

# Telework Adoption and Energy Use in Building and Transport Sectors in the United States and Japan

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**Abstract:** Telework (or telecommuting) has been proposed as a way of reducing transportation externalities such as congestion and passenger vehicle energy use. While there is contention among sources about the secondary induced transportation effects, many studies have estimated net benefits as a result of transportation reductions. Analyses including effects from shifts in commercial and residential building energy use, however, are not as visible. It is expected that commercial building energy use would decrease, and residential energy would increase as a result of telework adoption. We estimate macrolevel energy effects across these three energy intensive sectors (transportation, commercial, and residential buildings) to help characterize the potential of telework as a policy initiative to improve national energy efficiency. For current estimated teleworking populations and practices in the United States and Japan, we estimate national level energy savings of only 0.01–0.4% in the United States and 0.03–0.36% in Japan. In a future scenario with pervasive adoption of teleworking, where 50% of information workers telecommute 4 days per week, United States and Japan national energy savings are estimated at only about 1% in both cases. These energy savings are quite modest compared with currently available policy options to mitigate energy demand. By comparison, an improvement in average vehicle fuel efficiency of 20% would save 5.4% of total United States energy demand, suggesting that the direct benefits of adopting telework are relatively small given the large degree of behavioral and structural change required. Still, presuming that future work practices tend to favor greater adoption, the potential energy savings may merit direction towards environmentally beneficial implementation. If trends in the workplace favor more telework in the future, we suggest that maximizing environmental benefits merits greater attention to how telework is adopted. Obviously the increased number of avoided commutes is a factor, but more importantly, elimination of office space due to virtual offices yields energy savings that rival those from reduced commuting. Future analyses and implementation of telework should thus give greater attention to energy use in buildings and residences.

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## Introduction

Telework (or telecommuting) could become one of the major environmentally beneficial applications of information technology affecting infrastructure sectors. Particularly affected are transport and buildings, both significant consumers of energy. The transport sector represents 26% of total energy demand in the United States and 25% in Japan, of which around 1/3 can be attributed to commuting (EDMC 2001; Ministry of Public Management 2001b, EIA 2003a). Energy use in commercial and residential buildings combined represent 40% of total energy consumption in the United States and 27% in Japan (EDMC 2001; EIA 2003a). Major factors accounting for the dramatically higher share in the United States are larger per capita building space, more heating

and cooling of unoccupied spaces, and a more extreme climate. Telework has the potential to significantly reduce personal transport energy use through reducing commuting travel. Telework also affects energy use in commercial and residential buildings. A certain degree of office space and associated energy can be eliminated while additional time spent at home implies increased residential energy use.

Presuming for the moment that telecommuting is, on the whole, beneficial for the environment, reaping net energy benefits first and foremost requires that it be widely adopted. A recent study by the USBLS (2002) suggested 15% (20 million persons) of the work force did work in the home. However of that number, only 17% (3.4 million) were doing paid work at home, with the remainder bringing additional (unpaid) work at home or were self-employed. It is important to separate telework and potential telework among these categories. While the United States has been the world leader in adoption, Japan is well behind the United States with an estimated telecommuting workforce of 2.2 million persons (JTA 2000). As will be seen, total information workers can be estimated at 53 and 28 million, respectively, much higher than current telecommuting populations. From a theoretical perspective, it thus seems that telework is far from reaching its potential. Environmental considerations apparently are not key drivers in the adoption of telework. Not surprisingly, the two primary motives reported by firms and employees are desires to cut costs and improve productivity wasted in long commutes. If environ-

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mental benefits are significant, it is desirable that such considerations are more effectively incorporated into the milieu of forces governing its adoption. One option is policy action to promote greater adoption. Also, it is possible that benefits depend strongly on how telework is adopted, in which case assessment can play an important role in ensuring that it is implemented in an environmentally effective way.

Research assessing the environmental implications of telecommuting began in the late 1980s; much of the United States work to date has focused on analysis of transport impacts and has often been geographically centered in California. A variety of empirical surveys characterizing changes in the travel behavior of telecommuters have been undertaken (Hamer et al. 1991; Pendyala et al. 1991; Henderson and Mokhtarian 1996; Koenig et al. 1996). The consensus seems to be overall vehicle use reducing substantially (50–70% reduction on telecommuting days is typical). While the number of noncommute trips generally increases slightly with telecommuting, the total miles traveled for noncommuting purposes, surprisingly, usually does not (Mokhtarian 1998). This is perhaps due to people choosing closer to home locations for shopping or recreation if not commuting. A US Department of Transportation study from 1993 estimated that 5.2% of the work force telecommuting 3–4 days/week would save 1.1% of national gasoline consumption (USDOT 1993). Mokhtarian synthesized telecommuting studies into a model suggesting that 6.1% of the workforce telecommuting 1.2 days a week saves 0.5–1% of vehicle miles traveled (Mokhtarian 1998). Kitou and Horvath (2003) developed an integrated model including transport, commercial, and residential buildings, and electricity use by equipment. There are as yet relatively few assessments of telework outside the United States aside from early work by Hamer and collaborators in the Netherlands (Hamer et al. 1991). Arnfalk reports that four surveys of Swedish telecommuters indicate that 50–80% do not experience any reduction in travel (Arnfalk 1999). However, the definition of telecommuting used in these studies makes them difficult to interpret: many of the so-called “telecommuters” (80% in some cases) spend time at the company every workday.

