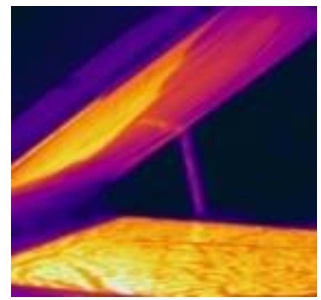
The Energy and Greenhouse Gas Emissions Impacts of Telecommuting and e-Commerce

Final Report by the Fraunhofer USA Center for Sustainable Energy Systems (CSE) to the Consumer Electronics Association (CEA)



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Acronyms Used

$CO_{2,e}$ – Carbon dioxide equivalent

CE – Consumer Electronics

CEA – Consumer Electronics Association

DOE – U.S. Department of Energy

e-Books – Electronic books

e-Newspapers – Electronic newspapers

EIA – U.S. Energy Information Administration

EPA – U.S. Environmental Protection Agency

GHG – Greenhouse Gas

HVAC – Heating, Ventilation and Air Conditioning

ICT – Information and Communication Technology

IT – Information Technology

LCA – Life Cycle Analysis

LDV – Light Duty Vehicles

MMBtu – Million British thermal units

MMT – Million Metric Tons

NDX – Newspaper Data Exchange

NHTS – National Highway Transportation Survey

VMT – Vehicle Miles Travelled

TC – Telecommuting

Tg – Teragrams (1 Tg = 1 MMT)

Executive Summary: Study Overview

- The Consumer Electronics Association (CEA) commissioned this study to investigate how consumer electronics-enabled telecommuting and e-commerce energy in the U.S. affects energy consumption and greenhouse gas (GHG) emissions.
- This study updates an earlier study (TIAX 2007) of the energy and GHG impacts of telecommuting, leveraging a much richer data set for national (U.S.) driving data, the 2009 National Highway Transportation Survey (NHTS).
- We also investigated two forms of e-commerce that have grown rapidly over the last several years: e-books and e-newspapers. In both cases, digital delivery and display "de-materialize" physical paper items.
- For all analyses, we used a life-cycle analysis (LCA) approach to evaluate the energy and GHG impacts to compare telecommuting and e-commerce to the default modalities, i.e., conventional commuting, paper books, and paper newspapers.

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We evaluated several dimensions of how telecommuting (TC) impacts energy consumption and GHG emissions.

- Data from the 2009 National Highway Transportation Survey (NHTS) indicate that almost 11 million workers telecommuted at least once per month
- Telecommuting reduces annual vehicle miles travelled (VMT) by a weighted average of almost 1,400 miles per telecommuter
- We also analyzed the impact of telecommuting on both residential and commercial building energy consumption
  - Two residential HVAC energy cases, based on default thermostat usage
  - Two commercial lighting energy consumption cases
  - Two cases for printing and paper use
  - No change in energy consumption for computers and networking infrastructure
- Our analysis considered a sensitivity case for potential reductions of commercial building floor space required due to widespread implementation of telecommuting in an organization ("ORG" case)

E-Commerce: e-Books approach

- We used two sources for book sales to estimate the number of print books displaced by the total number of electronic books in the U.S.
  - 318 and 393 million print books displaced
- For an average book weight of 320 grams, the avoided impact for each hard-copy book not printed equals 13 MJ of embodied energy and 3.2 kg $CO_{2,e}$
- The energy to download e-books is three orders of magnitude smaller than e-reader and tablet embodied energy attributed to e-books
- We also considered two modes for distributing e-books to consumers: in-store purchases and on-line/mail purchases
- We apportioned device embodied energy for reading e-books in two ways:
  - Tablets: Time to read a purchased book divided by the total device usage time over its lifetime
  - e-Readers: Unlike tablets, primarily used for reading – two cases: 50% and 100% of e-reader embodied energy divided by the average number of purchased e-books read over the e-reader's lifetime

E-Commerce: e-Newspapers approach (1 of 2)

- We used two approaches to estimate the number of paid print newspaper subscriptions displaced by paid digital newspaper subscriptions in 2013.

  1. The difference in the number of paid digital subscriptions between 2010 and 2013

  2. Difference in print subscriptions between 2010 and 2013

  - Both are based on historical data for U.S. newspaper subscriptions by format

- We applied data from surveys on how U.S. adults access news electronically to evaluate the use-phase and embodied energy for devices.

  - Two cases for the distribution of devices used to read e-newspapers:

    1) Based on residential installed base data

    2) Survey data for general news access by platform

  - Two use cases: 17 and 51 minutes spent reading an e-newspaper per day

E-Commerce: e-Newspapers approach (2 of 2)

- Based on an estimated average print newspaper weight of 301 grams, each conventional newspaper represents 12.8 MJ of embodied energy and 1.6 kg $CO_{2,e}$
- In all cases considered, the combined impact of the use phase and embodied energy of devices used to download and read e-newspapers is an order of magnitude smaller than the embodied energy of the print newspapers displaced
  - As with e-books, the energy to download e-newspapers is much smaller than the direct energy consumption and embodied energy of the device

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Telecommuting (TC) and the e-commerce activities evaluated all result in a net reduction in energy consumption and GHG emissions.

Activity	Functional Unit	Energy Savings [MJ/unit]	Equivalent Electric Energy Savings [kWh*, electricity]
Telecommuting (TC)	Telecommuting Day	90 – 148	6.5 – 10.7
e-Commerce: e-materialization	Print Book Displaced	39	2.7 – 2.9
	Daily Newspaper	12.0 – 12.5	0.87 – 0.91

*An average U.S. household consumed about 30kWh/day in 2013 (DOE/EIA 2014b).

For telecommuting, the high end of the range included commercial floor-space savings when organizations adopt TC.

Together, the approaches reduced energy consumption and GHG emissions by an amount equal to 0.11 to 0.16 and 0.15 to 0.21 percent of U.S. primary energy consumption and GHG emissions in 2013, respectively.

Activity	Description	Annual Energy Savings [PJ]	Annual CO_2 Reduction [MMT or Tg $CO_{2,e}$/year]
Telecommuting (TC)	10 million people who telecommute at least one day per month	80 – 120	5.9 – 8.0
e-Commerce: e-materialization	Books: 318 to 393 million print books displaced	11 – 15	1.4 – 1.9
	Newspapers: 5 to 6 million daily print newspapers displaced	22 – 28	2.7 – 3.5

The net energy impacts can be translated into the equivalent energy consumption of other systems.

Activity	Annual Energy Savings Equivalencies – Number of:	
	Households, Electricity Consumption	Average Power Plants, Electricity Production *
Telecommuting (TC)	508,000-733,000	1.8 – 3.0
e-Books	79,000-94,000	0.29 – 0.34
e-Newspapers	146,000-188,000	0.5 – 0.7

- Telecommuting in 2013 reduced annual:
  - Light-duty vehicle vehicle-miles travelled by an amount equivalent to the distance travelled by 1.3 million cars
  - Fuel consumption by 680 million gallons, or about 0.5% of total U.S. gasoline consumption

* Rosenfelds, i.e., generation of 3 billion kWh/year/plant; Chao (2010).

Sources: DOE/EIA (2014b), ORNL (2014).

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The Consumer Electronics Association (CEA) commissioned this study to investigate how consumer electronics-enabled telecommuting, e-newspapers, and e-books affect U.S. energy consumption and greenhouse gas (GHG) emissions

- A prior study (TIAX 2007) evaluated the national energy impact of telecommuting and e-commerce
  - Telecommuting yielded a net reduction in energy consumption equal to approximately 0.13 to 0.19 percent of U.S. national energy consumption
  - Video-on-demand realized a net reduction in energy consumption relative to renting a DVD from a store
  - The net energy impact of purchasing products on-line versus in a store was not clearly positive or negative
- The continued growth in e-commerce suggests that the national impact of e-commerce could be greater now than in 2007

Telecommuting replaces traditional commuting modes with information and communication technology (ICT)-enabled working from home.

Increases Energy Consumption	Decreases Energy Consumption

• Potential for higher non-work vehicle-miles travelled (VMT)
• Higher home occupancy
  • Thermostat setback eliminated
  • Lighting energy
• Increased home ICT energy
• Increased home lighting energy
	• Fewer vehicle-miles travelled (VMT) to and from work
	• Reduced office ICT energy
	• Reduced office lighting energy
	• If an organization adopts telecommuting at scale ("ORG" case):
	  • Less commercial building floor space required
	    • Lower building embodied energy
	    • Lower building energy consumption

Our analysis did not evaluate potential additional savings from reduced traffic congestion, nor from reduced use of the transportation infrastructure.

e-books and e-newspapers both displace the production and delivery of a physical object with electronic delivery and reading.

Electronic books (vs. physical books)	E-Newspapers (vs. printed newspapers)
• More than 2.7 million books are available on Amazon's Kindle store • Viewed using dedicated e-readers, tablet computers, etc. • Eliminates paper and book production, physical transport of books	• Paid digital newspaper subscriptions grew three-fold from 2010 to 2013 • Account for about one-third of total paid subscriptions • Viewed using dedicated e-readers, tablet computers, etc.

All three analyses used a Life Cycle Analysis (LCA) approach. LCA takes into account the energy and GHG emissions impacts of all phases of a given product or process

- The analysis of the impact of changes in automobile vehicle miles traveled (VMT) takes into account energy and GHG emissions from:
  - Fuel consumption and production, including the related infrastructure
  - Automobile production and maintenance
- The analysis e-newspapers and e-books takes into account energy and GHG emissions to:
  - Produce the materials comprising conventional books and newspapers
  - Manufacture those materials into books and newspapers
  - Purchase a conventional book or newspaper
  - Distribute a book from the publisher to a store or directly to a customer
  - Purchase, download, and read an e-book or e-newspaper
  - Produce the consumer electronics (CE) used to read an e-book or e-newspaper
  - Generate, transmit, and distribute the electricity consumed by CE

Throughout this report, we report energy consumption impacts in joules, the unit of energy used for LCA.

