Suggested citation: Hilty, L. M.: Why energy efficiency is not sufficient – some remarks on “Green by IT”. In: Arndt, H. K. (ed.): EnviroInfo 2012, Proceedings of the 26th Environmental Informatics Conference, Federal Environment Agency, Dessau, 2012

Why energy efficiency is not sufficient – some remarks on “Green by IT”

Lorenz M. Hilty[1]

Abstract

Most part of the “Green IT“ or “Green ICT“ discussion is addressing issues of energy efficiency, implicitly assuming that more energy-efficient technologies will substantially contribute to a reduction of total energy consumption and, as a consequence, of CO_2 emissions. This assumption is usually challenged by historical evidence for the rebound effect. This paper presents a case study on smart vending machines, showing that the ocurrence and size of the rebound effect can vary greatly depending on several factors. Some suggestions on how to avoid rebound effects when applying “smarter” technologies to save energy are derived.

1. Introduction

Almost five years ago, the term “Green IT” began its career from Gartner’s report “Green IT: a new industry shock wave” (Mingay 2007). Organizations as different as the Global eSustainability Initiative (GeSI 2008), the WWF (2008), and the OECD (2010) published well-received studies on the potential of IT or ICT[2] to reduce CO_2 emissions, either by reducing the power consumption of IT itself (“Green *in* IT”) or by using IT as an enabling technology for saving energy in other fields (“Green *by* IT”). A broad and fruitful discussion about the current and future role of IT in energy, environmental and – more general – sustainability issues has emerged both in academia and industry.

The goal of this paper is to provide a differentiated view on a recurring and essential theme in this discussion: the rebound effect. Depending on the assumptions one makes about the size of the rebound effect in a given application field of IT (e.g., in traffic optimization), the energy efficiency induced by IT will be either blessing or curse (less traffic or more as a result of the optimization).

I will focus on the direct rebound effect, which can be described as follows: If a unit of output can be produced using less units of input than before – which means to improve the efficiency of the production process – increased demand for the output can result, countering the potential savings on the input factor. Demand may increase because the price of a unit of output will usually decrease as a consequence of the efficiency improvement.

“Price” in this context covers more than the monetary price. Many services require the customer to spend some time on receiving the service or make other non-monetary contributions as well, so that the total price of a unit of service in fact amounts to more than the money paid for it. For example, if passenger transport is made faster (i.e., the production of the service “transportation” is made more efficient with regard to time), it is likely that people will use the service more frequently or make longer trips because it became “cheaper” in terms of time, even if the amount of money to be paid per kilometer remains the same. We all know from everyday life that faster data transfer makes us download larger files. Another

[1] Department of Informatics, University of Zurich, Binzmühlestrasse 14, CH-8050 Zurich, and Empa Materials Science and Technology, CH-9014 St.Gallen, telephone +41 44 635 6724, hilty@ifi.uzh.ch, http://www.ifi.uzh.ch/isr

[2] No difference is made between IT (Information Technology) and ICT (Information and Communication Technology) throughout this paper.

example is the increasing amount of electricity modern societies are using for computers, despite the dramatic progress in the energy efficiency of computation (Koomey/Berard/Sanchez/Wong 2011). The rebound effect materializes in a variety forms in the IT field (Hilty/Köhler/von Scheele/Zah/Ruddy 2006).

The crucial role of the rebound effect in the Green IT discussion results from the fact that the most common argument in favor of the "green" potential of IT is based on the idea of energy efficiency. Let's formulate this argument for the "Green *by* IT" case, where the potential is much higher than in the "Green *in* IT" case: *If we use IT as an enabling technology to increase the energy efficiency of processes, which is possible in almost any domain (industrial production, transport, media, heating, cooling, lighting, electricity grids), IT will substantially contribute to the necessary transition towards a "green" or low-carbon economy.* Given this perspective, the rebound effect can be used as a knockout argument against any hope that increasing energy efficiency (by Green IT) could make the world a better place. This paper argues that both extreme positions are false in their generalized form, because the same technology may either produce a rebound effect or not, depending on contextual factors.