In this paper we estimate national-level shifts in energy use in United States and Japan building and transport sectors due to current and future adoption of telecommuting. The main purpose is to scope the macrolevel potential of telecommuting as an energy savings “technology,” setting a context for its promotion and adoption via government policy and firm environmental strategies. We view the main contributions of this analysis to the literature as threefold. First, a particular effort is made to characterize macrolevel effects on energy use in commercial and residential buildings, a significant and complex factor that has received scant attention in the literature to date. Handy and Mokhtarian (1995) studied actual shifts in residential energy use but not the commercial sector, which actually uses much more energy in the United States. Kitou and Horvath included both residential and commercial buildings in their integrated model, but only in marginal terms accounting for the actual office space “assigned” to the worker (Kitou and Horvath 2003). However, total office building space and corresponding energy use is typically 3–4 times that of individual offices (CPEEB 2001; USEIA 2002), thus at the macrolevel where entire buildings can be eliminated, potential savings are much higher. Second, we believe this to be the first national estimates of telework-induced energy shifts that include the buildings sector. And finally, comparing United States and Japan should provide insights into how environmental costs and benefits vary according to population density and local

practices. One interesting difference in this vein is that central climate control systems are almost unheard of in Japanese homes—rooms are typically heated/cooled individually according to demand. This should lead to a far greater sensitivity of residential consumption to telecommuting adoption.

## Methodology

The main research question is how national-level energy use associated with transport and building infrastructures changes according to current and future wider adoption of telecommuting in the United States and Japan. Our energy assessment includes only direct shifts in consumption in vehicles and buildings, although indirect factors such as reduced congestion and construction of infrastructure could be significant.

The focus on the national level in the statement of the research question is key: the ensuing method must formulate appropriate averages of a variety of telecommuting practices. There is no obvious appropriate bound on the complexity of quantitative models that could be formulated to address this research question. For example, in areas with congested traffic, energy savings is a nonlinear function of the number of cars taken off the road. Metropolitan areas often have higher concentrations of information workers, thus it could be argued these should be modeled separately. The philosophy here is to start with an integrated scoping model, the elements of which can be upgraded in future work. More colloquially, our intention is to provide back-of-the-envelope estimates as a baseline for upgraded models. For the purposes of being able to compare United States and Japan cases, we will use a simpler model for assessing transport impacts compared with, for instance USDOE (1994) or Mokhtarian (1998).

The starting point is estimating how many workers can in principle telecommute. The assumption here is in line with existing literature, that “information workers,” i.e., clerical workers, designers, engineers, could do so (USDOE 1994). Mobile sales forces are something of a special case, and are counted as information workers here. The next issue is how to interpret macrostatistics on the structure of employment so as to distinguish the possible telecommuting subset of the work force, to be dealt with in later sections.

The next step is estimating the average energy shift in transport and building sectors. A simple linear model is assumed. An average energy per commute is estimated from macrostatistics, with energy use allocated according to the relative amount of time spent on commuting compared with other travel. This disregards any additional benefits due to reduced congestion, thus represents a lower bound on potential savings. There is currently insufficient data to allow an accurate estimation of savings in commercial buildings. This is estimated through review of the reported savings of firms implementing telecommuting, from which plausible scenarios are constructed. Residential energy is handled in Japan by assuming (quite plausibly) that each day telecommuting requires increased heating/cooling of one average room. The estimation of residential energy change is much more difficult for the United States because central heating/cooling is relatively insensitive to occupancy. This is handled by making assumptions about the effects of undoing the benefits of automated climate control systems in residences.

## Status and Trends in Telecommuting in the United States and Japan

What telework actually is poses a more complex question than one might think at first. Is working at home after hours included?

What about a freelance web designer who works from home? A variety of different definitions are possible and actually used in practice, contributing to a great deal of confusion as to the status of telework. Here we are mainly concerned with those workers for whom communication technologies (mainly computers and the Internet, but also phone) enable productive off-site work activity, avoidance of commutes, and entire days spent in an office. The "classical" salaried telecommuter in a certified telework program is clearly included, but we also believe that workers for whom information technology enables work at home (such as the aforementioned freelance web designer) should be considered as teleworkers as well.

There have been a number of surveys undertaken by various organizations over the years to characterize the level and patterns of telework adoption in the United States and Japan. Even so, the field is still plagued with uncertainty on basic questions such as the size of the current telecommuting population. United States studies of population of home workers give figures ranging from 3.6 to 15.7 million for 1997 and 1998 (FIND/SVP 1995; BLS 1997, 2003; Cyber Dialogue 1999; Keil 2000; Kuenzi, and Reschovsky 2001) to 19.6 million in 2000 (Telework America 2001). While it is not entirely clear why the figures should vary so much, Mokhtarian and collaborators suggest that differences in the definition and survey questions as well as statistical problems associated with small sample sizes are important factors (Mokhtarian et al. 2004). At any rate, it is clear from the wide range of results there is as yet no consensus regarding the size of the telecommuting population.

The US Census Survey of Income and Program Participation (SIPP) has the virtue that workers who spend some time at home or are entirely home based are clearly distinguished (Kuenzi and Reschovsky 2001), as well as the distribution of telecommuting frequencies. The number of "mixed workers," who work at home at least 1 day/week and also elsewhere, is estimated at 2.9 million in 1999. The number of "home workers," who work only at home, is estimated at 6.4 million, for a total telework population of 9.3 million.