- One joule (J) equals the force of one Newton applied over one meter [1J = 1kg x (m^2/s^2)], or the energy to power a 1 W device for one second
- Since a joule is a relatively small amount of energy, the prefixes kilo-, mega-, giga-, etc. are used for larger quantities of energy
- A megajoule (MJ) is equivalent to the total embodied energy of 0.07kWh of delivered electricity, enough electricity to power an LCD TV in active mode for 47 minutes (Masanet et al. 2013, Urban et al.)
- Total U.S. residential primary energy consumption in 2012 equaled 21.1 EJ (DOE/EIA 2014a)

SI Prefixes		
Number	Prefix	Symbol
1×10^{3}	kilo-	K
1×10^{6}	mega-	M
1×10^{9}	giga-	G
1×10^{12}	tera-	T
1×10^{15}	peta-	P
1×10^{18}	exa-	E

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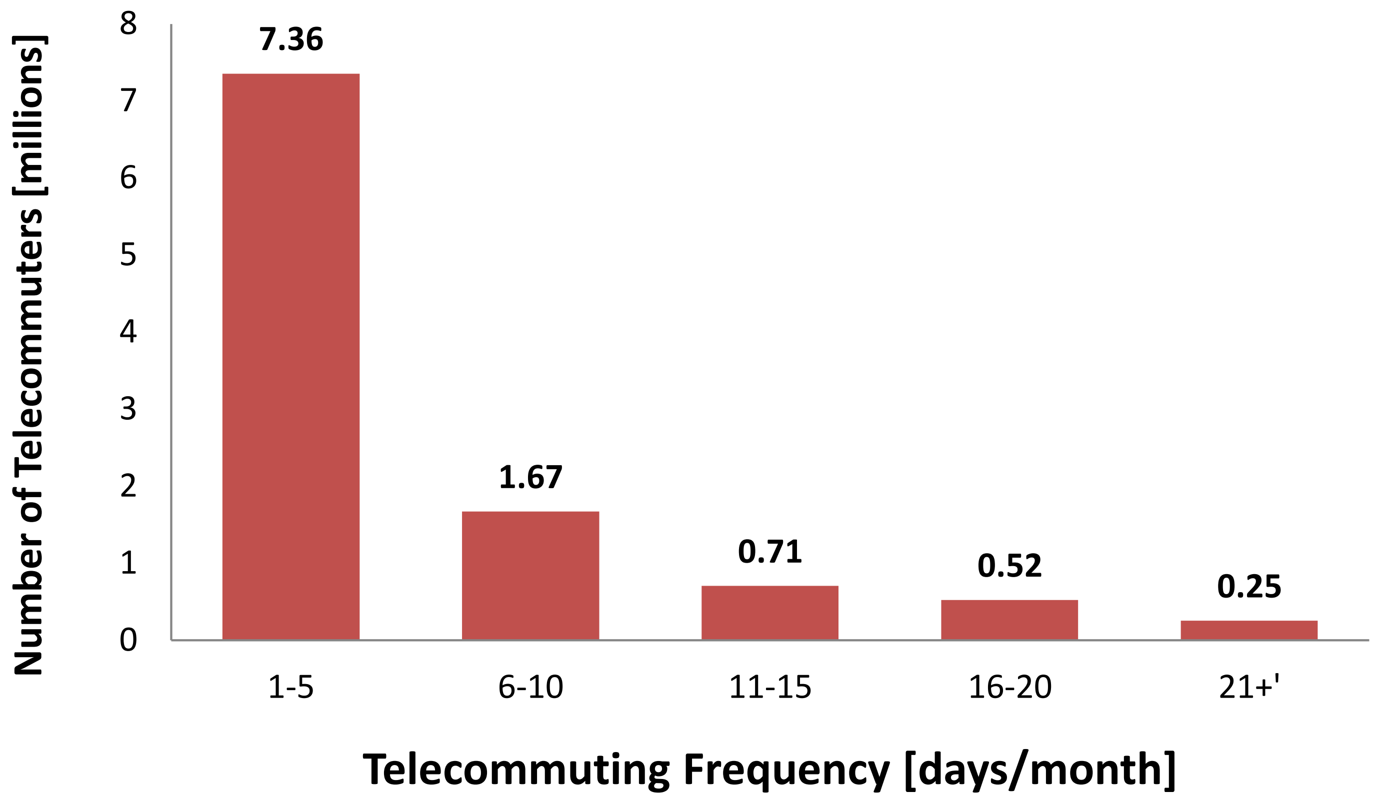
We used data from the 2009 National Highway Transportation Survey (NHTS) to evaluate the frequency of telecommuting and the impact of telecommuting on vehicle miles travelled (VMT).

- The NHTS (2009) obtains information about the travel habits of U.S. households
  - 150,147 households in 2009 survey
  - More detailed travel diary information recorded for a recent day
- Our analysis focused on working people who worked from home an average of at least one day per month (i.e., one day per week)
  - Five groups: 1-5, 6-10, 11-15,16-20, 20+ days/month
- For each, we evaluated average daily VMT for two cases:
  - Telecommuting: Work day when no work-associated trip using any mode of transport was made
  - Non-Telecommuting: Work day when at least one work-associated trip using any mode of transport was made
- Our analysis found that the travel status of telecommuters did not have a significant effect upon the travel of other household members

Based on the 2009 NHTS, we estimate that just over 10 million people telecommuted at least once per month in 2009.



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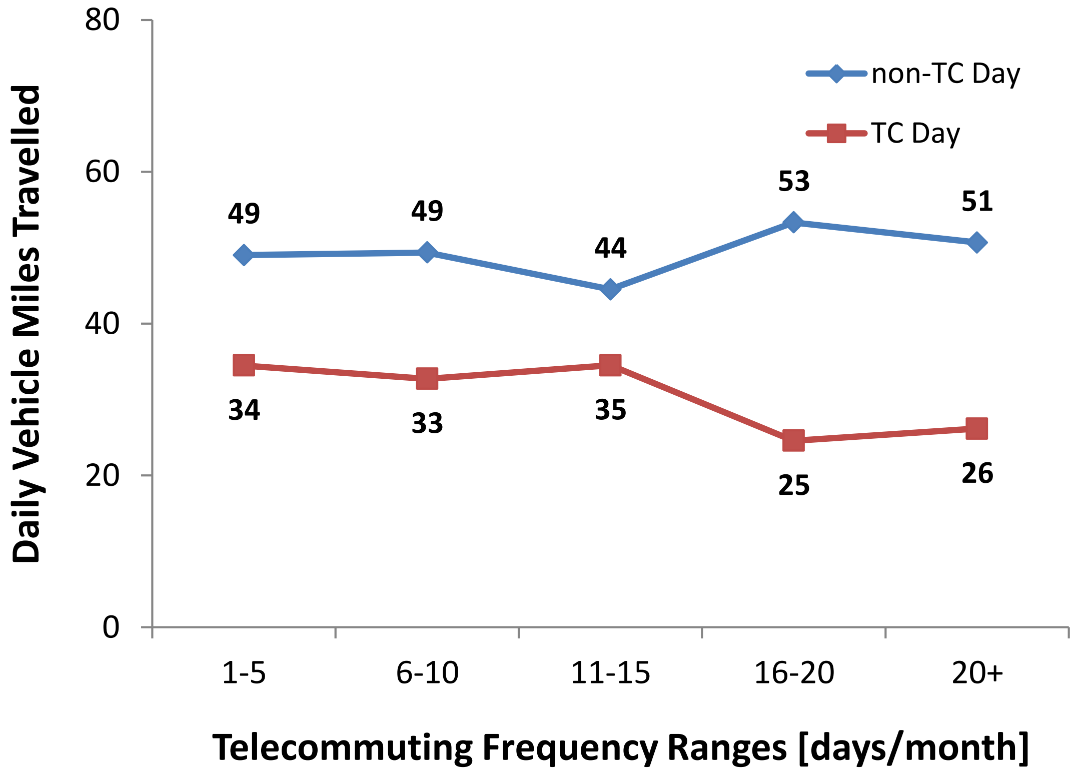
The average daily VMT is lower on telecommuting days than on non-TC days for all TC frequency ranges evaluated.



Confidence intervals for this analysis are presented in the Appendix.

The LCA model for the energy and GHG impact of changes in VMT used several common assumptions.

Variable (average)	Value	Source
LDV fleet fuel efficiency	22.3 miles per gallon	ORNL (2014)
Fuel energy density	125,000 Btu/gallon	EPA (2014d)
Fuel energy consumption per mile	5.9 MJ/mile	Calculation
Fuel embodied energy multiplier	1.3*	GREET 2014, Chester and Horvath (2009)
Fuel embodied energy / mile	7.7 MJ/mile	Calculation
Fuel CO_2 density	8.78 kg CO_2/gallon	EPA (2014b)
Fuel CO_2 emissions	0.39 kg CO_2/mile	Calculation
Fuel embodied CO_2 multiplier	1.43*	Chester and Horvath (2009)
Fuel embodied $CO_{2,e}$ emissions/mile	0.56 kg $CO_{2,e}$/mile	Calculation

*Accounts for fuel production and transport, vehicle manufacture and maintenance; our analysis excludes transportation infrastructure.

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Due to uncertainties in several model assumptions, we evaluated high and low cases for many residential and commercial energy impacts, including home HVAC.

- Home HVAC systems need to operate on TC days, while households may otherwise set up/back temperatures
- The frequency of setting up/back temperatures on non-TC days has appreciable uncertainty
  - Depends upon whether or not other people are typically home, portion of thermostats that are programmed to set up/back temperatures
  - Substantial volume of survey data, but real-world implementation less clear

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Based on the available thermostat usage data, we evaluated two cases for default daytime set back/up rates: 50% (high) and 25% (low).

- DOE/EIA (2013) Residential Energy Consumption Survey (RECS) rates:
  - 60% of households with central air and programmable thermostat claimed to adjust the thermostat during the daytime when no one was home.
  - 53% of households with programmable thermostat controlling their heating system reported using daytime setbacks
  - DOE/EIA (2009) – for households with a programmable thermostat:
    - Heating: 45% daytime setback (60% at night)
    - Cooling: 55% daytime and nighttime setup
- 51% of homes have someone home all day (EIA 2009, from Peffer et al. 2011)
- 2003 California Residential Appliance Saturation Survey: 28% of households set up temperature for AC during the day (CEC 2004)
  - Little difference in temperature set-up rates between households with programmable and nonprogrammable thermostats

The energy impact of decreased temperature set back/up is calculated using national weighted average HVAC embodied energy consumption data.

HVAC Fuel	Site Energy, 2010 [EJ; DOE 2012]	Embodied Energy Multiplier	Embodied CO_2 [kg/MMBTU]	Sources
Electricity	1.60	3.83	0.60 [kg/kWh]	Masanet et al. (2013), GREET (2014)
Natural Gas	3.69	1.17	73	GREET (2014)
Oil + LPG	0.92	1.21	92	GREET (2014)
Wood	0.43	1.00	94	U.S. EPA (2014c); assumption for embodied energy multiplier

- Average household HVAC = 105,000 MJ of embodied energy (114 million U.S. households in 2010; DOE 2012)
- Daytime setback/up reduces HVAC energy consumption by 8.2% (Energy Star 2006)
- Yields daily savings of 24 MJ
- **High case savings = 11.8 MJ/0.66 kg$CO_{2,e}$ per day** (50% setback/up on non-TC days)
- **Low case savings = 5.9 MJ/0.33 kg$CO_{2,e}$ per day** (25% setback/up on non-TC days)

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We also evaluated two cases for home and commercial lighting energy consumption, while assuming that computer and networking energy did not change.

