Residential Computer Usage Patterns, Reuse and Life Cycle Energy Consumption in Japan

Eric Williams, United Nations University
Takuro Hatanaka, Mizuho Securities

ABSTRACT

Information Technology (IT) hardware accounts for an increasing share of energy use, particularly if the manufacturing phase is considered. For home computers, about 80% of total energy use is in manufacture, only 20% during operation of the device, implying that extension of lifespan becomes an effective strategy for energy management. Enhancing reuse is an important avenue to extend lifespan. This is in general a relatively new challenge for industry, government and civil society.

Computer usage patterns play an important role both in determining total energy consumption of IT equipment and in potential reuse. Usage patters are however, as yet poorly understood. To help bridge this knowledge gap, a survey is undertaken of about 1,000 Japan residential users characterizing computer purchase, use and disposal patterns. Results of this survey are used to characterize macro-level energy use: the life cycle energy consumption of home computers in Japan, including manufacturing and operation, is estimated at 0.64% of national energy demand. The average length between buying new PCs in is 2.9 years. Older computers typically spend 2.8 years unused "in the closet" before next disposition (donation, recycling, or other). These results have implications for reuse, suggesting that there is a "hole" in the supply of mid-level used PCs (2-4 years old), with high-end ones (1-2 years old) being sold by power users buying new machines, and low-end ones (5-6 year) coming from storage. Prompt reselling of used computers could open a door to supplying inexpensive computers to the export market in developing Asia.

Background

The proliferation of computers in the last few decades has given rise to concern regarding environmental impacts associated with their production, use and disposal. Given the large number of devices and substantial energy requirements for production and use of equipment, energy use is clearly one major category of environmental impact. The issue of electricity consumption of computers during use phase gained public attention internationally on publication of the article "Dig more coal: the PCs are coming" in a 1999 issue of Forbes magazine. This article summarized a study by Mark Mills that suggested that computers and telecommunications networks account for an alarming 8% of total electricity US consumption in 1998 and projected that this share would rise to 20-30% in the next two decades (Huber 99). More reliable estimates from researchers at Lawrence Berkeley National Laboratory suggest that the scale of computer and networking device electricity use is actually far smaller, on the order of 2% of total US demand (Kawamoto 2000). This share is substantial enough to still suggest that response is needed to curb its growth. In Japan, estimates from the International Research Center on Superconductivity in Tsukuba are that computers (e.g. PCs, servers, mainframes), network equipment (routers, hubs, basic infrastructure) accounted of 4.3% of national electricity demand in 2000 (Tanaka 2001)

Existing estimates of the energy burden of IT infrastructure generally do not consider life cycle energy costs. In particular, manufacturing computers requires considerable energy. A recent life cycle assessment shows that around 6,400 megajoules (MJs) are needed to produce a desktop computer with CRT monitor (Williams 2004a). The weight of required fossil fuels, 260 kg, is some 12 times the weight of the computer, a ratio much higher than the 1-2 for other manufactured goods such as automobiles or refrigerators (MacLean & Lave 1998, Engelenburg et al. 1994). In previous work, it has been has suggested that the origin of the high energy intensity of manufacturing has a fundamental explanation in terms of entropy (Williams, Ayres & Heller 2002, Williams 2004b). The argument is that production of highly organized high tech components such as semiconductors requires especially large quantities of energy due to the need for highly purified starting materials and processing environments. This high energy intensity, combined with the short lifespan that computers are used in practice, combine to yield an annual energy burden of computer ownership that is surprisingly high: 2,600 MJ per year, 1.3 times that of a typical refrigerator (Williams 2004a). This result implies that, in contrast with many home appliances, around 80% of life cycle energy consumption for a home computer user in for the production, not operation of the machine.

While traditional energy policy focuses on improving the efficiency of products in operation, the above discussion suggests that an added emphasis on mitigating energy use in production is appropriate. Obviously, reducing the energy intensity in the production chain to manufacture computers is one avenue to achieve this. This is an approach with which industry and government has much experience. However, the fact that most computers are disposed of while still perfectly functional suggests another approach: extension of lifespan. The generally short lifespan of computers is driven more by perceived obsolescence than actual engineering limits on functionality. It is reasonable to argue, however, that non-rational factors (in the sense of economics) lead to the manufacture of significantly more new equipment than is actually required to deliver the computing services demanded by users.