It is certainly naïve to claim that investments in IT-related energy efficiency will automatically lead to energy savings. This means to ignore *all systemic effects* (also known as third-order effects) of IT, to which the rebound effect belongs. A review of existing studies on macro-level effects of IT showed that only a few of them had actually taken third-order effects into account (Erdmann/Hilty 2010).

However, the opposite view (the rebound effect as a knockout argument) is no less simplistic, because it ignores that some conditions may prevent or limit the rebound effect provoked by improved energy efficiency. It also ignores other third-order effects as well (such as structural change), which may work in the opposite (energy-saving) direction. Socio-technical systems have complex dynamics and their long-term development depends on many interacting factors. The following case study on smart vending machines demonstrates this in a manageable context and may provide some inspiration for a differentiated debate.

2. Case study: smart vending machines

The power consumption of vending machines first became an issue in the 1990s. In Japan, the country with the highest density of vending machines, there were already 5.4 million machines, one for every 23 Japanese, which together accounted for 3.7 % of the electricity consumed in Japan (Coleman 1997). Many countries started to look into the energy consumption of vending machines and potential improvements. First studies showed that refrigerated beverage machines (usually providing soft drinks in cans or bottles) operated on a 7x24 hour basis accounted for the bulk of the energy consumption; they were also found to offer the highest improvement potential in terms of energy efficiency (Munter 1995, Aebischer/Huser 1998, Deru/Torcellini/Bottom/Ault 2003, Collins/Ellis 2005).

Vending machines were included in the the Japanese Top Runner program in 2002 (UNEP 2011) and in the Energy Star program of the United States Environmental Protection Agency in 2004 (EPA 2004a). After the Japanese beverage vending machines had already improved during the 1990s and reduced their energy demand by 33% (IEA 2007, 109), the Top Runner program achieved an additional average reduction of 37% per machine (UNEP 2011, 127). Within 15 years, the energy efficiency of the Japanese machines had improved by 58%. A typical machine meeting the U.S. Energy Star criteria consumes at least 50% (1500 kWh/a) less energy than non-qualifying models (EPA 2004b). Both the Japanese and the U.S. programs are voluntary; nevertheless they have proven to create quite some pressure on the manufacturers to make progress towards energy efficiency.

The American anthropologist Joseph A. Tainter (2009) reports the following anecdote, showing the rebound effect from a business perspective: An entrepreneur proposed a new type of business, namely to place and service soft drink vending machines in *small* offices where *only a few people work*. Everybody wondered how this business model could ever be profitable. And if it could, why had no one else already placed vending machines in all these small offices?

The answer was found in the innovation that was going on at that time: A new type of vending machine meeting the Energy Star requirements cut the energy cost of operating the machine roughly by half. These new machines were equipped with intelligent energy management systems and sensors to detect the presence of people, which allowed them to enter a low-power mode when no potential customers were around for a longer period. Some smart vending machines also include remote monitoring technologies based on telemetric systems to significantly reduce labor and fuel costs for servicing the machines.

Given the fact that energy and servicing costs are the main components of the operating cost of a vending machine, the smart machines could be operated at a profit even in places where only a handful of people per day might purchase a drink. Since the number of small offices happens to be much higher than the number of big offices, this innovation obviously has a huge success potential in terms of the number of machines being installed. This "success", however, is the reason why the total power consumption of smart vending machines will exceed the total consumption of the fewer "dull" vending machines that had been in use before.