- Commercial Lighting on TC days
  - *Low:* **No change in incremental lighting usage**
  - *High:* **0.9kWh displaced**
    - Based on: 1W/ft^2 (Navigant Consulting 2012), 100ft^2 incremental / person (TIAX 2007), 9 hours/day
- Residential Lighting – **Incremental 1.0 kWh on TC Days**
  - Two lights on 9 hours/day; 1,100 lumens output, average efficacy = 19 lumens/W (Navigant Consulting 2012)
- Residential and Commercial Computers Network Energy: **No change**
  - Single portable PC used by telecommuter, similar data rates at home and work
  - Network energy consumption varies little with data rates, most home network devices remain on 24 hours/day (Urban et al. 2014)

We created two bounding cases for printing and paper impacts.

- Printing on TC days – Based on 10,000 images/worker/year, does not vary with day
  - *Residential:* Inkjet multi-function device in ready vs. sleep mode for 9 hours
    - **0.03 kWh/day** (Urban et al. 2011)
  - *Commercial*: Assumed 50% duplexing rate at work, 0% at home
    - Reduces daily paper consumption by ~10.8 sheets/day relative to home
      - Based on 20# office paper, embodied energy and $CO_{2,e}$ from EPA (2014)
      - **Energy = 0.19 MJ/sheet** (42.6 MJ/kg); **GHG = 0.04 kg $CO_{2,e}$/sheet** (8.78 kg $CO_{2,e}$ / kg paper)
    - *Low*: **No appreciable reduction** in printing and copying energy consumption
    - *High*: Eliminates all per-person-day copier and printer energy consumption
      - 6.0 TWh printer + copier energy consumption in offices (TIAX 2010)
      - 12,360 million ft^2 office space in 2008
      - Average office space/person = 280 ft^2 (Miller 2012)
      - **Savings per TC day = 0.6 kWh/person**

We estimate that the net energy impact of ICT + lighting is appreciably smaller than the VMT impact.

Impact	Low – MJ/TC day	High – MJ/TC day
Net Computer + Networking	0	0
Residential Lighting	14.4	14.4
Commercial Lighting	0	(12.4)
Residential Imaging + net Paper	2.6	2.6
Commercial Imaging + net Paper	0	(8.2)
Total	17	(4)

Negative = energy savings.

Telecommuting has the potential to reduce commercial building floor space if an organization embraces telecommuting. We evaluated this as a sensitivity case.

Base Case

- Organization does not change its use of space based on telecommuting
  - No impact upon the amount of commercial building floor space required

Organization ("ORG") Case

- Telecommuting is widespread in the organization and reduces its space utilization, e.g., using hoteling for employees who frequently telecommute
- We assume that floor space is reduced for frequent telecommuters (3+ TC days/week)
  - Incremental floor space per employee = 100 ft^2 (calculated in TIAX 2007)
  - Floor space reduction is proportional to TC frequency, e.g., an employee who telecommutes 4 days per week reduces floor space required by 80 ft^2
- Both commercial building embodied energy and energy consumption are reduced

In the “ORG” case, telecommuting reduces both commercial building embodied energy and direct energy consumption.

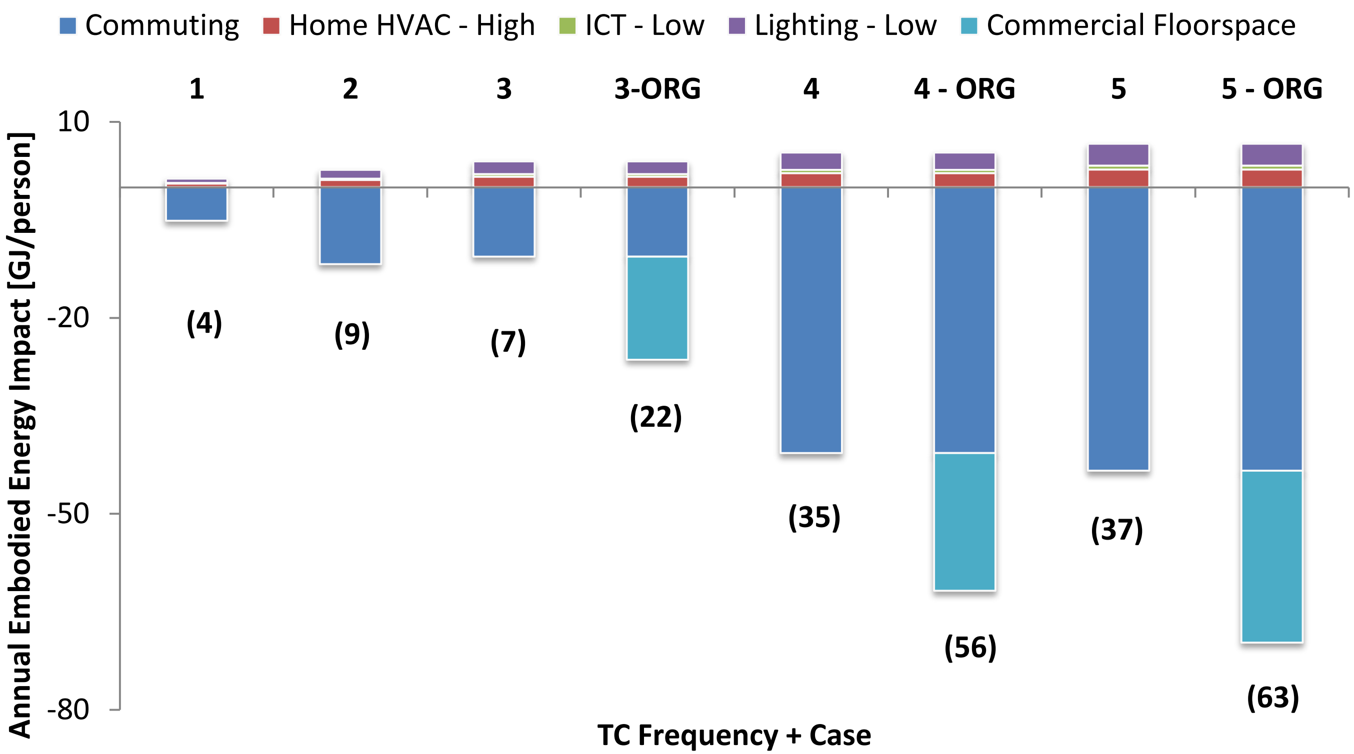
Building Embodied Energy

- Assumed that the value has not changed appreciable since circa 2007
- Use estimates from TIAX (2007), i.e., **23 MJ/ft^2/year**
  - Represents average over 50-year building life

Direct Building Energy Consumption

- Assumed office building is the workplace of typical telecommuter
- Calculate bottom-up embodied energy value based on 2003 CBECS values (DOE/EIA), excluding office equipment and computers = **230 MJ/ft^2/year**
  - **10.4 kg $CO_{2,e}$/ft^2/year** (based on $CO_{2,e}$ values tabulated on p. 26)

Telecommuting reduces annual energy consumption in all cases, and is dominated by reduction in VMT (low case annual values shown). The ORG case increases savings appreciably.



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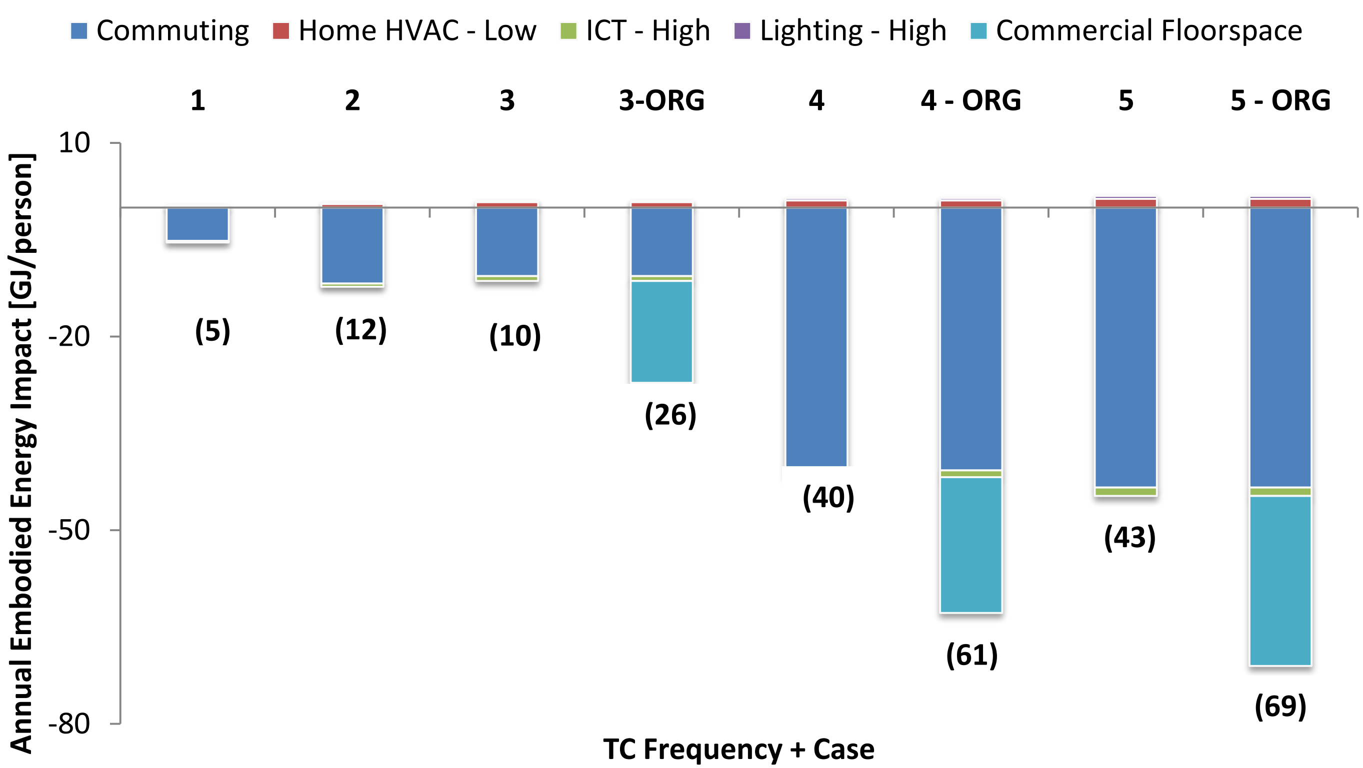
Telecommuting reduces annual energy consumption in all cases, and is dominated by reduction in VMT (high case annual values shown). The ORG case increases savings appreciably.