The used computer market is a key element to extending computer lifespan. Statistics on used markets and international trade are scarce, thus is it difficult to determine the scale and potential growth of this sector. There is much anecdotal evidence, however, that computers spend years unused in closets until users finally take action to sell, donate, or dispose of a computer. Given the rapid pace of technological change, a timely flow from first users is clearly important for computers to be attractive to potential secondary users. Also, "non-economic" obstacles to the growth of the used PC market have been identified, such as labeling that inhibits smooth transfer of software licenses when hardware is sold between users and lack of a proper "blue book" for used computers that allows seller and buyer to easily agree on a fair price (Williams & Kuehr 2003). Given the above issues and the environmental importance of the manufacturing phase, the characterization of the scale, potential, obstacles and ways to enhance used PC markets is an important research task.

Residential Computer User Patterns in Japan

The above discussion highlights two areas in need of further research for future energy management of IT equipment: estimation of life cycle energy use and enhancement of used markets. Computer usage patterns play an important role in making progress on both of these fronts. For energy use, decisions on how long to keep a given machine, whether to sell, upgrade or stockpile it determine lifetime, critically affects demand and manufacturing energy needed to produce new machines. The time and manner of computer operation also affects electricity consumption during use phase. Hours used is an obvious determinant, but whether and how power management functions (such as standby modes) are utilized is also important.

Despite the importance of usage patterns, quantitative data describing them is decidedly scarce. Existing analysis of energy use of IT equipment has been based on plausible assumptions regarding such key factors as computer lifetime and hours used, not actual data. For the secondary market, information on whether users are purchasing and selling used machines, their attitudes about used equipment and length of time machines are stored in closets are important issues as yet poorly understood.

In order to fill this persisting data gap to address the issues outlined above, this study undertakes a survey of residential computer users in Japan to characterize purchase, operation and disposal pattern. The results of the survey are analyzed in order to estimate life cycle energy use of personal computers in Japan and characterize the status and potential in the supply and demand of used computers, including considerations of international trade.

Survey

In broad terms, the goal of the survey is to characterize purchase, use and end-of-life behavior patterns of residential computer users. With respect to purchase, key questions include how often do users purchase new computers, whether used computers are considered, and if not, why not. Also, issues pertaining to what factors drive purchase decisions are also asked. In the use phase, hours used per day, whether computers are turned off when not used, and functionality/settings of standby modes are queried in order to clarify how much electricity is consumed during the operational life. At the end of life, how long computers are stored in closets before a decision on final disposition is made, and whether users consider selling to secondary market are important factors. One general principle which drove the framing of questions was to characterize actual, as opposed to theoretical behavior. Thus questions focused on how present and past computers were used as opposed to expectations of the future.

The survey was implemented using an Internet survey service, NTT Resonant Inc.. This firm works in cooperation with the Goo search engine (www.goo.ne.jp) and maintains a database of 40,000 Japanese Internet users whom they can ask to complete surveys in exchange for shopping discounts. The survey was distributed in December 2004 and 1,033 responses were obtained to a 40 question questionnaire.

A desired goal of the survey is to understand the behavior of a “typical” computer user in Japan. However, one might suspect those answering net-based questionnaires may well be “heavy users”, given that they have sufficient familiarity with the Internet to use the survey service. While a truly random sampling of the population, say by phone or mail-based questionnaires is clearly preferable, there were not sufficient resources available to do this. It is thus important to consider to what extent the results of the internet-based survey can be interpreted or analyzed such as to better reflect the behavior of an "average user".

One tool to explore this is to compare characteristics of the survey population with national averages. Here only a preliminary comparison of survey and average populations is attempted, a more sophisticated and thorough analysis will appear in future work. In terms of basic characteristics such as gender, age and distribution of professions, the survey sample is not substantially different. The means of Internet connection (i.e. modem vs. ADSL vs. cable vs. optical fiber) could potentially be a useful benchmark to understand how the sample population differs from the national average. A comparison of the Internet connection of survey respondents with the 2003 national average appears in Table 1 (MIAC 2004). It is clear from this table that a far greater portion of survey respondents have broadband connections as compared to the general population, suggesting a potential skew towards heavy users.