Tainter concludes: "In short, as technological improvements increase the efficiency with which a resource is used, total consumption of that resource may increase rather than decrease." (Tainter, 2009)

Let's analyse this case in some more detail. Statistics about numbers of enterprises by size class look roughly the same in all economies (see Figure 1 for EU-27 as an example): There are many small enterprises and only a few big ones. Assuming that the places (sites) where people work are distributed over size in roughly the same way, we can approximate the relation between potential customers and number of places by a negative exponential function as shown in Figure 2. If this is true, the number of machines must increase disproportionately if the number of potential customers needed to operate a machine at a profit decreases. Figure 3 shows how a reduction of the average power consumption per machine from 10 kWh/day to 4 kWh/day would theoretically affect the total power consumption (based on rough estimates for EU-27), which corresponds to the *area* of the respective rectangle.

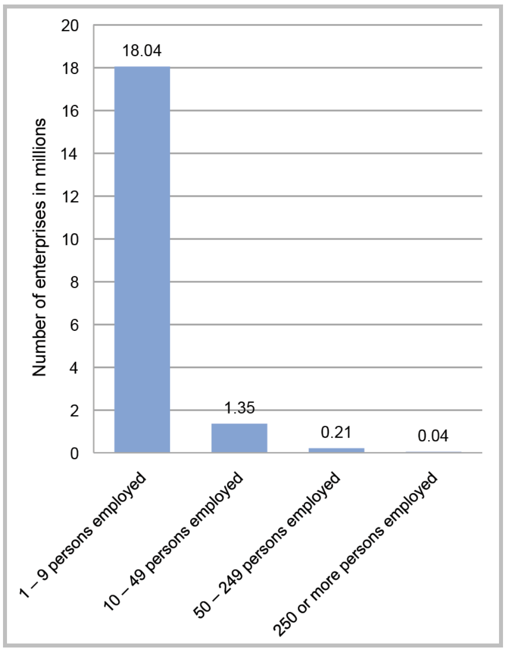

Figure 1
Number of enterprises in millions by size class (EU-27, non-financial business economy, 2005)
Data Source: Schmiemann (2008)

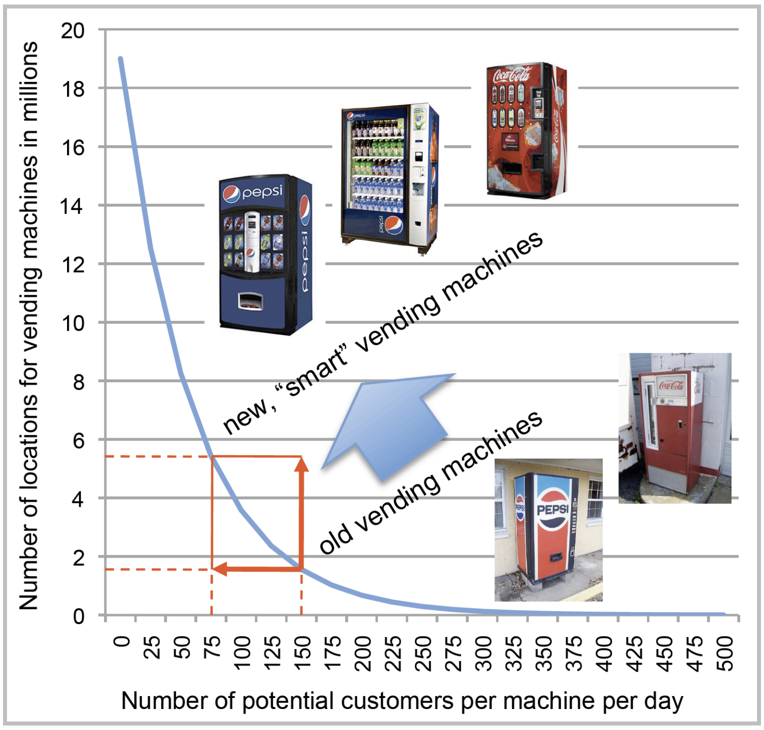

Figure 2
Number of locations in millions by number of potential customers per day
Source: Own worked example