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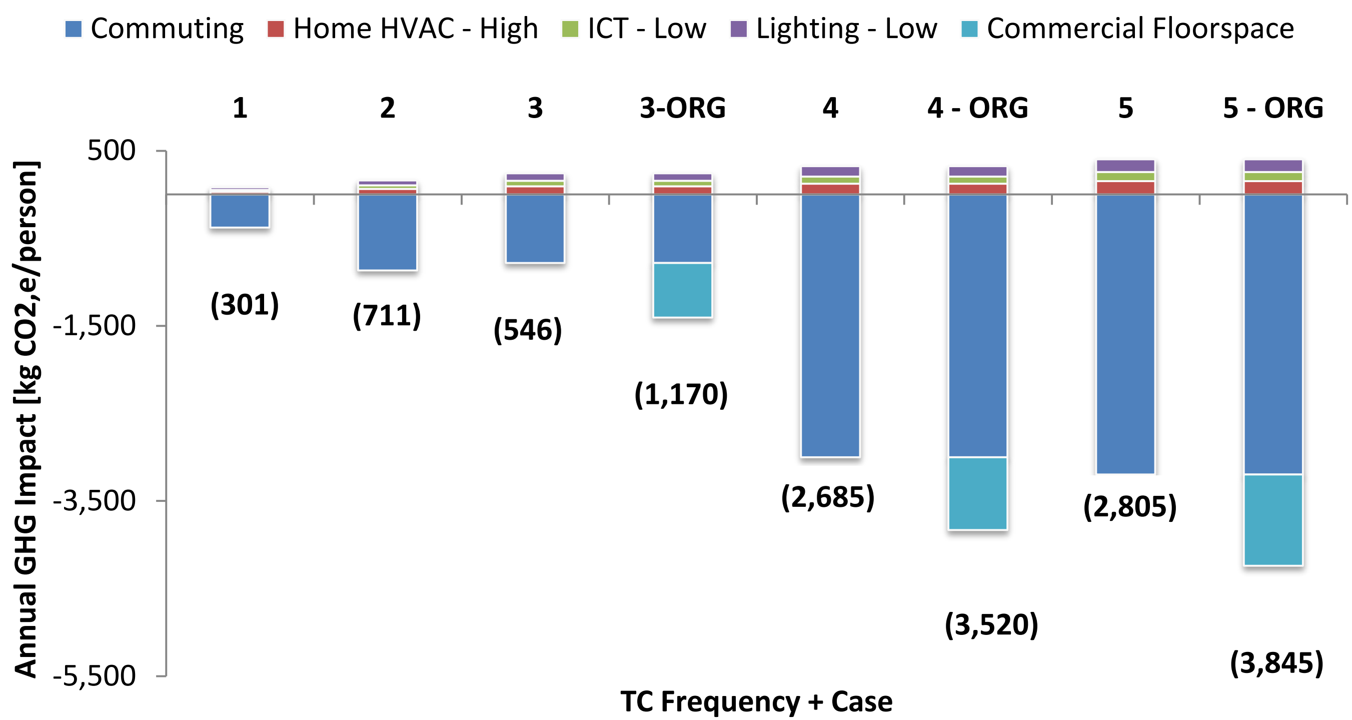
Similarly, telecommuting reduces annual greenhouse gas emissions, with VMT reductions accounting for most of the savings (low case shown).



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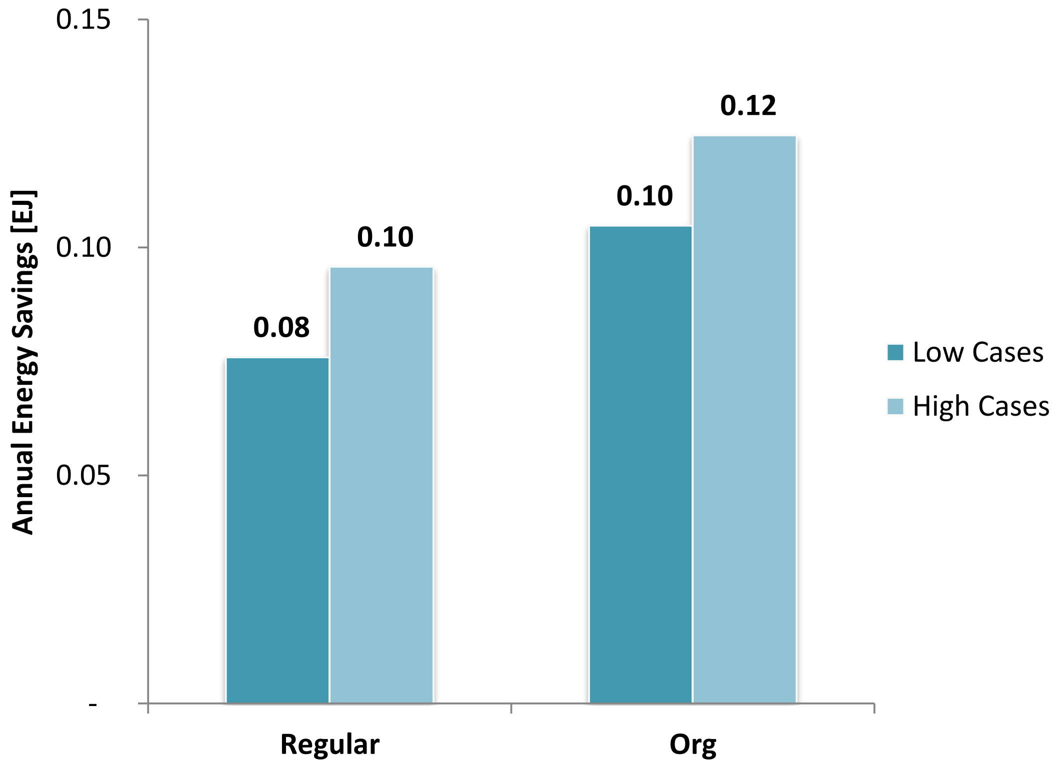
In total, telecommuting reduces annual energy consumption by 0.08 to 0.12 EJ. This equals 0.07% to 0.12% of U.S. primary energy consumption in 2013.



Source: DOE/EIA (2014a).

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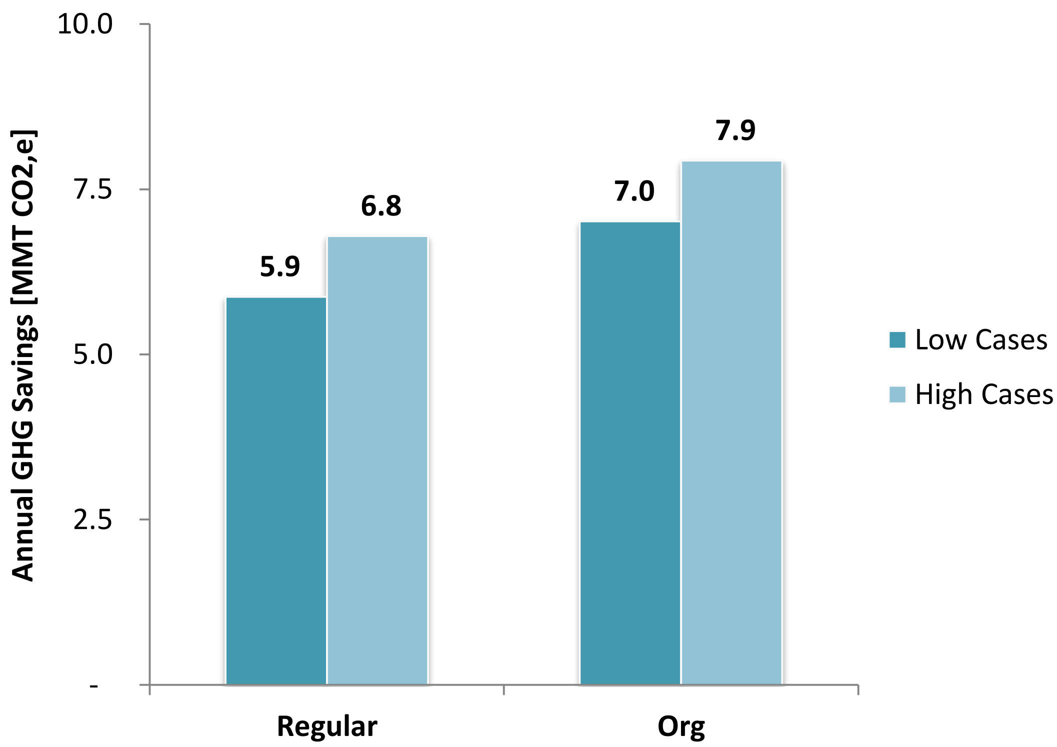
Telecommuting reduces annual GHG emissions by approximately 5.9 to 8.0 MMT per year, or between 0.09 and 0.12 percent of U.S. GHG emissions in 2012.



Sources: Current study, U.S. EPA (2014b).

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Electronic books (e-books) impact energy consumption in several ways.

Increases Energy Consumption	Decreases Energy Consumption
• e-Reader and tablet embodied energy to choose, download, and read e-books • Direct electricity consumption of • e-reader/tablet to choose, download, and read an e-book • Network energy consumption to download e-book	• Physical print books not printed and distributed • Physical books not distributed, i.e., not picked up from bookstores and not shipped from warehouses to homes

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We estimated the number of displaced print books by calculating the decrease in print-book sales since the introduction of e-books.

- The Challenge: How to estimate the number of physical books that *would have* been purchased if e-books did not exist
- Our analysis focuses on total books sold (i.e. print and electronic books)
- Base Case:
  - Compare print book sales in prior years to current print book sales
  - Assumes that the maximum difference in print books sold equals the number of print books displaced
- Potential Upper Bound Case: Assume that all e-books sold displaced print books
  - Not evaluated – Electronic book pricing is lower than paper books
  - Li (2013) estimates that about two-thirds of e-book sales displace print books, and the remainder are new sales

Our analysis of the number of print books displaced by e-books leverages a range of industry data.

