Plea for a Holistic Analysis of the Relationship between Information Technology and Carbon-Dioxide Emissions

Peter Marwedel, Michael Engel, TU Dortmund, Informatik 12, Germany

Abstract

An analysis of the relationship between information technology (IT) and carbon-dioxide (CO_2) emissions should not be constrained to an analysis of emissions caused during the operation of IT equipment. Rather, an analysis of emissions should be based on a full life-cycle assessment (LCA) of IT systems, from their conception until their recycling. Also, the reduction of emissions through the use of IT systems should not be forgotten. This paper explains these viewpoints in more detail and provides rough life-cycle analyses of personal computers (PCs). It will be shown that—for standard scenarios—emissions from PC production are exceeding those of their shipment and use. This stresses the importance of using PCs as long as possible.

1 Introduction

According to several forecasts, temperatures on earth will increase over the next decades. For example, NASA has made predictions based on several scenarios. NASA came to the conclusion that, for a "high growth" scenario, temperature increases beyond 8°C are expected in polar regions until the 2090/2099 time frame [13]. Increasing levels of CO_2 in the earth's atmosphere are considered to be a key reason for the rising temperatures. Other gases may contribute to this effect, and some of them with a large contribution.

Information technology is known to have an impact on global warming as well. For example, according to Gartner [7] it can be estimated that 2% of the total CO_2 emissions in the world are caused by the use of information technology. However, the available data is not very accurate. According to the Environmental Protection Agengy (EPA), the energy efficiency of actually operating servers should be monitored regularly and with standardized techniques [4]. Information on gases other than CO_2 is fequently not available. If it is, it is sometimes converted into the equivalent amount of CO_2.

In order to reduce the impact of information technology on global warming, a broad view on how information technology is influencing CO_2 production is needed. Only a comprehensive view will be able to provide us with the right information for taking decisions. Otherwise, there would the serious risk of working on changes whose overall impact is negligible while areas with a large impact are ignored.

The current paper will present such a broad view. In order to provide reasonably reliable data, we will focus on the overall contribution of using personal computers (PCs)[1]. In contrast to many other papers, we will present a ***life-cycle assessment*** [5] of the use of PCs, starting with their fabrication. We will try to estimate the impact of personal computers on the emission of CO_2. In this way, we try to avoid the uncertainties which exist for information about data centers. The estimates apply to single systems. We will not try to generalize the estimates into values for the IT industry in general. We will also not try to consider other gases. We are aware of the potentially large contribution of other gases, but we do not have enough information to really evaluate their contribution. We will use **CO_2 emissions as the metric for the impact of IT on global warming**. Other units will be converted into kg of CO_2.

The use of computers does not only cause CO_2 emissions. It does also **reduce** CO_2 emissions. Various industrial sectors as well as consumers benefit from IT saving energy, and hence also CO_2. In this paper, we will briefly present an overview over areas in which IT can help reducing the CO_2 emissions.

Due to the positive and negative impact of IT on emissions, there may be the question: what is the overall net impact of using IT? What is the balance? In this paper, we will show that the issues involved in this question are so complex that they can hardly be answered. The conjecture is that, overall, IT might reduce CO_2 emissions, and, in this way, helps to fight global warming.

The paper will be structured as follows: Section 2 contains (very) brief remarks about related work. In section 3, we will provide a life-cycle assessment of PCs. In section 4, we will describe how IT is helping to reduce CO_2 emissions. Section 5 contains a summary.

[1] Despite our efforts for finding reliable data, available data is not as precise as in other scientific areas. In this paper, we have to use the data that is available and we will try to estimate the impacts of variances of this data.

2 Related work

Life-cycle assessment (LCA) [5] of products is used in various areas to evaluate the overall impact of products from their conception onwards. We are not aware of any other life-cycle assessment of PCs or any other evaluation of the positive impacts of IT on CO_2 emissions. Please refer to the bibliography for pointers to other related work.

3 Life cycle assessment of personal computers

3.1 Production

We do not have information on the emissions resulting from the design of PCs. We assume that these emissions can be neglected, due to the large number of chips fabricated. Therefore, our life-cycle analysis starts with production.

