PNAS | BRIEF REPORT | ENVIRONMENTAL SCIENCES | OPEN ACCESS

# Climate mitigation potentials of teleworking are sensitive to changes in lifestyle and workplace rather than ICT usage

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Edited by Susan Hanson, Clark University, Worcester, MA; received March 24, 2023; accepted July 26, 2023

**The growth in remote and hybrid work catalyzed by the COVID-19 pandemic could have significant environmental implications. We assess the greenhouse gas emissions of this transition, considering factors including information and communication technology, commuting, noncommute travel, and office and residential energy use. We find that, in the United States, switching from working onsite to working from home can reduce up to 58% of work's carbon footprint, and the impacts of IT usage are negligible, while office energy use and noncommute travel impacts are important. Our study also suggests that achieving the environmental benefits of remote work requires proper setup of people's lifestyle, including their vehicle choice, travel behavior, and the configuration of home and work environment.**

remote work | hybrid work | information and communication technology | climate change

The COVID-19 pandemic has prompted a significant shift from in-person to remote and hybrid work, carrying complex environmental and societal implications. Previous studies investigated the environmental impact of remote and hybrid work on limited domains such as transportation and home- and office-related energy consumption (1, 2). We further examine significantly more dimensions of remote and hybrid work, uncertainties in different work modes, and changes in information and communication technology (ICT) usage.

Here, we analyze five elements of fully remote, hybrid, and fully onsite work—ICT, residential energy use, office energy use, multimode commuting, and noncommute travel. Working from home (WFH) more than 1 d per week could reduce greenhouse gas (GHG) emissions, mainly from less office energy use and commuting. However, one day of WFH has no benefits due to offsetting factors like more noncommute travel (see Fig. 2*A*), home energy use (see Fig. 2*D*), and commuting distance (see Fig. 2*G*); changes in ICT due to remote work, on the other hand, have negligible effects on GHG emissions. Our sensitivity analysis further suggests that realizing the environmental benefits of remote work requires careful configurations of lifestyle, home and office, and coordinated sustainable practices and incentives across individuals, companies, and policymakers. Our study, focused on the United States, provides a conceptual framework applicable for analyzing other countries.

## Results

**Baseline Environmental Profile.** Fig. 1 shows the variances in GHG emissions originating from five different sources, compared across remote, hybrid, and onsite workers. The per-workday carbon footprint results of six different work settings (from fully remote to fully onsite) are presented in Fig. 2. Under the assumptions detailed in *SI Appendix*, remote workers could have a 54% lower carbon footprint compared to onsite workers; hybrid workers with two to four workdays at home can reduce GHG emissions by 11 to 29%. Office energy use is the main contributor to the carbon footprint of onsite and hybrid workers, while non-commute-related travel becomes more significant as the number of remote work days increases. In contrast, the effects of remote and hybrid work on ICT usage have negligible impacts on the overall carbon footprint. This highlights that people should shift their focus from ICT usage to commute decarbonization, facility downsizing, and renewables penetration for office buildings to mitigate GHG emissions of remote and onsite work.

Occasional remote work may not provide significant climate change mitigation benefits for hybrid workers; hybrid workers who work from home just 1 d a week cut their carbon footprint by only 2% due to offsetting factors such as increased noncommute travel (Fig. 2*A*) and home energy use (Fig. 2*D*) on remote work days, along with greater commuting distance (Fig. 2*G*). As the number of remote work days increases, the GHG emissions' increase in residential energy use (Fig. 2*D*) is not significant enough to alter

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Author contributions: Y.T., L.Y., S.J., and F.Y. designed research; Y.T., L.Y., S.J., F.A., P.B., B.H., and F.Y. performed research; Y.T., F.A., P.B., and B.H. contributed new reagents/analytic tools; Y.T. analyzed data; and Y.T., L.Y., S.J., and F.Y. wrote the paper.

Competing interest statement: L.Y., S.J., F.A., P.B., and B.H. are employees of Microsoft. Y.T. was previously a Microsoft intern. L.Y., S.J., F.A., P.B., and B.H. own substantive Microsoft stocks.



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This article contains supporting information online at https://www.pnas.org/lookup/suppl/doi:10.1073/pnas.2304099120/-/DCSupplemental.

Published September 18, 2023.