Table 1: Comparison of Means of Internet Connection

Means of Internet Connection	Internet Survey	National Survey (Phone)
Dialup (analog modem)	6%	53%
ADSL	64%	35%
Cable	15%	8%
Optical Fiber	13%	4%

Source: MIAC 2004

The next question is whether this preponderance of ADSL over modem connections significantly affects key results. Table 2 shows results for two particularly relevant questions groups according to internet connection. While there is in general a variation in results in line the hypothesis that broadband users are more "heavy users", differences in purchase interval is not terribly large. The difference between hours used per day, however, is much smaller for analog modem users.

Table 2: Survey Results from Two Questions Grouped According to Internet Connection

Means of Internet Connection	How Many Years Between Purchases of New PC?	How Many Hours Used per Day on Weekdays?
Dialup (analog modem)	2.97	2.11
ADSL	2.74	2.97
Cable	2.76	3.05
Optical Fiber	2.56	2.91

It is clearly difficult to determine the extent to which the survey results can be adjusted to reflect national usage patterns. Ultimately, a survey given according to truly random sampling of the population is required. However, we believe that it is relevant to make the "best possible" estimate given currently available data. This translates into an attempt to analyze the results so as to correct for errors in the sampling population, despite the fact that such will be imperfect a priori. The first order method to do this used in this article is to re-weight the answers according to the national average internet connection. For example, for the interval of years between purchases, this is obtained by the dot product of the last column in Table 1 with the second column of Table 2, for an "adjusted" average result of 2.9 years. In later sections only these adjusted (i.e. re-weighted) results are reported.

Life Cycle Energy Consumption of Residential PCs in Japan

The goal of this analysis is to estimate the net energy consumption of home PCs in Japan, including manufacturing and operation.

Manufacturing Phase

Knowledge of how many new PCs are purchased annually is clearly needed for any estimate of net energy use of manufacturing PCs. Household PC purchases is estimated via a combination of national statistics and survey results:

Number of new PCs = number of households • PC penetration ÷ purchase interval
= 50 million • 64% ÷ 2.9 years = 11 million units,

where the number of households in Japan (50 million) has been drawn from statistics of the Ministry of Internal Affairs and Communication (MIAC 2004), the PC penetration rate from a survey of the Cabinet Office (Dentsu 2005), and the purchase interval is the average of results from the survey.

The total energy consumed to manufacture this number of PCs is given by:

National energy use = number of new PCs • energy requirement per PC
= 11 million units • 6,400 MJ per PC = 7.1 10^{10} MJ

The energy requirement per PC is taken from a recent study of desktop computers by one of the authors (Williams 2004). Two main questions arise regarding use of this figure to describe all PCs. One relates to the dynamics of computer manufacturing. Technological progress continues to be rapid, raising the issue of whether the net energy requirements to make a computer change quickly as well. As yet there are no analyses that suggest how net energy use per computer evolves over time, thus the static figure is used as an interim assumption. Further work is required to clarify how reasonable the assumption is, and if not, improve upon it. The other main question is whether energy use for laptop computers differs substantially from their desktop counterparts. While there is no hybrid study analogous to (Williams 2004a) as of yet, pure process studies do not indicate a large difference. For instance, firms publish results of process energy studies for declarations of product information for certification an Ecoleaf eco-label, energy needed to produce desktop and laptops is not so different, despite the smaller size of the laptop. The explanation for this is no doubt due to the relatively small share that bulk materials account for in the total energy burden, as well as additional energy needed to achieve the more compact forms in laptop computers.

Operation

To estimate energy use in the operation phase, information is needed on how many computers are in use, how many hours are spent in which power modes (full on, standby, off) and electricity requirements of different modes. The first element is estimated via

Number of PCs in use = number of households • PC penetration • active PCs per house
= 50 million • 64% • 1.6 units = 52 million units,

where the first two factors have been described above and the active PCs per household is taken from the survey.