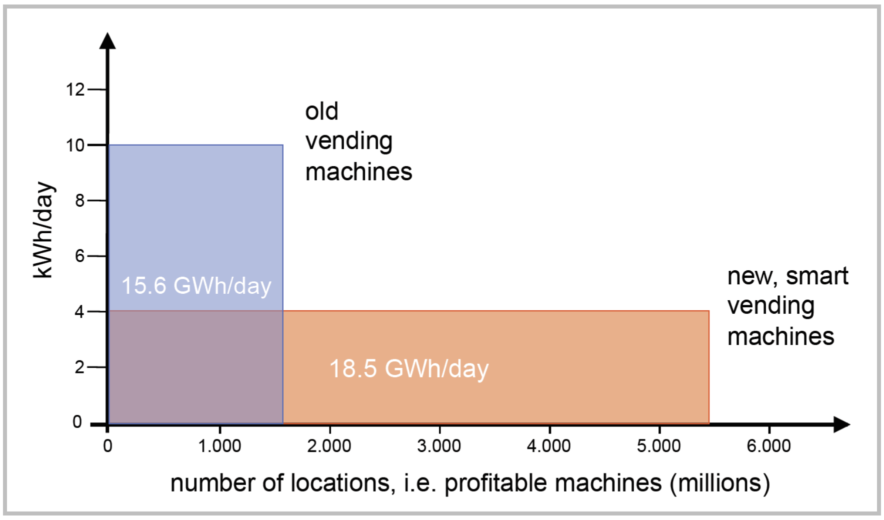

Figure 3
Energy consumption per vending machine by number of profitable locations for machines in millions. The example shows that the new generation of vending machines ("smart", "green" machines) consume 18.5 GWh/day, whereas total consumption of the old generation was only 15.6 GWh/day (EU-27 data)
Source: Own worked example

However, it is important to note that this argument is based on three implicit assumptions:

1. The increase in energy efficiency does sufficiently reduce the cost for the operator of the vending machine (even if potentially higher investment costs are included).
2. The number of vending machines operated is not limited by any other constraint than the profitability of their operation.
3. Someone wants to do this business.

Since we are interested in *avoiding* rebound effects, we can also read these assumptions as pre-conditions for the occurrence of a rebound effect and strive for situations in which they do *not* hold.

To begin with the last condition, we should assume that on a free market, a profit that *can* be made *will* be made by someone sooner or later (unless explicit regulation prevents it). The actors with the highest interest in a growing base of vending machines are their manufacturers. Not surprisingly, they report annual growth rates of the vending business of about 10% (US-Machine.com 2010), which means that the U.S. vending market doubles almost every seven years. The annual growth rate of the *production* of vending machines in the U.S. is reported to be about 5% (Bool 2006). This number may look small, but is means that every year more machines are produced than in the preceding year, and all of them will be installed and start guzzling power. Thus, the installed base of machines may grow faster than production, depending on the average lifetime of a machine.

Regarding condition one, refrigerated vending machines may indeed constitute a special case. In many other markets (for example: data centers), energy costs are small compared to other cost components. That means that we would not expect a rebound effect to occur in reaction to pure energy efficiency improvements there, This is exactly the reason why investments in energy efficiency are hard to motivate in this sector. So it seems that there are only two types of energy efficiency improvements: those creating a rebound effect and those for which the market provides no sufficient incentives. This sounds quite sobering. However, there is still one condition left.

The second condition is probably the most interesting one. Can the growth of a market be limited by something else than the condition of profitability (if not by legal force)? The answer is yes. Looking at the case of Japan, we can surprisingly observe that the installed base of vending machines has remained relatively stable despite high efficiency progress. The number of all vending machines grew from 5.4 million in the early 1990ies (Coleman 1997) to only 5.5 million in 2003 (IEA 2007). According to the Japan Vending Machine Manufacturers Association, the number of machines even started to decline slightly in 2009 (JVMA 2010). If we focus on beverage vending machines (49% of all machines and still the most energy-intensive ones, JVMA 2010), a stabilizing trend can be observed as well, as shown in Figure 4 (vertical bars). The top line shows the total energy consumption of all machines, which is decreasing due to efficiency improvements (second line from the top).