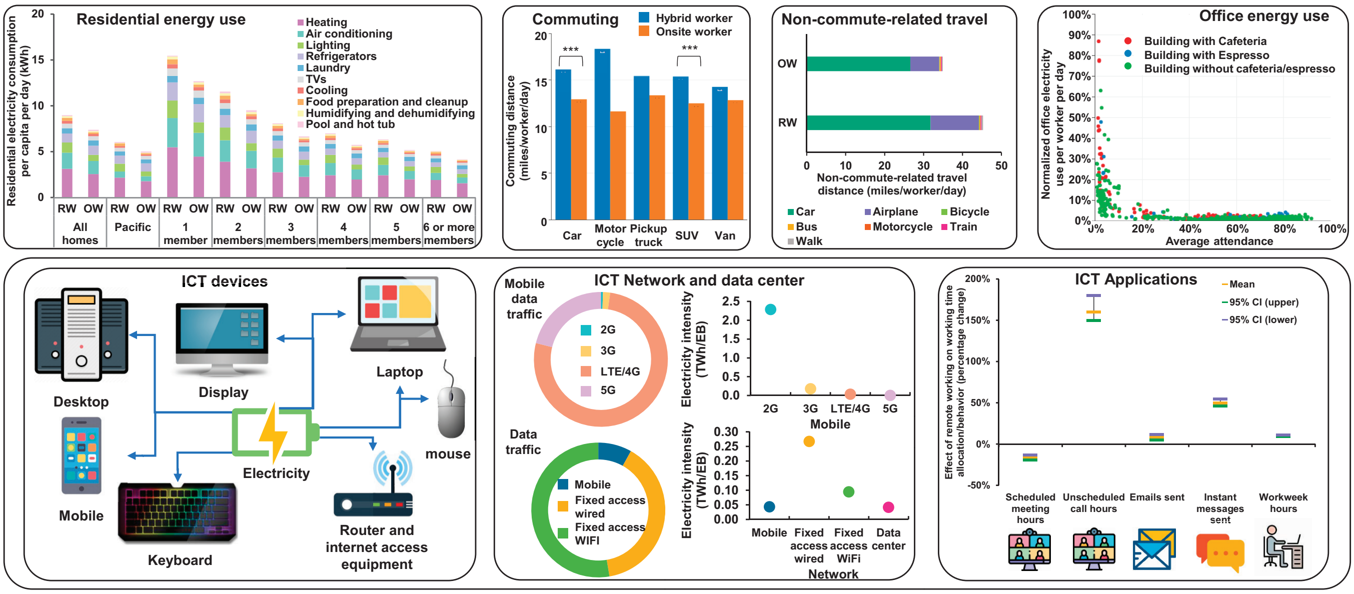


**Fig. 1.** Methodology to investigate the climate change mitigation effects of remote and hybrid work in the United States. Residential energy use, non-commute-related travel, commuting, office energy use, and ICT services are included in the system boundary. Acronyms: natural gas (NG), remote work/remote worker (RW), onsite work/onsite worker (OW).

the environmental profile of remote, hybrid, and onsite workers. In fact, decarbonizing office energy may make light remote work more carbon intensive than onsite (*SI Appendix*).

Commuting behavior varies across workers and affects their environmental portfolio. Hybrid workers tend to commute farther than onsite workers due to differences in housing choices (Fig. 2*G*). Although onsite workers tend to travel more for nonwork activities on noncommute days, the total distances driven for all types of non-commute-related activities are substantially higher for remote workers (Fig. 2 *A*–*C*). Specifically, we observe substantially more total travel miles for remote workers to drop off/pick up friends, conduct recreational activities, visit healthcare facilities, visit friends/relatives, and exercise. While the mean trip distance was 37% lower for remote workers, their average number of trips was about 1.6 times higher. It is worth mentioning that the carbon footprint of commuting for employees investigated in this study may be lower than the US national average because the company is in a large city with reasonable mass transit options.

**Uncertainty and Sensitivity Analysis.** Achieving the environmental benefits of remote and hybrid work requires proper configurations across all affected domains except ICT, as GHG emissions are highly dependent on many factors, such as the number of household members, office building configuration, the company's remote and hybrid work policies, and personal decisions about traveling during remote and hybrid work days (3). Notably, non-commute-related travel (including non-work days) accounts for 79%, 33 to 50%, and 31% of GHG emissions for remote, hybrid, and onsite workers, respectively. An onsite worker commuting by train may have a lower carbon footprint than a hybrid worker driving alone to work. Switching from traditional buses or trains to electric versions could advance climate change mitigation with the power grid decarbonization. Replacing conventional cars with electric ones may cut workers' carbon footprint by 13 to 19%, and progressively decarbonized US power grids could enable a further 38% reduction by 2050. However, the emissions' reduction from electric vehicles depends on the extent of power grid decarbonization. Reducing the building attendance from 50 to 10% can double the carbon footprint of an onsite worker since a substantial share of buildings' emissions is not sensitive to occupancy. On the contrary, seat sharing among workers under full building attendance can reduce GHG emissions by 28%, compared to the no-seat-sharing baseline. Thus, individuals, companies, and policymakers can implement coordinated sustainable practices to maximize the environmental benefits of remote and hybrid work, such as choosing public transit over driving, encouraging car sharing, assigning multiple headcounts per seat, reducing or eliminating office space for remote workers, and improving energy efficiency for office buildings.