The average hours used is taken from the survey at 2.6 hours per day. The question of what power mode the computer is in when not being used is key to reasonable estimation of electricity use. One question in the survey informs this question, with 78% of users reporting that computers are turned off when not in use, 3.4% always on, 7.1% always on except at night, 8.5% in standby mode and 2.7% in hibernate mode.

To briefly recap computer power low power modes, standby refers to a mode where many of the are powered down, but enough left on so that the computer can quickly “wake up” if a key is pressed. The hibernate mode, usually used for laptop computers, writes the contents of memory (DRAM) to a special hard disc buffer and powers down nearly all systems. The wake up time is longer for hibernate as compared to standby mode, but power use is near zero.

Average power requirements of desktop and laptop computers in different modes are not so simple to characterize. Measuring this for an individual machine is trivial with a Watt-meter, the difficulty lies in finding an appropriate average for the stock of machines in use. Also, the power requirements of computers also changes year by year. For example, different generations of microprocessors can have dramatically different electricity use, Pentium IV’s use far more electricity than Pentium III’s. Liquid crystal displays (LCD) use far less electricity than their Cathode Ray Tube (CRT) equivalents. Here we guess approximate averages based on the survey of existing measurements by Cole (Cole 2003). The assumptions are 120W for full on desktop system, 20W in standby mode, 20W for laptop, 3W in standby.

The results and assumptions above are combined to estimate total household PC use in operation at 2.5 10^{10} MJ per year, less than 1/3 of the energy used to manufacture the annual demand for new machines. This result makes it clear that inclusion of the manufacturing phase is essential for a reasonable estimate of total energy burden. This is contrast with automobiles, for which 90% and above of total energy use is fuel used while driving (MacLean and Lave, 1998).

The total energy consumed by home PCs in Japan is 9.7 10^{10} MJ, about %0.64 of total energy demand. While this is certainly much smaller than the share for personal automobiles (13%) (EDMC 2001), for example, it is not insignificant. Another point is that computer and internet adoption (and associated energy use) is increasing more rapidly than most other energy uses. In addition, this estimate for the computer itself is to an extent “the tip of the iceberg”, in that the rest of the information technology, peripheral devices such as printers and network equipment such as routers have not been accounted for. Given that a far larger share of the energy burden is hidden in the manufacturing of infrastructure as compared to automobiles, a more complete estimate will no doubt increase the share considerably. This is a task for future work.

To conclude, the above results strongly suggest that the energy burden of national IT infrastructure, including manufacturing, is significant enough to merit greater attention from policy makers and firms.

Caveats and Uncertainties

Caveats and uncertainties are numerous and significant. For usage patterns, there is error both in sampling and statistical error due to limited survey population. Table 2 gives some indication of the latter. The energy use per PC is clearly a rough estimate. The base figure used, 6,400 MJ, is supposed to reflect a desktop system produced in 2000. There are substantial uncertainties in this figure, the larger contributor to which is probably regional and facility variations in energy efficiency and value-added of processes (Williams 2004a). Also, this figure varies over time, and the average computer in use was probably manufactured in 2001-2002. Thirdly, different models and types of computers have varying energy requirements, the difference between desktop and laptops could be large. Future work will include error estimation that attempts to characterize effects of error on national energy use results.

Used Computer Markets

As mentioned above, we argue that extending lifespan of computers is important in their environmental management. One practical way to do this is by encouraging markets for used personal computers (PCs). Computers are normally disposed of long before they break down or wear out; rather, the user wants a new machine with better performance and new functions. Not all users require high performance, however; the most popular applications of PCs (e-mail, Internet, office software) often work just as well on older machines. Despite falling prices in recent years, PCs remain an expensive item; thus, presuming it can meet their computing needs, many users will find the lower price of a used machine attractive.

The used-PC market is primarily driven by economic forces; there are, however, "non-economic" obstacles to its reaching its full potential. The environmental and social benefits delivered by the used-PC market imply that efforts should be made to ensure that Adam Smith's "invisible hand" can do its work. The first step in maximizing the flow of used PCs is to understand their markets. This is surprisingly challenging. While it is intuitively obvious from daily life experience that much IT equipment ends up being stored in closets or thrown away while still functional, quantifying this and identifying driving factors is difficult. One major reason is generally scarce information regarding used markets of all kinds. Systems of national statistics are designed to track production and trade of new goods and rarely do categories exist for used or recyclable ones. Part of the purpose of the survey is to clarify the status and potential of used PCs markets in Japan and Asia. It is thus appropriate to review what is currently known about used markets. The main source of information is reports of consulting firms.