This means that there was only a very moderate rebound effect in Japan during a period of significant efficiency improvement. A possible explanation is that the scarcity of another resource limited the growth of the installed base, namely space. In a densely populated country like Japan, it may be just impossible or unaffordable to sacrifice more space to install additional machines. It is today possible to operate two or three machines with the power that has been needed for only one machine in 1990s, but it is not possible to operate them without claiming additional space. The machines became more energy-efficient, but not smaller. Therefore, the increase in energy efficiency did not create an impulse of quantiative growth, just because there was another factor limiting the number of machines.

To generalize this idea: It could be useful to look at the limiting factors in a given system before implementing efficiency improvements. What factor does prevent which quantities from growing? Increasing the efficiency with which a limiting factor is used may unleash the growth of that quantity, i.e. create a rebound effect. This is just a heuristic and much simpler than quantitative methods relying on price elasticities – however, it may sometimes be better to be roughly right than precisely wrong.

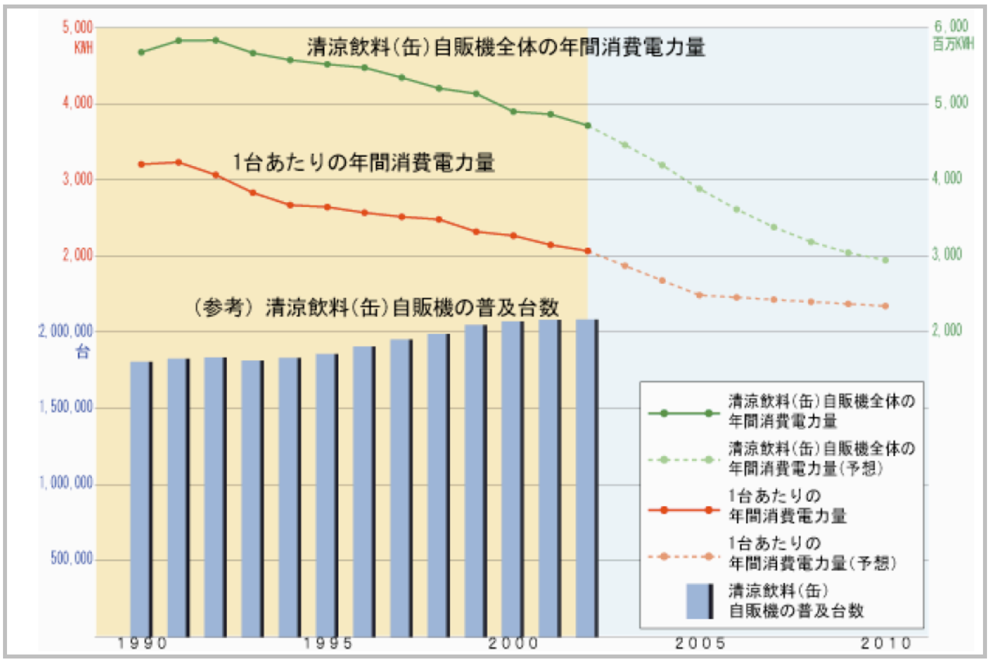

Figure 4
Number of soft drink machines in Japan (bars), energy consumed per machine (top line), and total energy consumed by the machines (second line from the top).
Source: Japanese Soft Drink Association, cited in IEA (2007, 109)

The history of the smart vending machine does not end here. Two developments changed the picture – at least in Japan – considerably during recent years: First, a new generation of smart vending machines is entering the market. Second, the Fukushima event made electric power a limiting factor for the operation of vending machines, at least temporarily.

The new generation, let's call it the *second generation* of smart vending machines, comes with extensive touch screens, cameras for face recognition, mobile payment interfaces and some of them even with free WiFi Internet access. They recommend products to users depending on their gender and age, and sometimes even store their individual purchasing histories (Keller 2010). It is reported that the new machines triple sales (Finnegan 2010). No information has yet been published about the energy consumption of the second generation of smart vending machines.