Data on the intensity of telework (e.g., number of days at home per week) is scarcer than that of the overall telecommuting population. As pointed out by Mokhtarian et al. 2004 many surveys ask how many hours people worked at home, a quantity difficult to translate into number of commuting trips avoided. Also, it will become clear that the estimation of commercial building savings requires not only data on the average number of telework days, but their distribution as well. This is because occasional telecommuting will not save any appreciable office building energy, but a worker with a virtual office eliminates the need for an entire commercial office (with associated overhead space). The SIPP survey reports that the distribution of telework intensity for mixed workers is 60% for 1 day/week spent at home, 21% for 2 days/week, 7% 3 days/week, 4% 4 days/week, and 8% for 5 or more days/week (Kuenzi and Reschovsky 2001). This translates into an average telework intensity of 1.8 days/week for the United States. However the SIPP survey is problematic because it forces respondents to work at least 1 day/week to be in the mixed worker category. Many teleworkers probably spend less than 1 day/week at home, as suggested by a 1.2 day/week average for all teleworkers reported by Handy and Mokhtarian (1995). For home workers in the SIPP study, 8% worked only 1 day/week, 3% for 2 days/week, 5% 3 days/week, 3% 4 days/week, and 81% for 5 or more days/week for an average of 4.9 days/week. Note that the average for all workers is given as 0.3 days/week.

In the United States, there are many federal, state, and local programs educating and encouraging firms and their employees to consider telework as an alternative to their current labor/work practices. At the federal level, telework is linked with Transportation Demand Management as an example way of improving the efficiency of transportation systems. Large firms known to be active in adopting telework include AT&T, EDS, HP, IBM, and Unisys. These programs have participants from sales, clerical, and management staff. AT&T notes that 17% of its managers work full time from home with an estimated annual benefit of \$150 million (Roitz et al. 2003). Six to ten percent of HP's United States staff work at home at least once per week.

The Japan Telework Association (JTA) did a survey in 2002 of Japanese workers to estimate the telecommuting population. In 2002, 4,125 surveys were recorded from company workers (60% response rate) (JTA 2003). The definition of teleworker entailed working in a place other than their primary business location (not necessarily home) and using ICT to accomplish their work tasks. They estimated national teleworkers in several categories. First, "broad definition teleworkers" are those who telework on average less than 8 h/week. Of these, 4.43 million were salaried and 1.91 million were self-employed. Second, "teleworkers" are those who telework at least 8 h/week. Of these, 3.11 million were salaried and 0.97 million were self-employed. The total telework population is 7.54 million salaried employees and 2.88 million self-employed (10.42 million total).

The 2002 JTA survey did not report telework intensities but the split of broad definition and regular teleworkers implies an intensity of about 1 day/week. However a similar study done by JTA (2000) reported 2.5 million salaried teleworkers with intensity of 20% 5 days/week, 20% 3-4 days/week, 30% 1-2 days/week, and 30% 2-3 times/month or less. This translates into an average telework intensity of 2.2 days/week. The disagreement between the average intensities could result from survey biases, nonhome telework, or simply workers doing extra work at home after a day at the office. We emphasize that the United States experience shows that survey results can vary widely and having only one data point from Japan implies that uncertainty correspondingly increases.

Two percent of Japanese firms surveyed reported that they have a telecommuting program (JTA 2000). Large firms well-known to be active in adopting telework are IBM, NEC, Price Waterhouse Coopers, and Fujitsu. Current telecommuting programs are mainly aimed at mobile sales and customer service forces, though with some specialists and office workers also participating (Ibid).

IBM Japan has implemented telecommuting for a significant numbers of its salespersons, system engineers, and customer engineers. In 2000, 4,500 of 20,000 IBM-Japan employees were participating. Generally telecommuters are expected to only come to the office 1 day/week though some choose to come more often. The closing of a large office building was largely accommodated by the switch to telecommuting and fitting four teleworkers in the office space of three.

Elmed-Eizai provides an interesting example of a firm that was planned from the start with telework in mind. The idea was to operate a national pharmaceutical sales force via a slim administrative center in Tokyo and salespersons telecommuting from distant prefectures. Telecommuters only report to work once a month for group meetings. The headquarters itself contains only administrative staff and meeting spaces.

## Potential Teleworkforce

As mentioned above, a primary need is an idea about the potential size of a teleworkforce given current job tasks and labor practices in industry. In principle, only information workers should be able to telecommute: These workers deal in information and do not necessarily have to physically be present at the workplace. Four characteristics are identified as key in determining whether a given job can be partially or entirely switched to telecommuting:

1. individual versus group work;
2. availability of clear parameters for evaluation;
3. whether the work requires ongoing personal contact with customers; and
4. if it requires physical work to be done on-site or not.

Group work here means that the jobs require substantive interaction with co-workers at least several times a day. Much office work fits into this category. While phone and email serve as partial substitutes for face-to-face interaction, activities such as strategizing, planning, multiperson meetings, and maintaining work relationships are better done in person. The issue of evaluation is also important. Work with clearly defined outputs such as sales figures, quality, and number of research/analysis generated is more easily switched to telecommuting. Other types of work often come in smaller packets and need closer contact with managers to communicate performance. Criteria 3 and 4 relate to the need for the physical presence of the worker. The obvious observation is that only jobs that deal in information processing of some sort can have their output mediated through communications systems. The neighborhood hair stylist, for example, will not be telecommuting anytime in the near future.