The energy consumption and the amount of gases released into the atmosphere during the production of a PC is not well documented. The book by Kühr and Williams [10] is the standard reference in this area. According to Kühr and Williams, 1500 kWh of energy are required for the production of a desktop PC and a CRT display. This is the amount consumed just during the production. Transportation of materials is not included in that number. According to less precise information by Michael Kuhndt from the Wuppertal Institute for Climate, Environment and Energy in an interview [16], it has been estimated that the overall energy consumption may be twice as high.

The situation regarding more recent LCD displays is more difficult to evaluate. According to Socolof [15], the production of LCD displays seems to be more energy efficient. However, according to the same source, SF_6 is required to during the production. This gas, if released into the environment, has a very strong impact on global warming. Apple Inc. computed an emission equivalent of 382 kg of CO_2 for the production of a 24" LCD display [1]. This is the same order of magnitude as computed above. Due to the lack of precise data for TFT displays, we continue to use CRT displays in our example.

We have no explicit information on the emissions resulting from the production of laptop PCs. However, most of the emissions are resulting from chip production. There is no major difference between the chip production technology for desktop PCs and laptops. Also, displays of large laptops may be almost as large as smaller standalone LCD-displays. Hence, we assume that—as a first order of approximation—the energy required for the production of a laptop to be in the same order as the energy required per desktop PC.

The impact of the production on the global warming will be considered in terms of the amount of CO_2 produced. This amount depends on the energy efficiency of power generation. According to [6], the generation of 1 kWh of electrical energy releases 600 to 1200 g of CO_2 into the atmosphere, unless a very efficient combination of power generation and heating buildings in the vicinity of the power station is used. Choosing a value of 800 g per kWh of electrical energy here, we estimate the production of a single PC and CRT monitor to release about

$m_p = 1200$ kg of CO_2

into the atmosphere.

It is difficult to estimate the trends since the publication of the book by Kühr and Williams. Efforts have been made to improve the recycling of materials. However, advanced fabrication and new processes have also become more complex.

Obviously, the production of PC chips requires very low energy costs. Otherwise, PCs would need to be more expensive than they are.

3.2 Transportation

Many PCs are manufactured in Asia. Transportation from Asia to Europe or the US might have an impact on CO_2 emissions as well. Vessels generate around 1 kg of CO_2 per 100 t of freight per kilometer [17][2].

Airplanes are less fuel-efficient: it has been estimated that a Boeing 747 cargo airliner would generate 50 kg of CO_2 per 100 t per kilometer [14]. This information is based on an analysis of information initially provided by Lufthansa via an initiative fighting against airport noise. Hence, we assume that this amount is not underestimated. Unfortunately, the initial source is no longer available.

Assuming 20 kg per PC and monitor, including packaging and transportation over 12,000 km by a sea-going vessel, we arrive at

m_{t1}= 2.4 kg of CO_2

for transportation over the long distance. This comparatively small number is the result of the large capacity of vessels. Note that we ignore the energy required for the production and demolition of vessels here. We assume that, due to the large capacity of the ships, these amounts will be negligible.

Assuming 4 kg per PC (laptop), we arrive at

$m_{t2} = 0.480$ kg of CO_2

for long-distance vessel-based transportation. Transportation of the same laptop by plane over 10.000 km[3] at 50 kg of CO_2 per 100 t per km leads to the generation of

$m_{t3} = 20$ kg of CO_2.

[2] As a sanity check, we might employ the fact that a smaller ship going up the river Rhine against the stream requires about 1 liter of diesel per 100 t per kilometer [12]. This fuel consumption would generate about 2.6. kg of CO_2 per 100 t per kilometer.

[3] We assume that flying over the continents is a bit shorter than traveling via oceans and channels.

Vessels provide transportation to harbors and airplanes provide transportation to a few large national airports. We have to consider local transportation as well. According to Clausen [2], mobile and stationary processes for parcel delivery cause a combined emission of approx.

$m_{t,local} = 0.6 - 0.7$ kg of CO_2

per parcel on average (Deutsche Post World Net, 2007). This amount includes the energy required in distribution centers.

Apple Inc. computed an emission equivalent of 39 kg of CO_2 for the transportation of a 24" LCD display [1]. Assuming air cargo and a weight of 8 kg, this is consistent with the numbers above.