One study put the total value of the global market for used IT equipment at $9 billion in 2001 (Lei 2002). This figure is no doubt rough, as national statistics (such as the U.S. Census) do not have a category for used IT equipment, and there is as yet no industry organization or consulting firm that regularly surveys the industry. For the United States, the International Data Corporation published a study in 1998 of the used-PC market (Luening 1998). According to their estimates, the total market in 1997 was 5.5 million units, with 14 percent annual growth. The study also predicted that the growth in the used market would decline to 10 percent per year due to competition from lower-priced new PCs. Apparently, there has been no follow-up analysis to determine if this actually happened. One estimate put the scale of domestic sales of PCs (including used) in the United States at 30.3 million machines in 1998 (Dyrwal et al. 2000), suggesting that the used market has around an 18 percent market share in unit sales.

For Japan, the Japanese Electronics and Information Technology Association (JEITA) estimates a total used market of 1,197,000 machines for 2001, with around 830,000 of these destined for export (JEITA 2003). Mic Research Institute Inc. estimates the Japanese market in 2001 for used computers at 830,000 machines and on track for 18 percent annual growth in 2002 (My-Com PC Web 2002). By comparison, the Japanese market for new PCs in 2001 was 12 million units, down 11 percent relative to 2000. It is difficult to know how accurate these figures are, as no details of how the estimate was made are publicly available. Given that much of the sales of used equipment are done by small and medium sales businesses, often in suburban and rural areas, collecting relevant data is a challenging task. Presuming both U.S. and Japanese estimates are reasonable, it would seem that the Japanese used market is much smaller than in the United States. There are many possible factors that might explain this; the reputed aversion of Japanese consumers for used goods is sometimes suggested by analysts as the main cause.

Survey Results and Domestic Used PC Supply and Demand

The following survey results are particularly helpful in characterizing the status and nature of used PC supply and demand in Japan

- The share of users reporting experience selling or buying used PCs is small (13% and 14% respectively)
- The dominant reason reported for not having sold a used PC was “never considered it” (55%).
- The main reason reported for not purchasing a used PC was “concerned about warranty” (39%). Reliability worries and a desire for to “my own new” computer were also strong (about 26% each)
- On average computers spend almost 3 years unused “in closets” before being given away, sold or otherwise disposed of.
- The main hardware intensive application of computers in demand is games (44% of respondents).

The combination of these results suggests a probable bottleneck in the supply of mid-level used PCs. Those users reporting experience with selling used PCs were in general those buying new ones more frequently (1-2 years). This suggests a pattern of managing costs of new PCs though timely selling of previous one while the price is relatively high. Most potential “mid-level” PCs (2-3 years old) are not ending up in the used market, rather in closets, apparently partly due to lack of awareness of users that the option to sell exists. If users could be convinced to part with these machines promptly after purchasing a new one, large increases in the supply of reasonable quality used PCs seem eminently possible.

Demand for used PCs is, apparently, comparatively weak. While over half of computer users do not require the hardware power of newer equipment, concerns over short warrantees and reliability, as well as desire to own a new product inhibit many from purchasing a used machine. It is interesting to consider the extent to which it is feasible for sellers to issue an extended warranty on used products for a reasonable price. One clear challenge is the lack of an appropriate system to evaluate the wear status of used components. Hard disc drives in particular tend to fail after several years.

International Trade in Used PCs

The issue of international trade in used PCs is potentially key. Given rapid declines in prices of new computers, the used computer market is facing increasingly difficult circumstances in recent years. However, it is important to note that the price gap between used and new computers, expressed in terms of purchasing power, is far larger for those in developing countries than for those in rich nations. For example, while a Japanese consumer faced with the choice between an $800 new system or a $300 used one, the $500 will likely not seem such an additional burden considering the benefits of a new system. For consumers in poorer countries, however, several hundred dollars often represents several months or more of salary. There is thus a potentially large demand in the developing world used machines deemed unattractive to users in industrialized countries. Note that in this case trade in used computers has much less a mitigating effect on demand, and association manufacturing impacts, of new computers. However, making computers more available to users in developing countries contributes to bridging the digital divide, and thus serves an important social purpose. However, little is known about the status and potential of international trade of computers. Trade statistics in most all nations do not separately track flows in used equipment, thus other, often indirect, means must be employed.