As evidenced by the variations in telework population estimates above, accurately estimating the number of jobs that will be switched to telecommuting as well as the number of telework days per week in practice, is clearly difficult. Our approach is to use national level statistics describing the structure of the labor force to identify the “information workers” in an economy. Clearly not all of these workers are or will be telecommuting, but we assume, for the purposes of estimating the long term environmental benefits of telecommuting, that all information workers can in principle telecommute. Mohktarian, based on empirical and behavioral considerations, suggests that about 50% of information workers could telecommute (Mohktarian 1998).

### **Labor Structure in the United States and Telecommuting**

Table 1 summarizes United States statistics on the distribution of different types of jobs (USBLS 1997, 2003). Note some of the official Census job category titles have been truncated and adjusted to match Japanese data below for comparison. The Professional Specialty category includes engineers, scientists, and technicians. The Sales category includes retail employees as well as mobile sales staff, marketing personnel, etc. Administrative support includes secretaries, as well as computer and data entry technicians. Technical support includes computer and other support positions.

The four categories we consider to be United States “information workers” are professional specialty, technical support, administrative support, and a fraction of sales. Given the current pattern of adoption, it is clear that the nonretail part of the sales sector is already ripe for teleworking. The professional specialty sector is telecommuting to a certain degree already and a very significant fraction of jobs can clearly make the switch.

**Table 1.** United States Working Population by Category (2002)

Category	Percent	Population (million)
Professional specialty	16.2	21.9
Management	15.2	20.5
Service workers	13.7	18.5
Administrative support	13.6	18.3
Sales (including retail)	11.7	15.8
Precision production	10.6	14.3
Machine operators	4.8	6.5
Transportation	4.2	5.7
Laborers	3.9	5.3
Technical support	3.3	4.5
Agriculture	2.3	3.1
Household service	0.5	0.7
Total	—	100

To be conservative, we assume that half of the sales positions are nonretail (e.g., corporate sales forces, marketing, etc.) and that managers will not be telecommuting in the near future (although several of the companies listed above show significant inroads in this work category). Note that retail is roughly 50% of sales jobs in Japan. It is not obvious to what degree telecommuting can currently be adopted in the administrative support sector. Many of the jobs qualify as “group work” and evaluation is not as simple as compared to, for instance, salespersons and designers. Improvement in communications technology could make a significant difference. In particular, the availability of reasonable quality videoconferencing-on-demand could help in circumventing barriers to telecommuting in the clerical sector. We include all three sectors in estimations of potential telecommuting sectors, where estimations for energy savings per individual labor sector can be obtained by multiplication of the appropriate ratio. Many jobs in sales, technical support, and professional specialty sectors can be made teleworkable, less so for the clerical sector. Overall we estimate 53 million potential information worker jobs in the United States (about 40% of the total workforce).

### **Labor Structure in Japan and Telecommuting**

Table 2 summarizes Japanese national statistics on the distribution of different types of jobs from 2001 (Ministry of Public Man-

**Table 2.** Japan Working Population by Category (2001)

Category	Percent	Population (million)
Factory, construction	28.2	17.7
Clerical	19.8	12.4
Specialty, technical	13.7	8.6
Service	8.7	5.5
Sales	7.5	4.7
Retail	7.4	4.7
Agriculture	5.2	3.3
Transport, communication	3.7	2.3
Management	3.0	1.9
Security, maintenance	1.6	1.0
Other	1.2	0.7
Total	100	62.9

agement 2001a). The sector “specialty/tech.” includes researchers, designers, engineers, and computer technicians. The sales sector here is by and large, mobile sales and support work (there is a separate retail sector). The service sector encompasses mostly personal (as opposed to business) services such as restaurants, hotels, entertainment, education, and medical. This crude division of work types is not entirely sufficient to inform what jobs are telecommutable or not. For instance, while most jobs in the service sector require personal contact with customers at the place of business, it also includes the advertising business, some components of which are definitely telecommutable. Even given this caveat, the categorization is useful for a first-order approximation of the share of jobs for which telecommuting may be feasible.

The four “information worker” sectors we consider for Japan are specialty/tech, management, clerical, and sales. Given the current pattern of adoption, it is clear that the sales sector is already ripe for telecommuting. The specialty/technical work sector is telecommuting to a certain degree already and a very significant fraction of jobs can clearly make the switch. It is perhaps safe to assume that managers will not be telecommuting in the near future. As mentioned above, it is not obvious to what degree telecommuting can currently be adopted in the clerical sector.

Table 2 shows the Japanese working populations in the sectors considered as “information worker,” the total of which is 28 million, about 44% of the total Japanese workforce.

## Effects on Energy Use in Commercial Buildings

### *United States Case*

Commercial buildings represent a significant share of energy use in the United States (14%). Total site consumption of energy in commercial buildings in 1999 was  $6 \times 10^{12}$  MJ (USEIA 2002). Note total primary energy consumption is roughly double  $-13.6 \times 10^{12}$  MJ. The total site energy consumed in United States office buildings was  $1.1 \times 10^{12}$  MJ in 1999 (USEIA 2002). Energy Information Administrative statistics also suggest that 29 million Americans work in office buildings (USEIA 2002), yielding a naïve “site building energy use per office worker” of 38,000 MJ. Note that the EIA source above has a fairly narrow definition of office buildings (such that only 29 million Americans work in such places) and has other similar categories that could be construed as office environments. However, we desire an estimate of energy use pertaining to these office environments and thus use the specific office building definition to derive the per worker energy use.