Variable	2013 Value [millions]	Source
U.S. Adult Population (16+)	242	U.S. Census Bureau (2014)
Total U.S. e-book unit sales	513	BISG BookStats (2014)
Total U.S. print book unit sales	620	Nielsen BookScan (2014)
Adults buying 1+ books	107	44% (Simba 2013); 2012 value, assumed same for 2013
Adults owning tablet or e-reader	104	43% (Urban et al. 2014, Pew 2014)
Number of tablet/e-reader owners who also bought print books	65	63% of tablet/e-reader owners (Simba 2013)
Number of tablet/e-reader owners who bought only e-books	12.5	12% of tablet/e-reader owners (Simba 2013)
Total adults *not* owning a tablet/e-reader who bought print books	41	Calculation.

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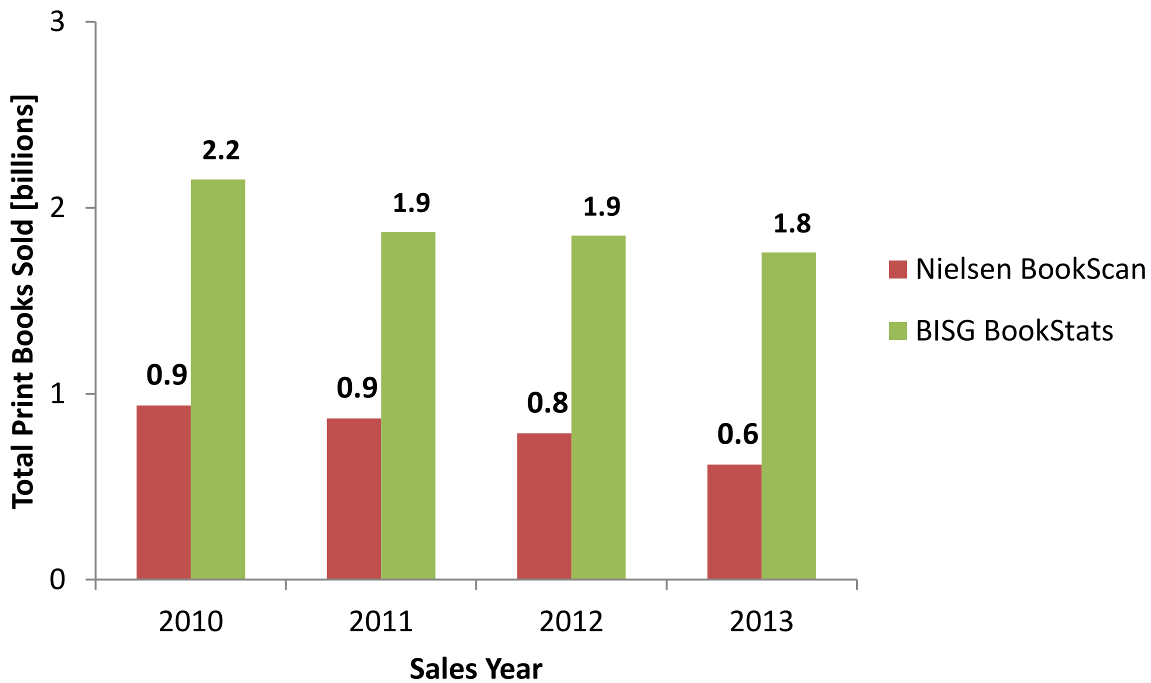
An average of 318 to 393 million print books were displaced in the U.S. between 2010 to 2013, excluding the total number of books returned without being sold.



This range agrees with one estimate (Li 2013) that 2/3 of e-book sales cannibalize print books, i.e., 513 million x 2/3 = 341 million.

The energy consumed to purchase and download an e-book is well under one MJ for all device cases considered.

- Purchasing energy equals the product of active-mode power draw and time to purchase
  - Estimated time to purchase an e-book = 20 minutes (Mathews et al. 2002)
  - U.S. Embodied energy factor for electricity = 13.8 MJ/kWh (Masanet et al. 2013)
  - Includes time to find and decide to purchase book, likely high for many cases
- We assume that an average e-book size equals 1,372 kB circa 2013 (Kozak 2003)

Device	Power Draw [W]	Embodied Energy [MJ]	Source
Portable Computer	29	0.13	Urban et al. (2014)
Desktop Computer + Monitor	95	0.44	Urban et al. (2014)
Tablet	**5**	**0.02**	Masanet et al. (2013)
e-Reader	**1.4**	**0.01**	Urban et al. (2014)
Network – wired or Wi-Fi delivery	*100µJ /bit*	*0.01*	Masanet et al. (2013), Kozak (2003)

We used EPA estimates for the average avoided embodied energy and GHG to not produce book in 2013.

Factor	Per kg of Textbook	Reference
Embodied Energy	41.3 MJ	U.S. EPA (2014a)
GHG Emissions	10.0 kg $CO_{2,e}$	U.S. EPA (2014b)

- We estimated the average weight of textbooks based on limited data
  - Standard paperback = 300g (Thomas 2012)
  - Average book shipped = 340g (Independent Online Booksellers Association 2002)
  - Note: Much lower than 1.1kg (Matthews et al. 2002)
- Based on an average book weight of 320 grams, **each book not produced (i.e. displaced) saves 13 MJ of embodied energy and 3.2 kg $CO_{2,e}$ of GHG emissions**

We also evaluated the energy consumption in the distribution of print books via both traditional and e-commerce modes.

- We evaluated the total embodied energy (incl. supply chain impacts) for book retailing in the U.S. based on the approach of Matthews et al (2002)
- For books sold in bookstores, the energy impact is very sensitive to transportation mode to-and-from the books store by people purchasing books and estimates for the *incremental* distance traveled to-and-from the bookstore
  - We updated the fuel efficiency of LDVs to reflect current values, i.e., 22.3 mpg (ORNL 2014)
- For books sold via e-commerce, final book delivery to the home has the greatest energy impact
- We assume that the volume of books distributed is proportional to book weight
  - Matthews et al. (2002) values for logistics energy impacts are adjusted for the average book weight (i.e. 320 grams) used in our study
    - That analysis assumed much heavier (~1kg) textbooks as a typical book
- We assume that the purchased books have a 35% return rate (Matthews et. al 2002)

For the average book weight evaluated, the Matthews et al. model finds that the avoided embodied energy in the distribution phase is 40 to 250 percent greater than that to produce the book.

	Traditional Bookstore [MJ per book sold]		e-Commerce [MJ per book sold]	
Shipping to Store/Home	35% Returns	No Returns	Shipped via Air	Shipped via Ground
Trucking	7.0	4.7	1.5	3.5
Air	N/A	N/A	5.5	N/A
Courier Delivery	N/A	N/A	14	14
Passenger Trips	39	39	N/A	N/A
Total	**46**	**43**	**21**	**18**

- Based on data for the sales channels for books (Greenfield 2013) and e-book and print book sales numbers (BookStats 2014), we estimate that 42% of print books were sold in stores and 58% were shipped directly to consumers.
- Applying these shipment weights and the embodied energy estimates shown above yields an **average distribution phase embodied energy of 29.4MJ per print book**.

The use-phase energy for reading e-books was higher on tablet devices than e-readers in 2013.

- We found few estimates for the average time spent reading a typical book
  - The median number of words for an average book equals 64,000 words (Habash 2012)
  - An average adult reads ~300 words per minute (Nelson 2012)
    - Yields **4 hours to read a book**; an informal on-line poll found an average of around 6 hours to read a 300-page book (GoodReads 2014)
- We estimated the time-of-use energy for both e-readers and tablets for reading electronic books in 2013
  - The time-of-use energy equals the product of the active-mode energy consumed (in kWh) and the U.S. embodied energy factor for electricity

	Per e-book [in kWh]	Per e-book [in MJ]
E-readers	0.006	**0.08**
Tablets	0.020	**0.28**

Subsequently, we evaluated the embodied energy of tablets and e-readers to access and read e-books.

Device/Category	Device Embodied Energy	References
E-reader	203 MJ*	Kozak (2003)
E-reader	289 MJ*	Matthews et al. (2002)
Tablet	1,713 MJ	Masanet et al. (2013)

- Although people do read e-books on computers and cell phones (Zickuhr and Rainie 2014), we assume that most e-book reading occurs on tablets and e-readers
  - We assume this time is split evenly among 78 million tablets and e-readers
- We attribute embodied energy based on the portion of time spent reading e-books
  - e-Reader: Base case = 50%, High case = 100%
    - Includes both time for purchased and non-purchased books

*Estimates for retail distribution of an e-reader are two orders of magnitude smaller than its embodied energy (Kozak 2003, Matthews et al. 2002)

The analysis of tablet embodied energy is based on the portion of total operating time spent reading e-books.

- The number of e-books read by tablet owners may vary between those that purchase print books and e-books, as well as those that exclusively purchase e-books
- For the population of e-reader and tablet owners, we assume the same ratio of owners who purchase print and e-books to those who exclusively purchase e-books, i.e., about 5.2 to 1 (see table, p. 40)
- We evaluated two cases: 1) Owners who purchase print and e-books purchase the same number of total books as those who purchase only e-books, and 2) Both device and non-device owners purchase the same number of print books, excluding owners that purchase only e-books (see table on p. 40)

Case	Book Type	Purchase print + e-books [books/year]	Purchase e-book only [books/year]
1	Print	3.5	0
	e-Book	6.0	9.5
2	Print	5.8	0
	e-Book	5.7	11.5

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Each e-book read on a tablet accounts for 2.5 to 3.0 MJ of tablet embodied energy.

- We allocate tablet embodied energy for the two cases based on estimated time spent reading e-books in a year, amortized over the average tablet lifetime
  - Average table usage equals 540 hours per year (Masanet et al. 2013)
  - Average time to read a book = 4 hours
  - Tablet lifetime = 5.1 years (CEA 2014)
    - This value may change in the future, as tablets become a more mature product (i.e., tablets became a major product category circa 2010)

Case	e-book portion of Usage		Embodied Energy [MJ/year]	
	Print + e-book	e-book only	Print + e-book	e-book only
1	4%	7%	15	24
2	4%	8%	14	29

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The embodied energy of e-reader and tablet devices attributed reading e-books in 2013 totaled between 1.6 and 2.5 PJ.

- Our model assumes an average embodied energy of 246 MJ for e-readers (Kozak 2003, Moberg 2007)
- We also evaluated two cases for the annual embodied energy of e-readers based on the portion of time spent reading e-books: Base case = 50%, High case = 100%
- The total device embodied energy equals the sum of the embodied energy for both e-readers and tablet devices used in reading e-books

Annual Embodied Energy [PJ]		E-reader	Tablet	Total
	Number of devices	38.9 million	38.9 million	77.9 million
	Base Case	0.94	0.64	1.6
	High Case	1.9	0.64	2.5

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Nationally, our models find that e-books result in a net reduction in energy consumption equal to 12 to 14 PJ in 2013.