3.3 Operating

According to the Energy Star Standard 4.0 [3] multimedia-PCs of class C requiring no more than 95 W of power while in idle mode are considered to be power-efficient. Smaller and larger numbers are possible: The IRTS-roadmap [8] predicts an operating power of up to about 500 W, while a smaller power consumption is possible with a careful selection of components. For office applications, power consumptions of less than 95 W can be achieved with a limited effort.

Measurements indicate an actual power consumption of 25 W for a 17" LCD monitor and of 30 W for a 12" MSI laptop of [11]. Apple Inc. indicated a power consumption of 57-81.2 W for its 24" TFT display, if operated from 220 Volts [1]. This is consistent with the larger power consumption of larger screens.

The energy consumption of network connections is not precisely known, but estimated to be in the order of the energy consumption of the PC itself.

Let us assume that a PC is used on 1800 working hours per year. This is the number of hours used as the basis for accreditation of German educational programs. Let us furthermore assume that the PC is replaced by a new one after four years. In high-tech areas replacement may even be more frequent. On the basis of 95 W for a desktop PC and 25 W for the display, we will cause an emission of

$m_{od} = 691$ kg of CO_2

into the atmosphere. For a laptop of 30 W and 25 W for the display (assuming an additional external display),

$m_{ol} = 317$ kg of CO_2

will be released.

3.4 Disposal

According to data published by Apple Inc., the disposal of it 24" LCD monitor is responsible for 1% of the total emissions of 980 kg of CO_2 [1]. It is unknown, which steps are included in this number. Due to the lack of precise information about the disposal, we do not consider it here. However, there have been reports about environmental pollution caused by the illegal disposal of PCs on African dump sites [9]. This means that the actual impact of manufacturing and disposing of PCs is likely to be larger than the numbers that we are using in this paper.

3.5 Putting it all together

As an example, let us consider the case of a desktop PC with a weight of 20 kg shipped by a vessel and used for 4 years at 1800 hours each. This will lead to the emission of CO_2 as shown in fig. 1.

Cycle	**CO_2 [kg]**
Production (m_p)	1200
Transportation, 20kg, vessel (m_{t1})	2.4
Transportation, 20kg, 2 parcels ($2 * m_{t,local}$)	1.2
Operating (m_{od})	691

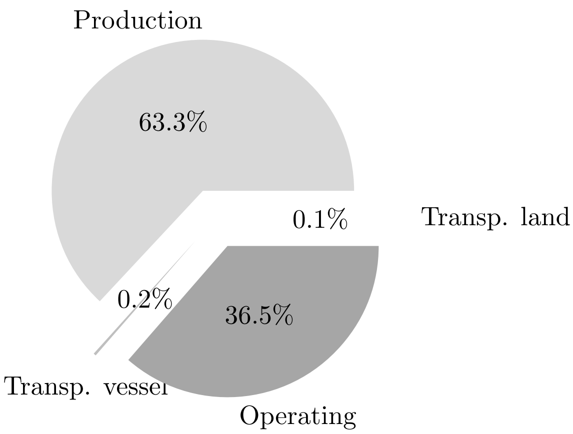

Figure 1: Emissions from desktop PC shipped by vessel

As a second case, let us consider a laptop, assuming the same emission during production as for the desktop PC, and shipping via vessel. The emissions are shown in fig. 2. Production is even more dominating than in fig. 1.

As a third case, consider a laptop flown-in as air cargo. The resulting contributions are shown in fig. 3. The contribution of transportation is visible in this case, but production is still dominating.

As can be seen from the figures, production dominates the total emission of CO_2 for all three use cases. This observation is unlikely to be affected by perturbations of the underlying basic data, since a number of emissions from production have not even been considered and since emissions from the use of PCs may be smaller:

- We are not including the transportation of raw materials to the production site.