## Discussion

Our research shows the potential of remote work to reduce carbon footprint and the actions to realize it. Implementing the actions in practice requires proper tradeoffs. WFH can help relieve congestion during peak hours in high-density commuting zones, which may improve fuel economy and mitigate climate change (4). However, business service workers' move from high- to low-density commuting zones during the COVID-19 pandemic (5) could result in higher commuting distances for hybrid workers and a greater carbon footprint due to poor accessibility to mass transit and the increased use of private vehicles. Moreover, WFH requires extra space at home (6), which can lead to extra residential energy consumption and higher GHG emissions for remote and hybrid workers. Besides, remote households own more vehicles than nonremote ones (7). If that relationship is causal, vehicle manufacturing and low vehicle occupancy can create more GHG emissions for remote and hybrid workers. The existing literature suggested that non-commute-related travel might offset commuting trips on remote work days (8, 9). In terms of the effect of remote work on workers' travel behaviors on their days off, our result suggests that climate change mitigation benefits of remote and hybrid workers remain as the resulting increase in

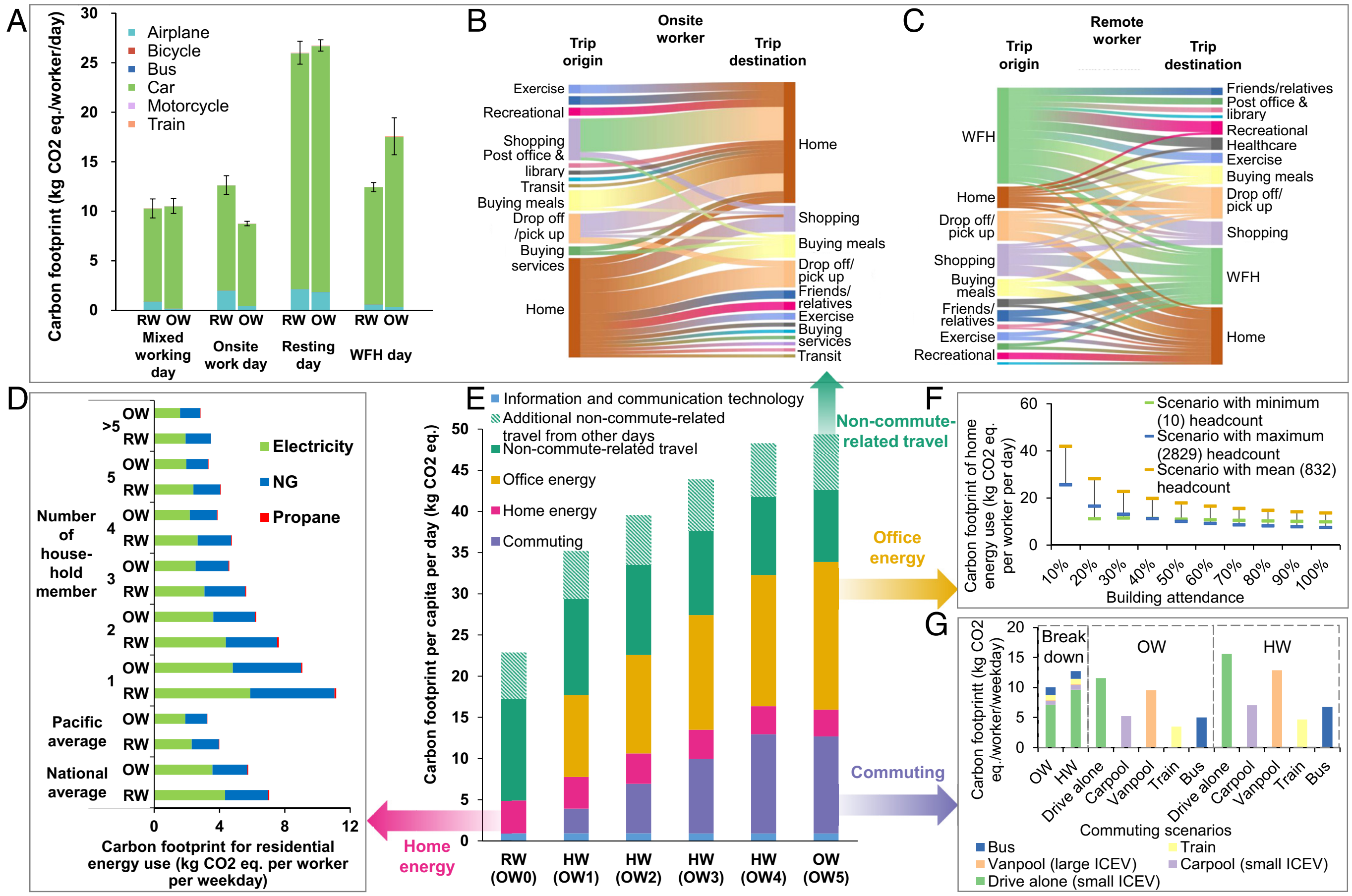


**Fig. 2.** Effect of remote and hybrid work on carbon footprint in the case of US Microsoft. (*A*–*C*) Show how transit type and trip origin and destination pairs differ by remote and onsite workers for non-commute-related travel. (*D*) Shows the variation in residential energy use. (*E*) Shows the breakdowns of carbon footprint for all six remote, hybrid, and onsite work scenarios. (*F* and *G*) Show the variation in household, workplace, and commuting GHG emissions for remote and onsite scenarios. Acronyms: remote work/remote worker (RW), onsite work/onsite worker (OW), combustion engine vehicle (ICEV).

the GHG emissions of transportation distance is similar when rest-day travel is accounted for, though a smaller increase in driving and a greater increase in flying is observed for remote workers compared to onsite workers. While remote work shows potential in reducing carbon footprint, careful consideration of commuting patterns, building energy consumption, vehicle ownership, and non-commute-related travel is essential to fully realize its environmental benefits.

## Materials and Methods

We leveraged data from Microsoft, American Time Use Survey, National Household Travel Survey, and Residential Energy Consumption Survey to measure the energy and material use of remote, hybrid, and in-person workers in the United States. Our thorough sensitivity analysis accounting for temporal and spatial variations of key variables shows the uncertainty and variability of our results. See *SI Appendix* for extended methods.

