nature sustainability

SUPPLEMENTARY INFORMATION

https://doi.org/10.1038/s41893-020-0514-9

In the format provided by the authors and unedited.

# A holistic analysis of passenger travel energy and greenhouse gas intensities

**Andreas W. Schäfer[1]✉ and Sonia Yeh[2]**

[1]UCL Energy Institute, University College London, London, UK. [2]Department of Space, Earth and Environment, Chalmers University of Technology, Gothenburg, Sweden. ✉e-mail: a.schafer@ucl.ac.uk

**A Holistic Analysis of Passenger Travel Energy and GHG-Intensities**

**Supplementary Information**

Andreas W. Schäfer

UCL Energy Institute

University College London

Sonia Yeh

Department of Space, Earth and Environment

Chalmers University of Technology

## Underlying data for Figures 1-3

### Aviation

- Bureau of Transportation Statistics (2015) Air Carrier Statistics (Form 41 Schedule T2) https://www.transtats.bts.gov/Tables.asp?DB_ID=111

### Railways

- **Canada:** Railway Association of Canada, 2017. Rail Trends 2017, Ottawa, ON.
- **India:** Ministry of Railways, 2018. Indian Railways, Annual Statistical Statements 2016-17. Government of India, New Delhi, India.

- **US Commuter Rail:** Public Transportation Fact Book, American Public Transportation Association. The Federal Transit Administration's National Transit Database (NTD) - the data for the year 2015. https://www.apta.com/resources/statistics/Pages/NTDDataTables.aspx.
- **US Amtrak:** Davis S.C., Williams S.E., Boundy R.G., 2017. Transportation Energy Data Book Edition 36. Center for Transportation Analysis, Energy and Transportation Science Division, Oak Ridge National Laboratory, Oak Ridge, TN.

**Urban and regional buses**

- **Barcelona:** Transports Metropolitans de Barcelona, 2018. Informe de gestión de 2017. Barcelona, Spain.
- **Berlin:** Berliner Verkehrsbetriebe, 2012. Bericht zur nachhaltigen Unternehmensentwicklung 2010-2011. Berlin, Germany.
- **London:** Transport for London, 2018. Performance Information Buses, http://content.tfl.gov.uk/2017-18-annual-performance-summary.pdf. Transport for London, 2017. FOI Request Detail: London Buses, https://tfl.gov.uk/corporate/transparency/freedom-of-information/foi-request-detail?referenceId=FOI-2200-1617. Transport for London, 2017. Travel in London Report 10, http://content.tfl.gov.uk/travel-in-london-report-10.pdf.
- **Zürich:** Verkehrsbetriebe Zürich, 2017. VBZ Geschäftsbericht 2016. Zürich, Switzerland.
- **Swedish regions:** Svensk Kollektivtrafik in 2015, The Swedish Public Transport Association http://frida.port.se/hemsidan/default.cfm

- **Taiwanese regions:** Ministry of Transportation and Communications R.O.C. http://stat.motc.gov.tw/mocdb/stmain.jsp?sys=210&funid=b310301
- **US cities:** American Public Transportation Association. The Federal Transit Administration's National Transit Database (NTD) - the data for the year 2015. https://www.apta.com/resources/statistics/Pages/NTDDataTables.aspx.
- **US counties:** American Public Transportation Association. The Federal Transit Administration's National Transit Database (NTD) - the data for the year 2015. https://www.apta.com/resources/statistics/Pages/NTDDataTables.aspx.

**Intercity buses**

- **Australia:** Bureau of Transport Economics, 1985. Australian Long-Distance Coach Industry Review, Occasional Paper 74, Canberra. (Although this data point was collected more than 30 years ago, we included in our analysis as it emphasizes the time-invariant relationship between energy intensity and vehicle occupancy).
- **Canada:** Statistics Canada, 2001-2004. Canadian Vehicle Survey, Annual 2000-2003. Ottawa, ON.
- **Costa Rica:** Ministerio del Ambiente y Energía, 2005. Encuesta de Consumo Energetico Nacional en el Sector Transporte de Costa Rica. San José.
- **US:** American Bus Association, 2016. Motorcoach Census. A Study of the Size and Activity of the Motorcoach Industry in the United States and Canada in 2014.

**Light-duty vehicles**

- **Australia:** Department of Infrastructure, Regional Development and Cities, 2018. Australian Infrastructure Statistics Yearbook, Canberra, Australia.

- **Canada:** Transport Canada's CVUS 2015 Reference Year public dataset http://tc.gc.ca/eng/policy/annual-2014-3141.html
- **France:** Ministère de la Transition Écologique et Solidaire, 2018. Les comptes des transports en 2017, 55e rapport de la Commission des comptes des transports de la Nation. Commissariat général au développement durable, Paris, France.
- **Germany:** Bundesministerium für Verkehr und digitale Infrastruktur, 2017. Verkehr in Zahlen 2017/2018. Deutsches Institut für Wirtschaftsforschung, Berlin, Germany.
- **Great Britain:** Department for Transport, 2018. Transport Statistics Great Britain. London, UK.
- **Switzerland:** Bundesamt für Energie, 2017. Analyse des schweizerischen Energieverbrauchs 2000-2016 nach Verwendungszwecken, Bern. Bundesamt für Statistik, 2017. Leistungen des Personenverkehrs, Bern.
- **US:** Davis S.C., Williams S.E., Boundy R.G., 2017. Transportation Energy Data Book Edition 36. Center for Transportation Analysis, Energy and Transportation Science Division, Oak Ridge National Laboratory, Oak Ridge, TN.
  2009 US National Household Travel Survey (https://nhts.ornl.gov/download.shtml). The US Energy Information Administration (EIA) added trip-related vehicle fuel consumption estimates to the disaggregate data of originally 404,787 household trips from the 2009 US National Household Travel Survey (EIA, 2011). Eliminating records with a vehicle fuel economy of less than 12 miles per gallon (greater than 23 liters per km) in order to remove trucks yields 404,727 light-duty vehicle household trips. We adjusted the trip-related light-duty vehicle energy use by 4% and 5% for each occupant in addition to the driver for automobiles and light-trucks, respectively, to account for the impact of occupant weight on vehicle energy use

(Schäfer *et al*., 2009). The 404,727 household trips were then aggregated onto a household level, thus yielding the average travel behavior of 76,527 households.