Cycle	CO_2 [kg]
Production (m_p)	1200
Transportation, 4 kg, vessel (m_{t2})	0.480
Transportation, 4 kg, 1 parcel ($m_{t,local}$)	0.6
Operating, (m_{od})	317

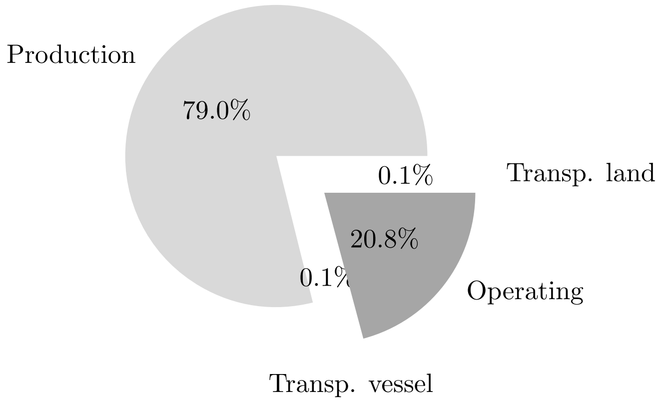

Figure 2: Emissions from laptop PC shipped by a vessel

Cycle	CO_2 [kg]
Production (m_p)	1200
Transportation, 4 kg, air cargo (m_{t3})	20
Transportation, 20kg, 2 parcels ($2 * m_{t,local}$)	0.6
Operating (m_{od})	317

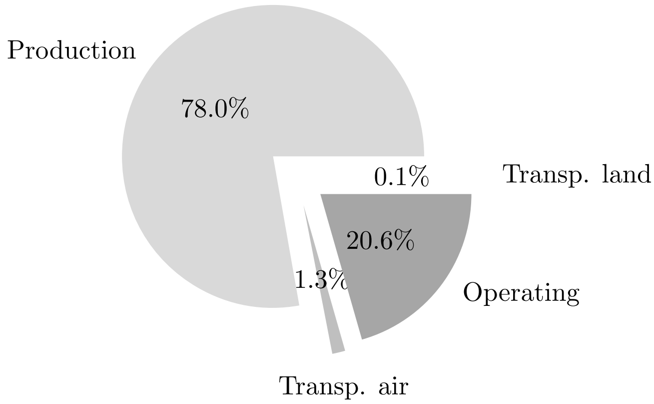

Figure 3: Emissions from laptop shipped as air cargo

- Gases other than CO_2 have not been considered. Other gases are emitted during production, but less so as a result of the use of computers. In particular, the use of SF_6 for LCD production can also have a strong impact on global warming.
- Thermal energy produced by operating the PC reduces the energy required for heating in winter.
- A power consumption of less than 95 W can be easily achieved for desktop PCs optimized for office applications.
- The external monitor for laptops will possibly not be needed.
- Energy required for the recycling of PCs is not considered.

Of course, for areas where cooling is required, the energy consumed during the operation of the computer increases. Also, we did not include the power required for the network and did not consider high-powered gaming or graphic workstations.

The observation resulting from this data, even after including possible perturbations of the data, is that CO_2 emissions from production will in most cases dominate the emissions from the operation of the PC.

This has important consequences: **just using a PC for another year might save more energy than shutting the computer down during inactive periods**. Combining two defective PCs to create a new operational one may save more energy than buying a new *power-saving* PC. The reuse of PCs should be given more attention. Obviously, this would not be in the interest of companies selling new PCs.

4 Reduction of CO_2 emissions by IT

When calculating the overall balance, we should not forget about IT's contribution to fight global warming. Due to using IT, it is possible to improve environmental friendliness and energy efficiency of systems. This concerns several phases of the lifetime of products:

- **Construction:** For example, system design and optimization software can help us designing more efficient combustion engines.
- **Fabrication:** IT systems can help to improve the energy efficiency of production sites and can also help to reduce the release of gases into the environment.
- **Operation:** IT systems avoid the generation of CO_2 as a result of design-phase optimizations. For example, the World Shipping Agency is attributing the efficiency of vessels to their highly sophisticated IT systems [17]. Clausen reported [2] that DHL could reduce the average mileage per delivery by more than 12% between 2001 and 2003. Electric cars will rely on a major amount of on-board IT systems.

- **Disposal:** Smart IT systems can help to deal with products at the end of their lifetime.

5 Indirect effects

In addition to these direct effects, there are various indirect effects. For example, people obtaining information about foreign regions via the Internet might give up on plans to travel to those regions or may be stimulated to visit those regions. Information about a product might stimulate acquiring the products. However, new products may be more energy efficient than the previous generation, but may require substantial amounts of energy for their production. Real products might be partially replaced by their virtual counterparts.