**Data, Materials, and Software Availability.** The public datasets used and extended figures and data tables for reproducibility are available at https://github.com/ylongqi/teleworking-sustainability (3). Due to employee privacy and other legal restrictions, raw confidential data from Microsoft Corporation are not available for public sharing. The underlying methodologies and emissions findings presented in this study may differ from those reflected in Microsoft's corporate disclosures and the Emissions Impact Dashboards for Azure and Microsoft 365. See *SI Appendix* for extended methods.

**ACKNOWLEDGMENTS.** This material is based upon work supported in part by the NSF under Grant No. CBET-1643244 (to F.Y.). The work was done in part when Y.T. was a research intern at Microsoft Corporation.

1. W. O'Brien, F. Yazdani Aliabadi, Does telecommuting save energy? A critical review of quantitative studies and their research methods. *Energy Build.* **225**, 110298 (2020).
2. A. Hook, V. Court, B. K. Sovacool, S. Sorrell, A systematic review of the energy and climate impacts of teleworking. *Environ. Res. Lett.* **15**, 093003 (2020).
3. Y. Tao, *et al.*, Extended Data Tables and Figures. teleworking-sustainability. Available at https://github.com/ylongqi/teleworking-sustainability. Deposited 21 July 2023.
4. R. Shabanpour, N. Golshani, M. Tayarani, J. Auld, A. Mohammadian, Analysis of telecommuting behavior and impacts on travel demand and the environment. *Transp. Res. D Transp. Environ.* **62**, 563–576 (2018).
5. L. Althoff, F. Eckert, S. Ganapati, C. Walsh, The geography of remote work. *Reg. Sci. Urban Econ.* **93**, 103770 (2022).
6. M. Boesel, S. Chen, F. E. Nothaft, Housing preferences during the pandemic: effect on home price, rent, and inflation measurement. *Business Economics*, **56**, 200–211 (2021) https://doi.org/10.1057/s11369-021-00241-4.
7. J. de Abreu e Silva, P. C. Melo, Does home-based telework reduce household total travel? A path analysis using single and two worker British households. *Journal of Transport Geography*, **73**, 148–162 (2018) https://doi.org/10.1016/j.jtrangeo.2018.10.009.
8. B. Caldarola, S. Sorrell, Do teleworkers travel less? Evidence from the English National Travel Survey. *Trans. Res. Part A Policy Pract.* **159**, 282–303 (2022).
9. E. D. V. Cerqueira, B. Motte-Baumvol, L. B. Chevallier, O. Bonin, Does working from home reduce CO2 emissions? An analysis of travel patterns as dictated by workplaces. *Transp. Res. D Transp. Environ.* **83**, 102338 (2020).