### *Japan Case*

Commercial buildings also represent a significant share of energy use in Japan (13%). Total consumption in 1999 was  $191 \times 10^{10}$  MJ. The total energy consumed in Japanese office buildings is  $34 \times 10^{10}$  MJ in 1999 (EDMC 2001). Labor statistics suggest that 28.7 million workers work in office buildings, yielding a naïve “building energy use per office worker” of 11,800 MJ.

The question of actual savings in office building energy use due to telecommuting is complex to answer. Much depends on how the program is designed and managed by the firm. One point is that reducing office space does not automatically lead to significant energy savings. Around two-thirds of the area in office buildings (and energy use) is not actually office space, but rather hallways, meeting rooms, etc. In the United States, total building

area per office worker is 39 with  $13 \text{ m}^2$  office area (USEIA 2002). In Japan, the total building area per office worker is  $16.8 \text{ m}^2$ , while office space is  $5.5 \text{ m}^2$ —more than 50% less in both categories (CPEEB 2001). Taking a specific example, IBM-Japan reports a 25% reduction in desk space with their 4 day/week telecommuting program for sales staff. If “supporting area” is similarly reduced, office energy use should also fall around 25%, but if only office space is reduced, these savings are cut to 6%. The potential for space reduction is related to the number of times per week workers telecommute: once or twice per week may not lead to any change in commercial energy use at all. This is because the office layout remains the same and as nearly all the space is communal, the absence of a few workers will probably not affect energy use. Currently, analysis of the relationship between telework choice and building energy use as well as the distribution of firm adoption of telework choice is insufficient to make a detailed estimate. The issue will be treated in this estimate through constructing plausible scenarios connecting telework model and building use.

## Effects on Energy Use in Residences

Workers spending more time at home implies increased energy use in the residential buildings sector. The three main power uses to consider are for climate control, lighting, and office/IT equipment use. It is assumed that the difference between power consumption of using IT equipment at home or at the office is negligible compared to the climate control and lighting factors.

### *United States Case*

The majority of United States homes have centrally managed heating/cooling systems (as opposed to room-by-room control). Further, many of the homes occupied by workers in these job types and income ranges have programmable thermostats that reduce energy use during the workday. Thus it is not straightforward to estimate the additional heating/cooling effects of a teleworker spending the day at home. Inefficient energy management, i.e., spaces heated/cooled regardless of occupancy, implies less potential benefit from telecommuting. However one approach to estimating this value is to consider the energy efficiency benefits of programmable thermostats—about 5–15% (USDOE 1997) and assume that these thermostats would be “turned off” for the day while teleworking, thus eliminating that 5–15% benefit. Since the average site energy use per United States household is 97,000 MJ/year (USEIA 2003b), 10% would be 9,700 MJ/year in additional energy use for a 5 day/week telecommuter. Note that total primary energy use (including primary energy used to generate electricity) is 174,000 MJ/year. Separately, the USEIA (2003c) Residential Energy Consumption Survey 2001 found that average energy consumption for households where at least one person is home all day was 103,000 MJ (versus 92,000 MJ) and 121,000 MJ when a home is used for business (versus 95,000 MJ). The differences between these subsequent household types are generally in the 5–15% range noted above but could encompass many scenarios other than telework business. Thus, we exclude the primary energy needed for electricity generation and assume a conservative 9,700 MJ more per year needed as a result of 5 day/week telework. Any less telework per week is a linear function of the 5 day amount.

## Japan Case

With respect to climate control, central heating/cooling is almost unheard of in Japanese homes: temperature is generally controllable room-by-room, on demand. This means that the additional energy use for the home office can be estimated by calculating the requirements of a single room. Annual per household use of energy for climate control is 14,250 MJ (EDMC 2001). A home office probably takes one third the area of an average Japanese residence when energy of the primary workspace and ancillary space is considered. The average wattage/room for climate control can be estimated by assuming 12 hour/day usage 365 days/year, yielding an estimate of 300 W per room. For lighting, it is assumed that one home office will typically require 200 W of power. Using these figures, a 5 day/week telecommuter should expect to see residential energy consumption rise by 3,200 MJ annually. Regardless, these values are significantly less than the United States case.

## Effects on Transport Use

Transport energy saved per worker is estimated via macrostatistics on energy and time use. A telecommuting day, by definition, is set at no commuting travel for that day. We assume that a telecommuting day means that the full distance of a commute is avoided, but only for workers in a single-occupancy vehicle. The first part of this assumption is that there is zero noncommute travel induced by telecommuting. We find this counterintuitive: One would expect that a fair number of shopping and entertainment trips are normally combined with commuting: i.e., stopping by the grocery store on the way home. Empirical work, however, suggests that noncommute travel decreases with telecommuting as often as it increases (Mokhtarian 1998). This may be because some noncommute trips are eliminated because without the work commute, these destinations are too far away to be attractive. Also, multiperson use of automobiles complicates the issue. The rate of single occupancy vehicle use for daily commutes in the United States is around 80% (USCB 2003), an indication that people sometimes ride to work and school together, and unless all persons involved telecommute, travel may not be avoided. We assume that only single occupancy commutes will be avoided and apply an 80% savings factor to telecommuters in both the United States and Japan. More precise estimates of these factors is a task for future work. To sum up, commuting energy is estimated by simply allocating its share according to the relative distance commuting versus other travel, and then assuming that 80% of this energy is saved on a telecommuting day.