6 Conclusion and summary

With this paper, we are trying to stimulate moving toward a holistic view of the relationship between IT and the environment. We have focused on the relationship between IT and CO_2 emissions. As for additional emissions caused by IT, we have provided a rough life-cycle analysis of PCs. Our examples clearly demonstrate that CO_2 emissions during production of PCs will typically exceed those resulting from their use. This should be a motivation to extend replacement intervals and to think more carefully about a market for used computer components.

There is huge number of areas in which IT is reducing CO_2 emissions. This impact exists in an abundance of industrial sectors and for many phases of product life-cycles. The overall emission reduction by IT is difficult to quantify.

There is no hope, that we will ever be able to quantify indirect effects. Therefore, the overall balance resulting from the additional CO_2 emissions and reductions of CO_2 emissions is likely to never be known. This should not prevent us from trying to minimize the release and maximizing the reduction. We should also not just look at the emissions and condemn information technology altogether. The reductions should also be recognized.

References

[1] Apple Inc. Led cinema display - environmental report, 2009. http://images.apple.com/environment/reports/docs/LED-Cinema-Display-Environmental-Report-20091120.pdf.

[2] Uwe Clausen, Simon Deymann, Jörg Friedrichs, and Martin Schmied. Measures to abate green house gas emissions in logistics companies, 2008. http://logistics.de/logistik/entwicklung.nsf/f1b7ca69b19cbb26c12569180032a5cc/d45ca5c753567d50c12574ce004a3cc4!OpenDocument.

[3] Energy Star. ENERGY STAR program requirements for computers V 4.0, 2007. http://www.ecoinfo.cnrs.fr/IMG/pdf/Computer_V4.0_Final_Spec.pdf.

[4] Environmental Protection Agency (EPA). EPA report to congress on server and data center energy efficiency, 2007. http://www.energystar.gov/ia/partners/prod_development/downloads/EPA_Report_Exec_Summary_Final.pdf.

[5] International Organization for Standardization (ISO). ISO 14040:2006 Environmental management – Life cycle assessment – Principles and framework, 2006. http://www.iso.org/iso/catalogue_detail?csnumber=37456.

[6] Glizie GmbH. CO_2-Emissionen bei der Stromerzeugung, 2009. http://www.bhkws.de/bhkw_co2.htm.

[7] Heise. Computer und Telekommunikation verursachen 2% aller Kohlendioxidemissionen, 2007. http://www.heise.de/newsticker/meldung/Computer-und-Telekommunikation-verursachen-2-aller-Kohlendioxidemissionen-172462.html.

[8] ITRS Organization. International technology roadmap for semiconductors (ITRS), 2008. http://public.itrs.net.

[9] Klaus Hieronymi. Domestic E-Waste in Africa Recycling for a Profit? In *International Workshop on Environment and Alternative Energy, Garching, Germany*, 2009. http://www.c3p.org/Workshop%202009/Presentations/WEEE%20and%20E-Waste%20Recovery/Klaus%20Hieronymi_Domestic%20EWaste%20in%20Africa%20Recycling.pdf.

[10] R. Kühr and E. Williams. *Computer and the Environment – Understanding and Managing their Impacts*. Kluwer Academic Publishers, 2003.

[11] Malte Marwedel. Personal communication. 2009.

[12] Matthias Marwedel. Personal communication. 2009.

[13] NASA. Future temperature changes, 2007. http://www.epa.gov/climatechange/science/futuretc.html.

[14] Notgemeinschaft der Flughafen-Anlieger Hamburg e.V. Klimakiller Flugzeuge, 2009. http://www.fluglaerm.de/hamburg/klima.htm.

[15] Maria Leet Socolof, Jonathan G. Overly, and Jack R. Geibig. Environmental life-cycle impacts of CRT and LCD desktop computer displays. *Journal of Cleaner Production*, 13:1281–1294, 2005.

[16] Spiegel Online. So machen Sie Ihren Computer grün. http://www.spiegel.de/netzwelt/tech/0,1518,538102,00.html.

[17] World Shipping Council. Liner shipping and carbon emissions policy, 2009. http://www.worldshipping.org/pdf/liner_shipping_carbon_emissions_policy_presentation.pdf.