After the Fukushima event, vending machines were heavily criticized for their energy hunger when the rest of the country was trying to save energy, given that their total demand still corresponds to half of a nuclear power plant. A grass roots campaign was launched to persuade Coca-Cola to switch off their 980 000 machines (Hickman 2011). Tokyo governor Shintaro Ishira even suggested to get rid of all vending machines (Westlake 2012). The manufacturers reacted by announcing additional efficiency improvements.

3. Conclusions

Our case study on vending machines showed that a variety of conditions decide on the size of the rebound effect. By generalizing some of the arguments that emerged from this analysis, we can create a list of heuristic rules on how to avoid or minimize rebound effects when implementing energy efficiency measures. Each rule is followed by a short discussion.

1. Improve energy efficiency only in processes where energy costs are a *minor* cost component. This is against economic rationality, but will – for exactly this reason – avoid a strong rebound effect. Implementing such a measure requires using other forces than market forces, because the market will not create enough incentive for the investment. Therefore, unfortunately, there is some risk of suboptimal allocation (as being discussed, e.g., in the case of the light bulb ban in some countries).
2. If energy efficiency is improved in processes where energy costs are a *major* cost component, there is a high risk of rebound effect, i.e. the success in terms of energy efficiency is likely to be annihilated by the success in terms of quantiative growth. It is exactly this type of energy efficiency improvement politicians promote with enthusiasm: They may believe to create a "win-win" situation because it looks as if both, some financial investors ("the economy") and "the environment" could profit from the development. In fact, profits will in this case be highest if the rebound effect is highest and environmental goals are not met. The rebound effect can be minimized in such situations by one of the following measures:
   a. Look for the limiting factor that currently prevents the system under study from growing. If the limiting factor happens to be something else than energy, the risk of a rebound effect is small. For example, the limiting factor of personal transportation systems is usually the time people spend in traffic; increasing the speed of transportation therefore creates a rebound effect. Increasing the energy efficiency of vehicles, however, will create no or only a small rebound effect. In the vending machine case study, we found that there must have been a limiting factor other than energy (before the Fukushima event) in Japan that stabilized the number of machines already during the 1990s.
   b. If energy *is* the limiting factor in the system under study, growth must be prevented by regulation if the goal is to reduce energy use. This sounds politically incorrect (who would want to prevent economic growth?), but it can be a logical consequence of setting reduction targets for energy consumption (or energy-related CO_2 emissions): Whenever something does not happen *because energy is scarce*, it will happen as soon as the energy efficiency of the process is improved; no overall reduction of energy use will occur and the political targets will not be met.

Provided that society would manage to use energy efficiency improvements without creating rebound effects: There are still other issues to be solved if we are to use the fascinating progress in IT for and not against sustainable development. In particular, the material flows caused by ever shorter-lived technical goods, in particular the increasing amout of small electronic devices entering the waste streams (Kräuchi/Wäger/Eugster/Grossmann/Hilty, 2005; Köhler/Hilty/Bakker 2011), are going to affect the availability of resources to our future generations (Wäger 2011).

Bibliography

Aebischer, B., Huser, A. (1998): Energieverbrauch von Automaten und Energiesparmöglichkeiten, Studie des Kompetenzzentrums „Energie und Informationstechnik". Bundesamt für Energie, Bern

Bool, H. (2006): Vending Machines, Ezine Articles, http://EzineArticles.com/204905 (last accessed 7 July, 2012)

Coleman, J. (1997): Japan's vending machines not as upright as they look, The Sunday Gazette, December 28, 1997

Collins, R., Ellis, M. (2005): Analysis of the Potential for Minimum Energy Performance Standards for Refrigerated Beverage Vending Machines, Prepared for The Australian Greenhouse Office and NAEEEC under the National Appliance & Equipment Energy Efficiency Program