## United States Case

It is assumed that the energy relevant to commuting in the United States pertains to use of personal automobiles, as it is the primary mode of transport for workers in most of the country. In addition, using less public transportation on a marginal basis is unlikely to lead to any reduced scheduling of bus, rail, or other mass transit vehicles.

In the United States, the average personal vehicle (including cars and light trucks) in 2001 drove 11,800 mi/year (19,000 km) and consumed 700 gal. (2,650 L) of fuel at an average fuel economy of 17 mi/gal. (7 km/L) (USEIA 2003a). The fuel for these vehicles is predominantly gasoline. Assuming no ridesharing and an average commuting distance of 12 mi (19 km) each

**Table 3.** Annual Energy Use Per Worker/Household in Building and Transport Sectors

	United States (MJ)	Japan (MJ)
Office Bldgs (per worker)	38,000	11,800
Residential (per household)	97,000	14,250
Commuting (per worker)	42,000	14,400

way (ORNL 1995), we assume a 24 mi (38 km) average commute per day. Over 250 workdays per year, this is 6,000 mi (9,600 km) commuted, which would consume 353 gal. (1,330 L) of gasoline. At 120 MJ per gallon, this is 42,000 MJ of commuting energy consumption per year (the 80% savings is dealt with inside the model).

## Japan Case

The total energy consumed in Japan by automobiles, passenger trains and buses is estimated at  $220 \times 10^{10}$ ,  $8.2 \times 10^{10}$ , and  $6.1 \times 10^{10}$  MJ, respectively, for 1999 (EDMC 2001). National surveys of time use indicate that the population over age 10 spends on average 72 min/day on travel, of which 56% is for commuting to and from work or school (Ministry of Public Management 2001b). Statistics do not distinguish between energy use for commuting to work and school, thus an assumption is needed to estimate the share used by only work commuting. The conjecture used here is that most school travel is via low-energy bus and train modes and thus can be neglected: all energy use by cars, buses, and trains is allocated to adults from age 20 to 74. The Japanese population fitting this criterion is 91 million persons (Ibid), combining this with the previous figures yields that the energy use for personal transport (autos, trains, buses) in commuting is 14,400 MJ/person in 1999.

Residential and commercial building energy use and commuting energy per worker for the United States and Japan are summarized in Table 3. The much smaller values for Japan in all categories is notable. For residences, we believe the main reasons are significantly smaller house size in Japan and the lack of central heating systems, which means that heating and cooling is only applied as needed in particular rooms. We believe this also explains why energy use per residence in Japan is close to that per office worker, while for the United States there is a factor of 2 difference. For commercial buildings, smaller office sizes in Japan are likely the dominant factor in explaining the smaller figure. For transport, greater uses of public transportation and shorter commute distances are likely the main factors accounting for the difference.

## Scenarios for Adoption of Telecommuting and National Energy Use

The preceding discussion of labor structure and energy use by workers in commuting, office and residences are now combined with scenarios for adoption in order to estimate macrolevel status and potential for telecommuting to reduce energy use of information workers in the United States and Japan.

The three scenarios of telework adoption we consider are:

1. Current adoption (no self-employed workers): assume 2.9 million telecommuters spend 1 day/week at home in the United States (0.4% of total worker days) and 2.5 million in

**Table 4.** United States Energy Savings According to Telework Adoption Scenarios

Scenario	Telework population (millions)	Average intensity (days/week)	Transport savings (10 <sup>10</sup> MJ)	Commercial building savings (10 <sup>10</sup> MJ)	Resid. Increase (10 <sup>10</sup> MJ)	Total savings (10 <sup>10</sup> MJ)	Share of total energy
1 (with 0% office savings)	2.9	1	1.9	0.0	0.6	1.4	0.01%
1 (with 16% office savings)	2.9	1	1.9	1.8	0.6	3.1	0.03%
2 (with 60% office savings)	9.3	4	25.0	21.2	7.4	38.8	0.39%
3 (with 70% office savings)	26.3	4	70.7	70.0	21.0	119.6	1.2%

Japan also at 1 day/week. Net savings in office energy use of 0 and 16% are considered for both countries. See below for further details on assumptions.

- High end current adoption (including self-employed workers): the number of teleworkers set at 9.3 million in the United States and 4.1 million in Japan, with average 4 days/week spent at home (5.5% of total worker days in the United States). The commercial building energy saved per teleworker is considered as 60%.
- Wide adoption of occasional telecommuting: 50% of all information workers in the United States and Japan, both 4 days/week (16% of total worker days in the United States), with a 16% average reduction in office building energy use per teleworker.

To set the stage for the assumptions on office energy savings: An idealized office with perfect elasticity of energy use with respect to worker occupancy would save energy proportional to telework intensity (i.e., 2 days/week average yields 40% energy savings per teleworker). This does not occur in practice, indeed for low-intensity telecommuting it is likely that no energy, other than perhaps computer electricity use, is saved because lights, heating, etc. are operating regardless of whether a particular worker is in the office or not.