The JEITA report suggests that there exists a degree of export of used PCs from Japan (830,000 units in 2001) (JEITA 2002). The latent supply of mid-level used PCs and weak domestic demand suggest that the potential for increased export is very high. The extent to which there is demand for these PCs is a key question. Considering only performance and price, the used machine has potential: many people in poorer nations can afford a used computer much more easily than a new one. Many “non-economic” barriers exist however. One relates to the ewaste issue: some nations, fearing becoming a dumping ground for junk equipment, place trade restrictions that inhibit trade in used machines. China has done so, for instance, though part of the motivation is probably to provide a protected market for their domestic computer industry aiming at the low-end market. A second issue relates to software. Used computers often ship without any software included at all, partly due to flaws in the labelling of licensing agreements (Williams & Kuehr 2003). Also, software is in the native language of the origin country, not useful in many destination countries. In practice, developing nations often get around this by resorting to piracy, but this is not a long-term solution.

Despite these obstacles, in some regions import markets for used PCs are flourishing. Ho Chin Min city in Vietnam boasts a robust used market, mainly selling computers from the US. A Pentium II system typically goes for US$50-100, while a Pentium III runs US$150 (Kojima 2004). India reportedly receives many donations of equipment, though many of these end up being sold by middlemen. Thailand allows import of computers under 3 years old, though it is not clear how this can be effectively and easily checked in practice. The extent, destinations, and kinds of used PCs being exported to Asia from Japan are not yet clear. The hole in the supply of mid-level used PCs suggest that exports might be a mix of high and low-end machines.

With respect to Japan's future place in this market, issues stand out. One is the role of the national computer recycling system. Residential users now pay US$30-70 per computer for its recycling under the government mandated system. Currently, the system uses this income to cover the costs of transportation and focuses on domestic recycling of materials. It is interesting to consider whether these fees could be used to enhance collection and testing for resale as well as materials recycling. The other is how to change user behavior to shift the current supply of low-end machines to mid-level ones through prompt reselling. With regards to these and the other issues not detailed here, the stance of Japanese government and industry towards the used market is clearly important in shaping and implement public response.

Cutting the High Cost of Energy in the US

The implications of these results for cutting energy costs in the US are subtle. On one hand, they clearly indicate that a life cycle perspective can suggest radically different approaches to energy conservation, in particular encouraging markets for secondary products. However, it is worth making the distinction between cutting "total energy use" and "domestic energy use". To whit, much computer manufacturing takes place overseas, thus a large portion of energy saved through reduced demand for new machines will be seen outside of the US. The embodied energy associated with imports and exports of manufactured goods is not usually considered in national energy management. Also, international trade in used computers likely does not substitute for new production, rather serves the social purpose of reducing the digital divide. If the objective of energy management is to reduce energy use strictly defined by fuel consumption within U.S. boundaries, promoting reuse and recycling for other products, such as steel or aluminum intensive ones, may be more effective than for computers.

In closing, we discuss some implications of these results for manufacturers and retailers. The computer sector, like many other consumer products, tends to be dominated by the "sell and farewell" model, meaning that income is generated at sale of a new product, which is generally not seen again by the manufacturer or retailer. This model clearly creates an incentive to sell as many new products as possible, a framework in which extension of lifespan would be bad for business. While there is certainly some truth in this, the real world is more complicated than this simplistic view. Leasing is on the increase, especially in the business sector, as firms increasingly wish to outsource the headache of keeping hardware and software up-to-date. This trend tends to rationalize the match of equipment and computing needs, probably leading to greater reselling of used equipment. Also, there is the potential for upgrade and buyback services offered by manufacturers to give an edge over competitors in an increasingly tough market. Also, as customers become more IT savvy, they will increasingly understand the issues they face at the end of use of their computer, and perhaps favorably consider manufacturers who save them money via support of upgrades and reselling.

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