Deru, M., Torcellini, P., Bottom, K., Ault, R. (2003): Analysis of NREL Cold-Drink Vending Machines for Energy Savings, National Renewable Energy Laboratory, Golden, Colorado

EPA (2004a): Energy Star and Other Voluntary Programs, 2004 Annual Report, United States Environmental Protection Agency

EPA (2004b): Energy Star University of Buffalo Case Study, United States Environmental Protection Agency

Erdmann, L., Hilty, L. M. (2010): Scenario Analysis: Exploring the Macroeconomic Impacts of Information and Communication Technologies on Greenhouse Gas Emissions, in: Journal of Industrial Ecology, 14 (5), pp. 824-841

Finnegan, M. (2010): “Smart” Vending Machines Triple Sales, TechEye.net, 15 November 2010

GeSI, Smart 2020 (2008): Enabling the Low Carbon Economy in the Information Age, A Report by The Climate Group on behalf of the Global eSustainability Initiative (GeSI)

Hickman, L. (2011): The rise of the hi-tech vending machine. The Guardian, 31 March 2001

Hilty, L. M., Köhler, A., von Schéele, F., Zah, R., Ruddy, T. (2006): Rebound Effects of Progress in Information Technology, in: Poiesis & Praxis: International Journal of Technology Assessment and Ethics of Science, 1 (4), pp. 19-38

IEA (2007): Quantifying the Effect of Market Failure in the End-Use of Energy, International Energy Agency, Paris

IEA (2011): Energy Efficiency Policy and Carbon Pricing, Energy Efficiency Agency, International Energy Agency, Paris

JVMA (2010): Frequently Asked Questions, Japan Vending Machine Manufacturers Association, http://www.jvma.or.jp/information/qa_01.html (last accessed 14 July 2012)

Keller, P. (2010): Smart vending machine: Culture & Society, Interaction Design, 11 August 2010

Köhler, A. R., Hilty, L. M., Bakker, C. (2011): Prospective Impacts of Electronic Textiles on Recycling and Disposal, in: Journal of Industrial Ecology, 15 (4), pp. 496-511

Koomey, J., Berard, S., Sanchez, M., and Wong, H. (2011): “Implications of Historical Trends in the Electrical Efficiency of Computing” Annals of the History of Computing, IEEE, March 2011, Volume: 33 (3), pp. 46 - 54

Kräuchi, Ph., Wäger, P., Eugster, M., Grossmann, G., Hilty, L. M. (2005): End-of-life Impacts of Pervasive Computing, in: IEEE Technology and Society Magazine, 24 (1), pp. 45-53

Mingay, S. (2007): Green IT: The New Industry Shock Wave, Gartner Inc.

Munter, P. (1995): SEAS Energy Advisory Services, Cold & Hot Drinks Automatic Vending Machines – Preliminary Project on Improved Energy Efficiency, Haslev, May 1995

OECD (2010): Greener and Smarter – ICTs, the Environment and Climate Change. Report to the Working Party on the Information Economy (WPIE), OECD

Schmiemann, M. (2008): Enterprises by size class - overview of SMEs in the EU. Eurostat. Statistics in focus, 31, 1

Tainter, J. A. (2009): Foreword, in: J. M. Polimeni, K. Mayumi, M. Giampietro, B. Alcott (2009): The Myth of Resource Efficiency and the Jevons Paradox. Earthscan, London, pp. ix-xvi

UNEP (2011): Decoupling natural resource use and environmental impacts from economic growth, A Report of the Working Group on Decoupling to the International Resource Panel, United Nations Environmental Program

US-Machine.com (2010): Vending Machines. http://us-machine.com/vending-machines.php (last accessed 14 July 2012)

Wäger, P. A. (2011): Scarce metals – Applications, supply risks and need for action, in: Notizie di Politeia, 27, pp. 104-112

WWF (2008): The potential global CO2 reductions from ICT use – Identifying and assessing the opportunities to reduce the first billion tonnes of CO2. WWF Sweden