For Scenario 1, the average telework intensities for the United States and Japan are inspired from the SIPP (mixed workers) and JTA 2000 surveys, respectively. However due to potential bias in responses of these surveys, we adjust downward the telework frequencies to 1 day/week on average in the United States and Japan. To estimate office building savings, we use the SIPP survey, which shows 81% telecommuting 1–2 days/week and 19% 3–5 days/week. We assume that no office building energy savings are achieved for 1–2 days/week telecommuting and that a flexible/virtual office system is in place for those workers telecommuting 3–5 days/week. This translates to an average 16% energy savings per teleworker (19% of workers needing no office 80% of the time on average). In lieu of firmly estimating the office space savings, we bound the result with 0 and 16% cases.

Scenario 2 reflects the case where self-employed home workers are included in telecommuting population. This represents an upper bound on current energy savings as many such jobs (such as a self-employed building contractor) should not be classified as telework. The frequency of telework is much higher if self-

employed home workers are included: 9.3 million workers (mixed and home workers from the SIPP survey) in the United States and 4.1 million in Japan (all teleworkers in a JTA 2002 study) with an average intensity of 4 days/week. Note that 9.3 million is currently about 1/6 of United States information workers. The distribution is 60% 5 or more days/week and 35% 1–2 days/week (SIPP). We assume that those working at home 5 or more days per week have no space in an office building, and that there are no energy savings for the infrequent 1–2 days/week telecommuter. Thus, overall office buildings savings are 60%.

Scenario 3 reflects a hypothetical future where 50% of all possible information workers telework 4 days/week. This reflects roughly a factor of 3 increase over current levels in both countries and is a reasonable bound on the composition of the workforce that could telework. Of course 5 days/week is certainly a safer choice of upper bound. However, we do not believe that face-to-face contact can be entirely eliminated from the workplace, thus we set a 4 day/week average as a lower, though more uncertain, upper bound. Given complete elasticity as a function of occupancy, a 4 day average telework week would save 80% of office building energy. We use a slightly lower figure of 70% savings, assuming that while most telecommuters would have virtual offices, a few will not and there is also need for additional meeting spaces.

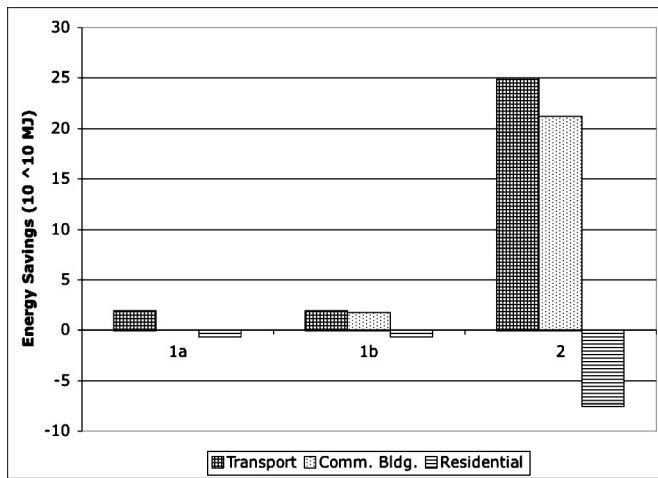
The effects of these telecommuting scenarios on macrolevel energy use are estimated by multiplying the number of workers per sector (Tables 1 and 2) by the per worker figures for transport and building uses (Table 3), adjusted according to scenario data. The results of these calculations appear in Tables 4 and 5. Fig. 1 visualizes the effects across the three sectors in the current telework Scenarios 1 (with and without office space reduction) and 2 in the United States case. Results from Japan do not differ significantly.

Current annual site energy savings estimates range from 0.01 to 0.4% for the United States and 0.03 to 0.4% for Japan. Note that in Scenario 1 with 0% office space savings, even 2/3 less transport energy savings—i.e., a 4 m commute—would have energy benefits due to the intensity of transportation energy. In the 16% case the office building savings are a factor of 3 higher than the residential increase.

Future telework energy savings are 1.2% in the United States and 1.3% in Japan. As a point of reference, even if 100% of

**Table 5.** Japan Energy Savings According to Telework Adoption Scenarios

Scenario	Telework population (millions)	Average intensity (days/week)	Transport savings (10 <sup>10</sup> MJ)	Comm. building savings (10 <sup>10</sup> MJ)	Resed. increase (10 <sup>10</sup> MJ)	Total savings (10 <sup>10</sup> MJ)	Share of total energy
1 (with 0% office savings)	2.5	1	0.6	0	0.2	0.9	0.03%
1 (with 16% office savings)	2.5	1	0.6	0.5	0.2	0.4	0.06%
2 (with 60% office savings)	4.1	4	3.8	2.9	1.0	5.6	0.36%
3 (with 70% office savings)	13.8	4	12.7	11.4	3.5	20.6	1.3%



**Fig. 1.** Display of energy effects across sectors in current scenarios (United States)

information workers teleworked 4 days/week, the net energy savings would only be about 2% in both countries. While these levels of telework may take many years to achieve, the results show that even if achieved, the energy benefits would be minimal. Kitou and Horvath (2003) focused on air emissions, which tend to be dominated by transportation impacts, but came to the conclusion that significant emissions savings could be achieved. Our focus on energy yields more modest savings.

