kW. As for the end-point equipment, we sum the contribution of each device involved accordingly to estimate the equipment's power (energy consumed per hour) to be 909 W. Summing these values yields a total operating power per endpoint of 12.3 kW.

Similarly, the embodied energy involved can be calculated by summing the lifecycle energy contribution of each individual device. All devices involved except the LAN devices are assumed to be dedicated to videoconferencing, so the embodied energy cost should be uniformly amortized over the active hours of the product lifespan. We assume that LAN devices operate for 10 hours per business day, with 5 hours dedicated to videoconferencing. We obtain a per-hour embodied energy of 11.6 kW for each endpoint including 10.5 kW attributed to the lifecycle cost (excluding opex) of the Internet.

Thus, the total per-hour energy consumption, including the direct energy consumed by the generation of electricity and the embodied energy from the lifecycle of devices involved in the videoconference for each endpoint is 23.9 kW. Note that the total energy involved in a video conference is highly dependent on the bandwidth of the video call. If the call bandwidth is high, the contribution from end user equipment is less significant (8.4% of the total power in our upper bound estimation). On the other hand, when the average bandwidth of a videoconference is low, the energy contribution of end-user systems becomes significant (as we shall see shortly: 36% of the total power in our lower bound estimation).

Lower Bound: To obtain a lower bound on the total energy involved in a videoconference, we consider a laptop-based videoconference which has minimal device overhead. The laptop is assumed to have internal microphone, speakers, camera and display, which are used in the video call. However, a laptop is generally used for other purposes over its lifespan rather than being dedicated for videoconferencing only. Therefore, we assume that both the LAN and laptop are used for other activities for 5 hours per day.

We calculate the network energy opex by considering the minimum bandwidth required for a video call of 128 kbps [25] and the lower bound Internet energy intensity estimate of 2.17 kWh/GB. This gives us 125 W for the network energy opex. In terms of the per-hour operating energy consumed by end-user devices, only the laptop and home/office network are considered here, giving a sum of 60 W. Likewise, the total embodied energy of the laptop and home/office network is 2362 MJ, or 63 W when the cost is amortized over the active lifetime when the laptop is used for videoconferencing. The minimum estimate of the embodied energy intensity of the Internet is 93 W. The sum of the operational and embodied energy cost yields an estimate of the total per-hour lifecycle energy of 341 W consumed by each endpoint.

Case Study: We consider the case of a 5 hour meeting with 2 local participants (who need not travel), 1 domestic participant (who travels 1000km) and 1 international participant (who flies 5000km). We consider three different cases where the domestic participant travels by plane, train and private car. Utilizing the transportation lifecycle energy data in Section IV.A, if the meeting is held face-to-face, the travel cost would be 21.2 GJ (plane), 17.4 GJ (train) and 19.9 GJ (car) for the different modes of transport taken by the domestic participant. On the other hand, if the meeting was held via a videoconference, the same meeting will cost 0.025 GJ (lower bound) or 1.3 GJ (upper bound) taking into account the lifecycle energy for all end user and network devices. Note that the number of endpoints is assumed to be 4 for the lower bound calculations (individual terminal for each participant), while it is assumed to be 3 for the upper bound case (as the two local participants should use the same telepresence studio).

In terms of the carbon emissions, the lifecycle carbon footprint of transportation in the face-to-face meeting is 3533 $kgCO_2e$ (plane), 2900 $kgCO_2e$ (train) and 3317 $kgCO_2e$ (car), while the carbon emissions of the same meeting via videoconferencing is between 4 $kgCO_2e$ (lower bound) and 215 $kgCO_2e$ (upper bound). Hence, considering the full lifecycle energy and environmental cost of both meeting modes, videoconferencing only takes an upper bound value of 6.7% of the cost for a physical meeting.

As a sensitivity analysis, we first evaluate the effect of the meeting time on the resulting carbon savings. Regardless of the total meeting time, the lifecycle energy (and thus the corresponding carbon footprint) for a physical meeting would stay constant as no additional travel is involved. However, the lifecycle energy from a videoconference scales linearly with the duration of use. For example, if the meeting time increases to 10 hours, the total energy involved in videoconferencing increases to 0.05 GJ (upper bound) and 2.6 GJ (lower bound), which are twice the values for a 5-hour meeting. In other words, if the meeting duration is the only variable, the breakeven point in which both meeting solutions incur the same energy cost is when the total meeting duration is 75 hours. Thankfully most meetings are not this long!

If the distances change, the carbon emissions from travel will vary accordingly. However, this should have little impact on the energy cost of a videoconference. This is because a large proportion of the Internet's opex lies in the access networks rather than the core network (access networks consume about 10 times the energy of core networks per bit of data transferred [26]). If the distance between the end points increases, this should only increase the number of core router hops without affecting the access router hops. Since the energy consumption of the core network is relatively small, in this study we assume that the videoconferencing cost stays constant with varying meeting distances. If the travel distances from our case study are halved, such that the domestic participant travels 500 km and the international participant travels 2500 km, the overall energy contribution from the face-to-face meeting will fall by half to give 10.6 GJ (Plane), 8.7 GJ (Train) and 10 GJ (Car). The travel distances will need to be shortened 15-fold (e.g. to a miniscule 67 km for the domestic participant) to reduce the lifecycle energy cost of the face-to-face meeting such that it matches the cost of videoconferencing.

VI. FUTURE TRENDS

What of the future? As noted, the Internet's bandwidth is rising faster than its power consumption. This implies that the energy intensity of data transfer is decreasing, with one estimate being that the decrease is 1.65-fold/18-months [27]. If we consider an upper-bound telepresence setup, which is likely to become more common in the future because it offers a higher level of immersion, the Internet constitutes approximately 90% of the overall videoconferencing energy use, so the decline of Internet power consumption should make it even more attractive environmental-wise. Even in the worst case where the embodied energy intensity of the Internet is assumed to remain constant in coming years, the network opex still constitutes 50% of the videoconferencing energy cost, thus we can estimate that the energy cost of videoconferencing will fall by 20% every 18 months.

However, these energy reductions do not necessarily translate into the equivalent energy savings of videoconferencing over face-to-face meetings. One can similarly argue that transportation will also become greener, leading to reduced energy and carbon emissions from travelling. Transport has historically improved in efficiency by a compound rate of about 3% p.a. since 2004 [28], which is almost an order of magnitude less than the decrease in Internet energy usage. As a best case consideration, we assume that in the future all transportation is electrically powered since this is the most efficient means of transport available in terms of its energy consumed and emissions, e.g. an electric car uses 0.87 MJ/km whereas a petrol fueled car uses 3.57 MJ/km well-to-wheel [29]. Even in this best case situation which reduces carbon emissions from transportation by 75%, videoconferencing, at current efficiency levels will only contribute up to 27% of the energy/carbon cost of face-to-face meetings, which is a moderate rise from the present upper bound value of 6.7%, but still well below the energy/carbon cost for physical meetings.

VII. Conclusion

This study has compared the life-cycle carbon emissions of videoconferences and face-to-face meetings. We evaluated both the direct and embodied energy contribution for both meeting solutions, which is the impact from the manufacturing, deployment, opex and end-of-life handling for all end-user and network devices for videoconferences, and also for the vehicles and transportation infrastructure involved for face-to-face meetings. Our results show that videoconferencing currently takes at most 6.7% of the energy/carbon of a face to face meeting, and that the economy of videoconferencing is likely to persist into the future. Future work could consider the costs of saving energy and carbon emissions in terms of factors such as financial cost and trustworthiness of non-face-to-face communication media.

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