Energy Impact	Case	PJ / year
Print books displaced	Low: 318 million	(4.2)
	High: 393 million	(5.2)
Device operational and embodied energy	Low	1.7
	High	2.6
Distribution phase energy	Low	(9.3)
	High	(11.5)
TOTAL	**Low**	**(11)**
	High	**(15)**

(Negative) = energy savings.

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We used data from tablet and e-reader LCA studies to evaluate their embodied GHG emissions.

- We used GHG emission data for Apple tablets in the 2013 installed base to estimate average device GHG emission factor for tablets (Apple 2012-2014)
  - Calculated based on a straight average of tablet models
  - Yields tablet embodied GHG of 121 kg $CO_{2,e}$ over a lifetime of 5.1 years (24 kg $CO_{2,e}$/year)
- Very few estimates for the embodied GHG of e-readers are available
  - Kozak (2003) yields 23.7 kg $CO_{2,e}$/year for an e-reader over 5-year lifetime
    - Likely high for current e-readers (i.e., similar to current tablet value, but e-reader has much less functionality)
- We also estimated the net GHG emissions associated with the time-of-use energy of tablet and e-reader devices used in reading e-books in 2013
  - Equals the product of device time-of-use energy (in kWh) and the U.S. average electricity emission factor of 0.6 kg CO_2/kWh (U.S. EPA 2014c)

We evaluated four cases for the net GHG impact associated with reading e-books on CE devices.

- Our model considered two scenarios of displaced print books and the impact from both device energy use (in kWh) and device embodied energy (in MJ)
- Scenario 1: Assuming a total of **318 million print books were displaced** in 2013,
  - **Case 1**
    - Case #1 for device time-of-use impact (i.e., use time of 17 min./device)
    - Case #1 for device platform use impact (i.e., weighted frequency of devices owned based on residential installed base)
  - **Case 2**
    - Case #2 for device time-of-use impact (use time = 51 min./device)
    - Case #2 for device platform use impact (i.e. weighted frequency of devices preferred in accessing news websites)
- The same assumptions were made for the cases in Scenario 2, i.e., **Cases 3 & 4**, while assuming that a total of **393 million print books were displaced** in 2013

We also evaluated the net GHG impact of distributing printed books in 2013.

- As shown earlier (see p. 42), the energy consumed to download e-books is much smaller than that to distribute print books
- We calculate the GHG of the distribution phase based on the ratio of LDV average GHG emissions to fuel embodied energy per VMT travelled
  - Assumes that LDV and delivery trucks* have similar embodied-to-fuel energy and GHG ratios
    - Matthews et al. (2002) generally supports this assumption for energy; GREET (2014) supports GHG assumption for fuel cycle (vehicle embodied energy not known)
  - Based on LDV values in the Telecommuting section, this ratio equals 0.073 kg $CO_{2,e}/MJ_{embodied}$
  - For the average of 29 MJ/book of embodied energy for print book distribution, **the net distribution GHG emissions equals 2.1 kg $CO_{2,e}$ per book**

*Air travel accounts for a smaller portion of distribution energy.

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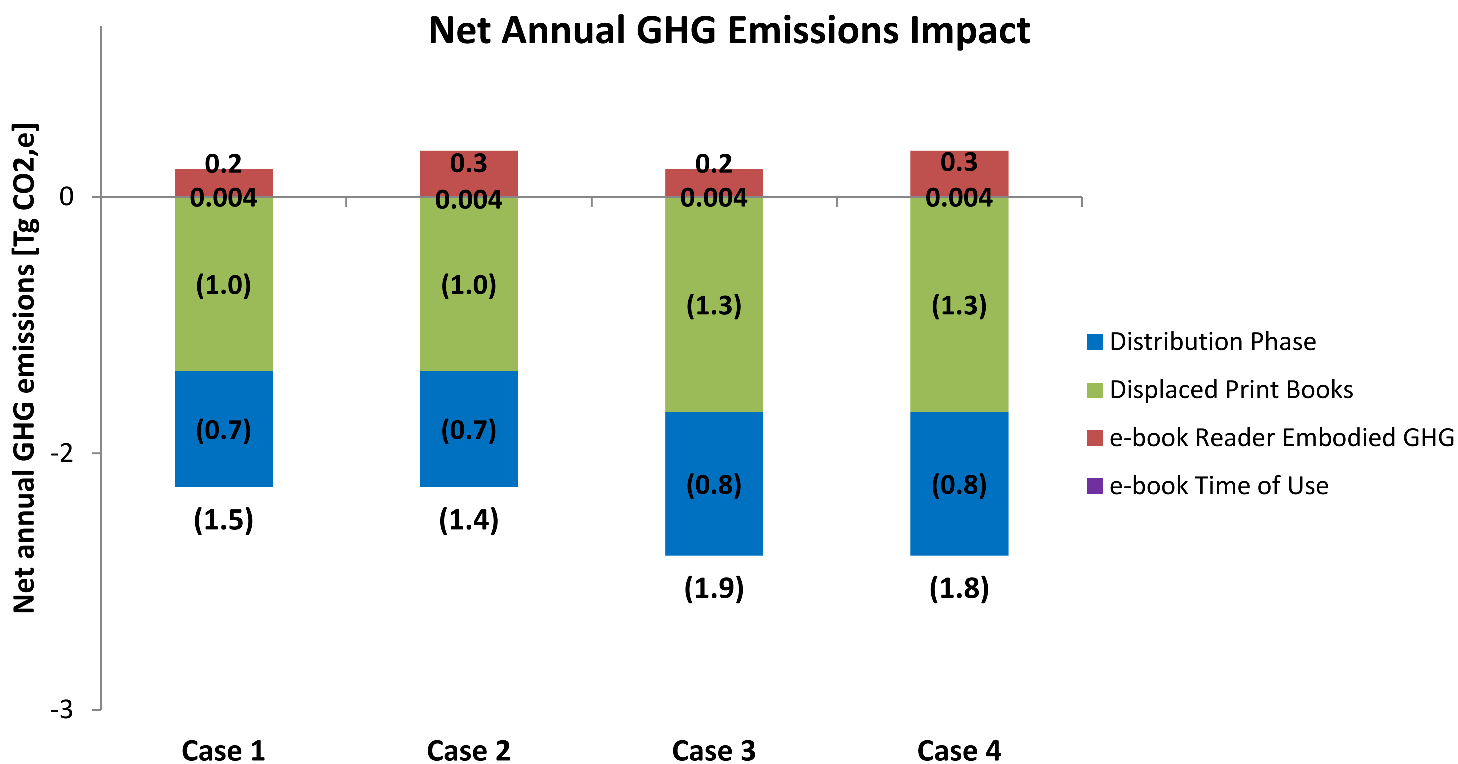
Digital books reduced annual GHG emissions by 1.4 to 1.9 Tg $CO_{2,e}$ per year, or between 0.02 and 0.03 percent of U.S. GHG emissions in 2012.



Negative = emissions avoided

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- Executive Summary
- Study Objectives and Scope
- Telecommuting
- E-commerce: E-books
- **E-Commerce: E-Newspaper**
- References
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We evaluated several different energy and GHG impacts associated with electronic newspapers for the year 2013.

- Embodied energy and GHG emissions for displaced printed newspapers
- Energy consumed by the IT infrastructure to download newspapers (servers, network energy, etc.)
- Energy consumed to access and read e-newspapers on devices (i.e. time-of-use energy)
- Embodied energy and GHG emissions associated with the production of devices used to access and read e-newspapers

The LCA takes into account national data about the devices used to access news electronically in the U.S.

Variable	2013 Value	Source
U.S. Adult Population (16+)	242 million	U.S. Census Bureau (2014)
Adults owning tablet device	85 million	35% as of Sept. 2013 (Pew 2014)
Number of tablet owners who get news weekly	48 million	64% of tablet owners (Pew 2013)
Number of tablet owners who get news daily	28 million	37% of tablet owners (Pew 2013)
Percent of mobile news consumers that paid for digital news subscription (both bundled and digital-only)	19%	Pew (2012a); assumed to be the same in 2013

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The estimated number of U.S. print newspaper subscriptions displaced by e-newspapers is based upon changes in the number of digital and print subscriptions.

- The Challenge: Need to estimate the number of physical newspapers that *would have been* purchased if e-newspapers did not exist
- We considered two cases for determining the total displaced print newspapers

  Case 1$_{\textbf{print}}$: Difference in paid **digital** subscriptions between 2010 and 2013

  Case 2$_{\textbf{print}}$: Difference in paid **print** subscriptions between 2010 and 2013
- We did not take into account additional e-newspapers provided for free to paid subscribers of daily printed U.S. newspapers

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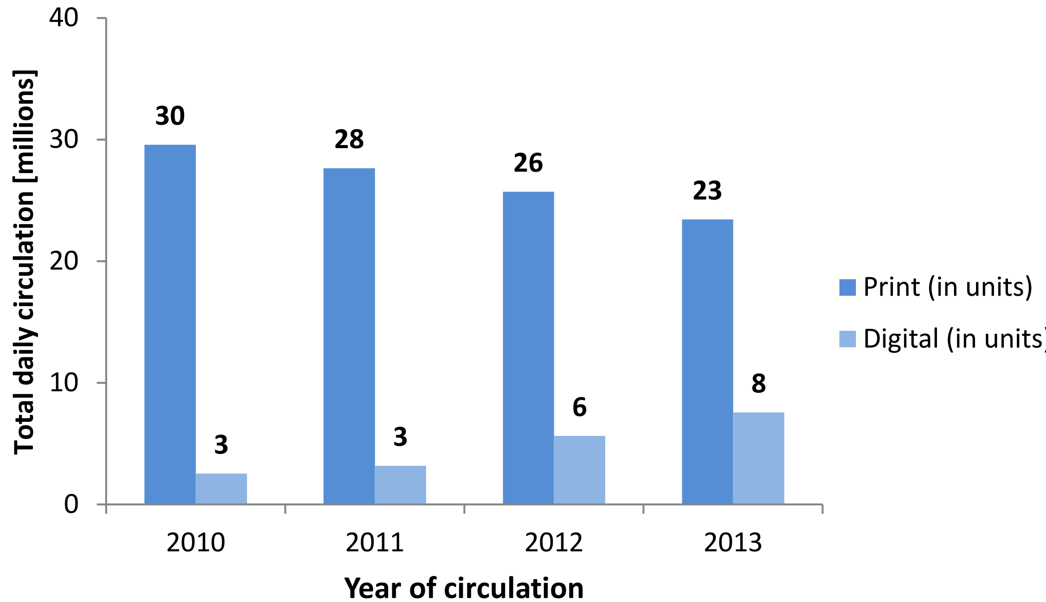
An average of around 5 to 6 million U.S. daily print newspaper subscriptions have been displaced by digital subscriptions.