It is notable that despite radically different energy intensities, the relative sizes of different factors are very close, which leads to the similarity in results for the two countries. For very frequent telecommuting, the potential savings in office building energy is similar in magnitude to transport reduction, thus this factor in particular deserves increased attention. Note that the energy savings in Scenario 1 remain positive even for average telework days of 1 day/week, mainly due to the extremely large amount of transport energy consumption per worker. However, it should be noted that in particular cases the energy balance can be negative. For office workers who commute via public transport, infrequent telecommuting can lead to a rise in residential energy use larger than savings in commuting energy.

### Caveats and Uncertainties

We separate the discussion of caveats into two components: one being uncertainties in those factors estimated here and the second the potential importance of issues not included in the analysis (although this distinction is sometimes difficult to make). Regarding the former: In the estimation of potential telecommuting population, we relied on categorization of types of work based on aggregate labor statistics. This is clearly a rough approximation, the error in which is difficult to characterize. For scenarios of current adoption, figures for telecommuting populations and practices were taken from surveys. As Mokhtarian and collaborators argue, there is a high degree of uncertainty in these figures (Mokhtarian et al. 2004). It is also not clear what fraction of homebased/self-employed workers ought to be counted as telecommuters. We also believe there are substantial error bars for the estimations of office building energy savings in the United States and Japan, and residential building savings in the United States. From above, it is clear that lack of pertinent data compelled us to

make estimations based on plausibility arguments. Residential energy use in Japan appears to be elastic with respect to occupancy, allowing a reasonably accurate estimate of effects of telecommuting. The prevalence of central heating systems in United States homes makes an accurate estimation much more complex. However, we want to emphasize again that an accurate estimation is not our intention here, rather to bound potential energy savings according to different levels and patterns of adoption. We believe the analysis should be robust at this level.

We next discuss those factors not considered in the analysis. With regards to the potential telecommuting population, possible changes in the structure of labor were not included. Given increasing servicization (including increased importance of e-commerce and other Internet-related work) it is likely that the fraction of the labor force doing work suitable for telecommuting will increase in the future. There are also nonlinear effects on transport systems that come into play with wider adoption of telecommuting, such as reducing congestion and idling time. While there is a large correction factor on the results for Scenario 3, this does not change the order of magnitude of savings. In Japan, however, the congestion factor becomes much more significant (see “Effects on Transport Use”).

While including the above factors would affect the estimation to a certain degree, we suspect that these corrections could be small compared to the potential of indirect effects. One issue is that of what workers do with the time they save via telecommuting. If this is primarily additional work, the potential to increase productivity, and thus stimulate economic growth and associated consumption-related energy use, is significant. Another possibility is that if energy prices rise, increased telecommuting implies higher energy bills for residences, which would encourage greater energy efficiency, an area with huge potential gains, at least in the United States. Also, potential changes in urban design and lifestyles could have an important effect. While telecommuting was considered in isolation, in actuality it is embedded in a milieu of evolving technologies and lifestyles, such as online shopping and delivery of goods and services. It could also become part of a package of internet-delivered modes of communication that allow people to travel virtually while living a more local lifestyle. On the other hand, telecommuting and e-commerce could contribute to urban spread, increasing travel distance and size of residences (Matthews et al. 2000). Both potentials exist in principle, so the question becomes that of which direction societies will adopt in practice, a question still very much unresolved.

### Discussion and Issues for Future

According to this analysis, do the potential national level savings due to telecommuting merit greater policy attention? One approach to answering this question is comparison of the macrolevel savings expected from telecommuting with other major changes in society or technology. Under extremely optimistic assumptions for the long-term future adoption of telecommuting, potential energy savings are only 1–2% of national energy use. In comparison, increasing the fuel efficiency of the United States vehicle fleet (assuming no rebound effects) by 20% would save 5.4% of national energy use. Alternatively, United States people switching to Japanese style homes would save around 15% of national energy consumption. While increased telecommuting and fuel efficiency are not mutually exclusive goals, it appears that the potential (direct) benefits of telecommuting are relatively small given

the large degree of behavioral and structural change needed to achieve large benefits.

On the other hand, in the United States at any rate, the average consumer has shown little interest in more fuel-efficient vehicles, even quite the opposite given the recent boom in SUV sales. The recent popularity of hybrid vehicles is an effect that may be worth tracking in this domain. Workers have, however, displayed the desire to avoid long commutes on congested roads. Thus from a public acceptance and thus political will perspective, telework appears more attractive in the United States policy context. In Japan, reducing congestion comes to the fore as an important factor in the telework equation. Also, we believe the more relevant policy question may be not whether telework should be promoted or not, but rather how should it be implemented assuming adoption. Recent progress in adoption of broadband Internet access can enable enhanced modes of communication such as virtual interactive offices that enable more workers to telecommute. Once interactive video-on-demand becomes widely available, it is quite possible that there will be a boom in telecommuting. In this case, appropriate policies and firm strategies should be deployed to assure that the environmental benefits of telework are actually realized. As noted above, conservation of office space is critically important and the way in which it affects several scenarios has been shown.

We want to reemphasize that this analysis is a rough estimate of direct factors; indirect effects such as productivity and/or lifestyle changes could be significant. The estimation of direct effects can clearly be improved in a variety of ways, especially regarding building energy use. We also believe that estimation of the macrolevel scale of indirect effects of telecommuting is a priority area for future research.

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