- Newspaper Data Exchange (2014) reports news circulation trends for over 100 million U.S. households
- Data are for subscriptions to the top 100 U.S. dailies, representing about two thirds of total circulation

We used EPA sources to estimate the avoided embodied energy and GHG emissions of an average printed newspaper.

Attribute	per kg of newspaper	Reference
Embodied energy$_{Newspapers}$	42.4 MJ	U.S. EPA (2014a)
GHG Emission factor$_{Newspaper}$	5.26 kg $CO_{2,e}$	U.S. EPA (2014b)

- We measured and calculated the average weight of the daily print versions of the *Wall Street Journal* and the *Boston Globe* in November and December in 2014
- Based on an average print newspaper weight of 301 grams, **each print newspaper not produced (i.e. displaced) saves about 12.8 MJ of embodied energy**
- The **avoided GHG emissions for each newspaper equals 1.6 kg $CO_{2,e}$**
- The net annual environmental impact equals the product of each attribute and the total number of displaced print newspapers in a year

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We developed two time-of-use cases and device population distribution cases to evaluate embodied and use-phase energies.

Time-of-use

- A Pew Research survey (2012a) estimated the average daily time spent reading news on internet-enabled devices including tablets, desktops and laptops
  - 51 minutes for people who used a single CE device to read digital news content
  - 76 minutes for dual-device news subscribers
- We analyzed four groups of subscriber device owners : 1) Desktop only, 2) Laptop only, 3) Tablet only, and 4) Tablet and Desktop/Laptop
- For each group, we evaluated two use cases
  - **Case 1_u**: Newspapers account for one-third of the total time spent reading news, i.e., 17 or 25 minutes/day (similar assumption as Moberg 2010)
  - **Case 2_u**: Newspapers account for 100% of on-line time reading newspapers, i.e., 51 or 76 minutes/day

We also evaluated two cases for the distribution of electronic devices used to read e-newspapers in 2013.

Device population distribution

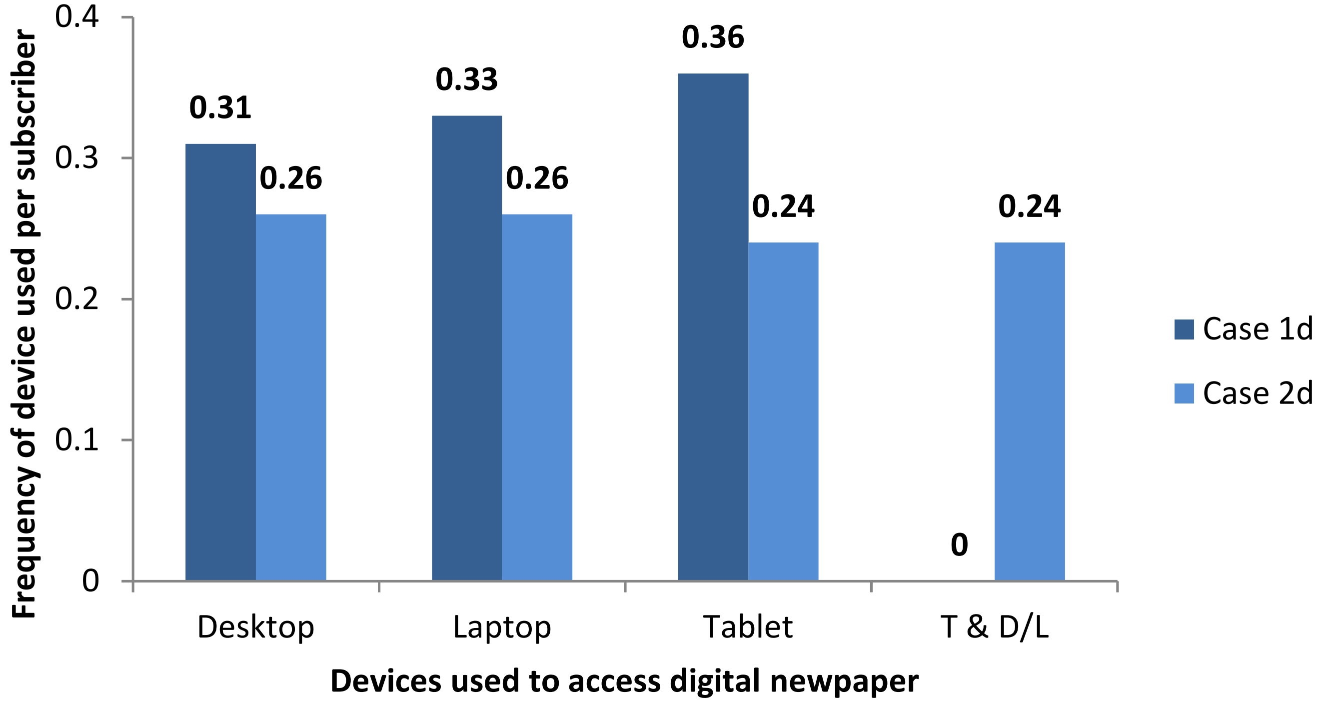
Case 1_d: Based on data for daily U.S. digital newspaper website visitors accessed using various devices from Newspaper Association of America, NAA (2014)

- More than 300 U.S. newspapers analyzed in 2014 survey
- We considered three groups of daily digital newspaper website visitors: 1) Mobile only, 2) Desktop/Laptop only, and 3) Dual device, i.e., Desktop/Laptop and Mobile
  - 2013 values were calculated using trend data from the 2014 report
  - Values for each group are weighted relative to the total number of daily visitors
  - We assumed that all mobile devices are tablets
  - For dual-device, we assigned 50% of usage to tablets and 25% to both desktops and laptops

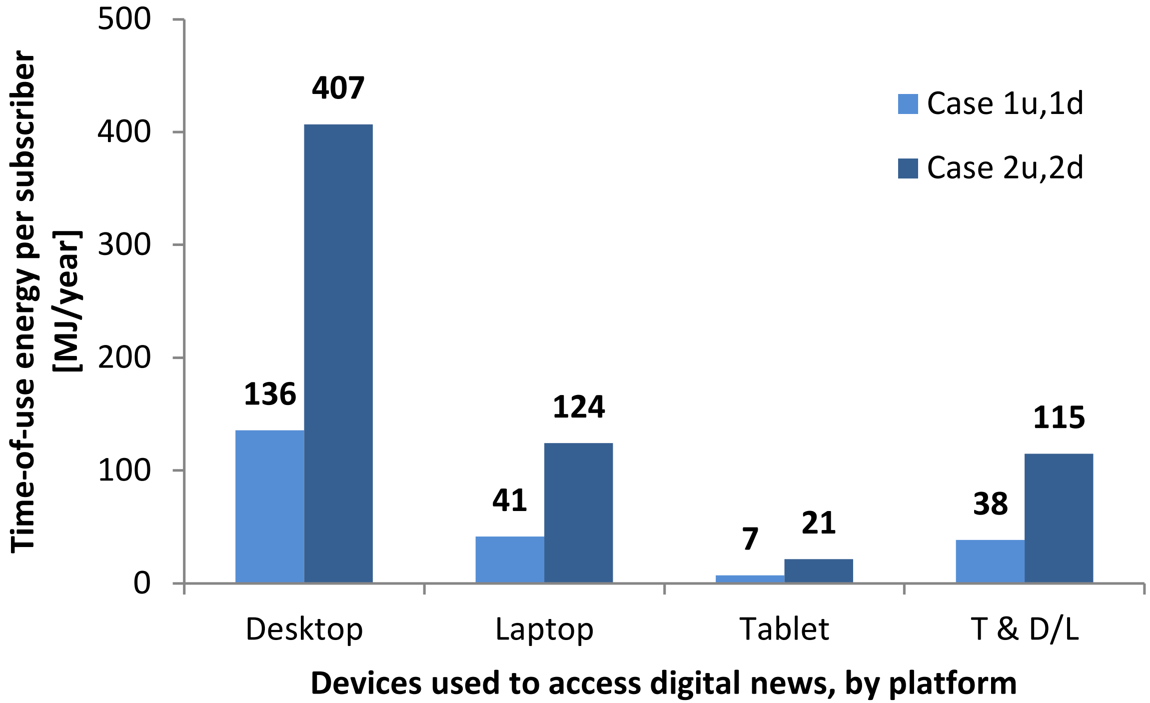
Case 2_d: Assumes distribution of devices used to read e-newspapers is proportional to installed base U.S. residential homes in 2013 (Urban et al. 2014)

- Considers Tablets, Desktops, and Laptops

Both models find that tablets account for a larger portion of devices used to access digital news than desktop and laptop platforms.



Averaged over the distribution of devices used, the average annual time-of-use energy for e-newspapers ranges from 58 to 171 MJ for the two cases evaluated.



For the results shown, use case 1_u is combined with device distribution case 1_d, while use case 2_u is combined with device distribution case 2_d.

The analysis of device embodied energy is based on the time spent reading e-newspapers by digital newspapers subscribers on each device type.

- We attributed the portion of time spent reading e-newspapers relative to their total annual operating hours over the average device lifetime
- We believe there is appreciable uncertainty in the estimate for annual tablet usage (540 hours/year)
  - It is likely that additional usage does not decrease remaining product life but instead increases total usage time for device (i.e., most tablets removed from use due to product obsolescence instead of product failure)

Device / Category	Embodied Energy [MJ]	Annual Active Hours	Device lifetime [years]	References
Laptop	1,158 MJ	1,770	5.5	Urban et al. (2014), Masanet et al. (2013) CEA (2014)
Desktop + Monitor	2,941 MJ	2,789	5.9	
Tablet	1,713 MJ	540	5.1	

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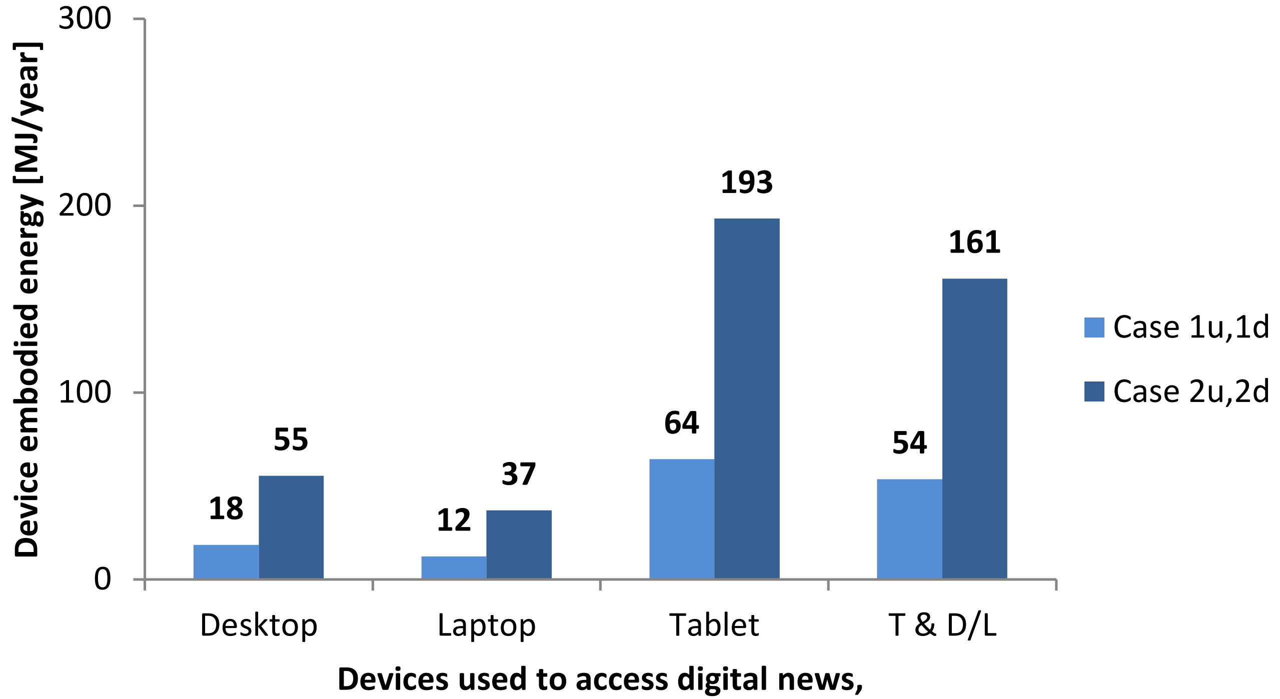
Our model yields a weighted average device embodied energy to access and read e-newspapers per digital subscriber of 33 and 109 MJ per year for the two cases evaluated.



For the results shown, use case 1_u is combined with device distribution case 1_d , while use case 2_u is combined with device distribution case 2_d.

The network energy consumed to download an e-newspaper is much smaller than the time-of-use and device embodied energy impacts.

- Embodied energy to download a copy of a digital newspaper issue is a function of the embodied energy to operate the IT infrastructure
- For wired/wireless data transmission, embodied energy equals 100 µJ per bit (Masanet et al. 2013)
- We measured a size of 4.2MB for the download of a weekday issue of *The New York Times* to a tablet
- Assuming 4.2 MB is a typical e-newspaper size, the product of the embodied energy per bit and 4.2MB yields an embodied energy of **0.003 MJ/day**
- The annual embodied energy to download an entire year of *The New York Times* on CE devices is around one order of magnitude smaller than the embodied energy of a printed newspaper delivered on a given day
- Consequently, we did not include network energy in our net energy and GHG emissions calculations

The total device embodied and use-phase energy impact of digital news subscribers was between 0.5 to 1.6 PJ in 2013.

- The total daily paid digital news subscriptions in 2013 was around 5.6 million units (NDX 2014)
  - This assumes that each e-newspaper subscription is downloaded by only one person per day
  - Our analysis accounts for only paid digital subscriptions

Energy Impact		PJ Impact / year
Device embodied energy	Case $1_{u,d}$	0.2
	Case $2_{u,d}$	0.6
Use-phase energy	Case $1_{u,d}$	0.3
	Case $2_{u,d}$	1.0

Relative to print, e-newspapers reduce annual energy consumption in all cases evaluated for the year 2013, with a net energy savings of between 22 to 28 PJ.

Energy Impact		PJ Impact / year
Print newspapers displaced	Case 1_{print}	(24)
	Case 2_{print}	(29)
Total device use and embodied energy	Case 1_{tot}	0.5
	Case 2_{tot}	1.6
TOTAL	**Low**	**22**
	High	**28**

Negative = energy savings.

- The average annual weight of print newspapers displaced per digital newspaper subscriber in 2013 equals 110kg
  - On a national level, we estimate **that e-newspaper subscriptions displaced a total of 550 to 620 million kg of print newspapers in 2013**

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We used available LCA data for CE devices to calculate the embodied GHG emissions attributed to e-newspaper reading.

- We used product GHG emissions data for Apple desktop, laptop, and tablet computers to estimate average device embodied GHG emissions (Apple 2012-2014)
  - We calculated the straight averages of device models in the 2013 installed base, and amortized the values over the device lifetimes (p. 66) and the portion of annual active-use time used to read e-newspaper (p. 62, 66)

	Desktop + Monitor	Laptop	Tablet
Lifetime GHG Emission per device, excluding use phase [kg $CO_{2,e}$]	829	348	121

- We also calculated the GHG emissions associated with the time-of-use energy for the CE devices used to read e-newspapers in 2013
  - Equals the product of the time-of-use energy for each device (in kWh) and the U.S. average electricity emission factor of 0.6 kg CO_2/kWh(U.S. EPA 2014c)

We considered four cases to evaluate the net GHG impact of e-newspapers in 2013.

- We modeled two scenarios for displaced print newspapers and the impact from both device energy use (in kWh) and device embodied energy (in MJ)
- **Scenario 1: 5 million print newspapers displaced daily in 2013**
  - *Case 1*
    - Case #1 for device time-of-use impact (daily use time = 17 or 25 min./device)
    - Case #1 for device platform use impact (i.e. weighted frequency of devices owned based on residential installed base)
  - *Case 2*
    - Case #2 for device time-of-use impact (i.e. use time of 51 or 76 min./device)
    - Case #2 for device platform use impact (i.e. weighted frequency of devices preferred in accessing newspaper websites)
- **Scenario 2**: The same assumptions are made for the cases in Scenario 2 (i.e. *Cases 3 & 4*), but with **6 million print newspapers displaced daily**.

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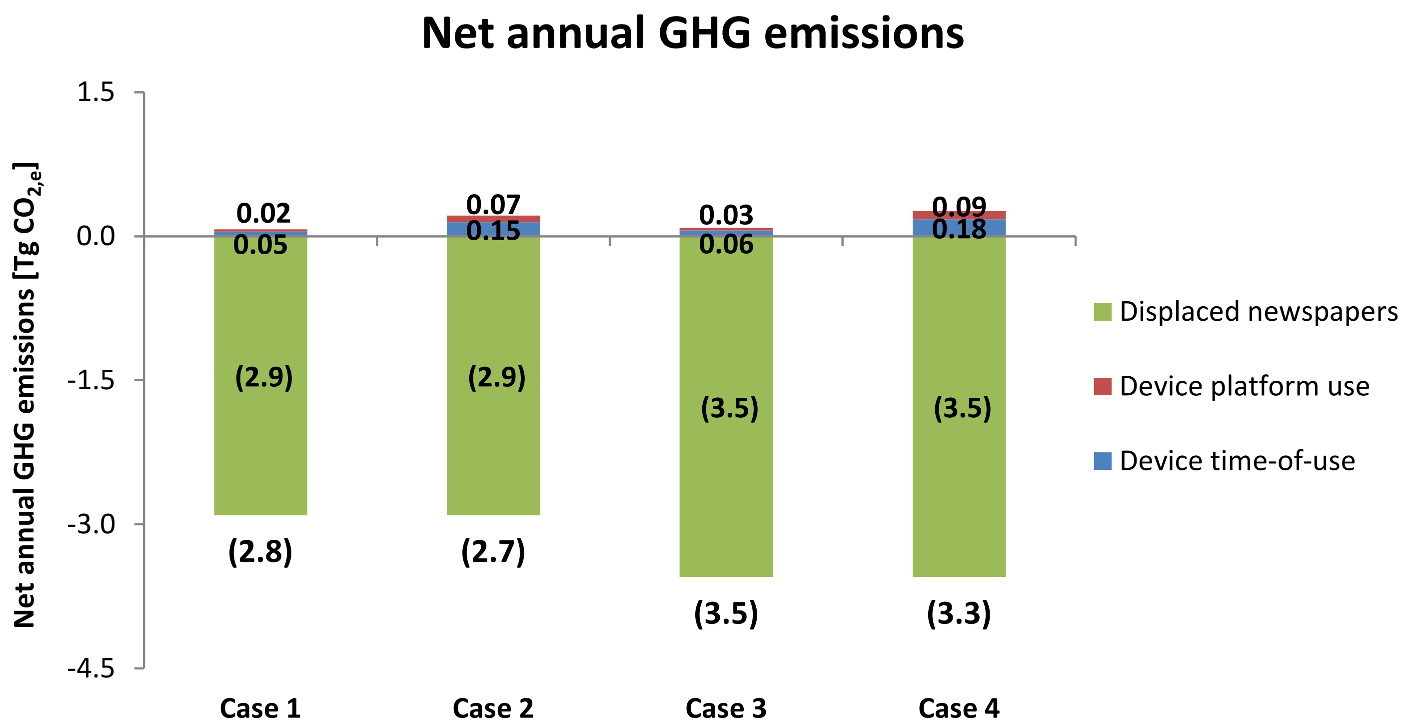
Digital newspapers reduced annual GHG emissions by 2.7 to 3.5 Tg $CO_{2,e}$ per year, or between 0.04 and 0.05 percent of U.S. GHG emissions in 2012.



Negative = emissions avoided

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This table presents the average and 90% confidence intervals for daily VMT data for telecommuting (TC) and non-TC days, based on 100 bootstrap runs. Due to sample sizes, confidence intervals increase as the number of TC days/month increases.

TC Days/Month	1-5	6-10	11-15	16-20	20+
TC Day – Average	34.5	32.7	34.5	24.6	26.2
High	39.7	42.9	44.4	31.1	32.4
Low	29.4	22.8	23.2	16.9	19.6
Non-TC Day Average	49.0	49.4	44.5	53.3	50.7
High	52.7	55.6	55.6	69.0	74.2
Low	45.2	43.5	35.7	36.0	18.5