EIA, 2011. Methodologies for estimating fuel consumption using the 2009 National Household Travel Survey, March 2011. https://nhts.ornl.gov/2009/pub/EIA.pdf

- **Automated Vehicles:**
    - ITF/OECD, 2017. Transition to Shared Mobility, International Transport Forum.
    - Moreno A.T., Michalski A., Llorca C., Moeckel R., 2018. Shared Autonomous Vehicles Effect on Vehicle-Km Traveled and Average Trip Duration. Journal of Advanced Transportation 2018, 10.
    - Gurumurthy K. M., Kockelman K. M., 2018. Analyzing the dynamic ride-sharing potential for shared autonomous vehicle fleets using cellphone data from Orlando, Florida. Computers, Environment and Urban Systems, 71:177-185.
- **Taxis:** NYC Taxi and Limousine Commission: 2014 Taxicab Factbook (https://www1.nyc.gov/assets/tlc/downloads/pdf/2014_tlc_factbook.pdf). This source assumes an average NYC taxi fleet fuel efficiency of 29 miles per gallon, which translates into an energy use of 2.6 MJ/km.

  TLC Trip Record Data (http://www.nyc.gov/html/tlc/html/about/trip_record_data.shtml). This sources provides average occupancy levels for NYC taxis.
- **Uber:** Cramer J., Krueger A.B., 2016. Disruptive Change in the Taxi Business: The Case of Uber. American Economic Review **106**(5): 177-182.

  Henao X., 2017. Impacts of ridesourcing - lyft and uber - on transportation including VMT, mode replacement, parking, and travel behavior. Doctor of Philosophy, University of Colorado.

**Results of the econometric analysis**

**Table SI-1** Determinants of energy intensity (t-statistics in parenthesis) using eq. 2 and the data shown in Figure 1.

| | Full model | | Occupancy only | |
|---|---|---|---|---|
| **Light-duty vehicles at US household level** | | | | |
| N | 76,527 | | 76,527 | |
| Adj. $R^2$ | 0.699 | | 0.698 | |
| Constant $\beta_0$ | 1.309 | (572) | 1.284 | (1131) |
| Occupancy $\beta_1$ | -0.890 | (-410) | -0.892 | (-413) |
| Average distance $\beta_2$ | -0.011 | (-13) | | |
| **Light-duty Vehicles at aggregate levels (Reference: Canada)** | | | | |
| N | 820 | | 825 | |
| Adj. $R^2$ | 0.857 | | 0.720 | |
| Constant $\beta_0$ | 1.455 | (159) | 1.343 | (154) |
| Occupancy $\beta_1$ | -0.939 | (-60) | -0.979 | (-51) |
| Average distance $\beta_2$ | -0.009 | (-8.6) | | |
| LDVs in the US $\beta_3$ | -0.149 | (-21) | | |
| LDVs in European countries $\beta_4$ | -0.514 | (-19) | | |
| **Urban & regional buses (Reference: US)** | | | | |
| N | 243 | | 243 | |
| Adj. $R^2$ (log-linear model) | 0.903 | | 0.785 | |
| Adj. $R^2$ (multiplicative model) | 0.880 | | 0.827 | |
| Constant $\beta_0$ | 2.817 | (56) | 2.933 | (42) |
| Occupancy $\beta_1$ | -0.783 | (-27) | -0.992 | (-30) |
| Average distance $\beta_2$ | -0.135 | (-8.1) | | |
| Swedish regions $\beta_3$ | -0.384 | (-9.9) | | |
| Taiwanese regions $\beta_4$ | -0.506 | (-7.9) | | |
| European cities $\beta_5$ | -0.207 | (-2.3) | | |
| **Intercity buses (various countries)** | | | | |
| N | | | 14 | |
| Adj. $R^2$ (log-linear model) | | | 0.923 | |
| Adj. $R^2$ (multiplicative model) | | | 0.922 | |
| Constant $\beta_0$ | | | 1.755 | (9.4) |
| Occupancy $\beta_1$ | | | -0.741 | (-13) |
| **Railways (Reference: US)** | | | | |
| N | 21 | | 21 | |
| Adj. $R^2$ (log-linear model) | 0.937 | | 0.905 | |
| Adj. $R^2$ (multiplicative model) | 0.935 | | 0.917 | |
| Constant $\beta_0$ | 4.800 | (18) | 4.467 | (16) |
| Occupancy $\beta_1$ | -0.775 | (-15) | -0.804 | (-14) |
| Average distance $\beta_2$ | -0.123 | (-2.6) | | |
| Indian railways $\beta_3$ | 0.320 | (2.8) | | |

| | | | | |
|---|---|---|---|---|
| **Aircraft (US only)** | | | | |
| N | 389 | | 389 | |
| Adj. $R^2$ (log-linear model) | 0.962 | | 0.879 | |
| Adj. $R^2$ (multiplicative model) | 0.942 | | 0.906 | |
| Constant $\beta_0$ | 4.722 | (28) | 3.535 | (59) |
| Occupancy $\beta_1$ | -0.555 | (-14) | -0.640 | (-49) |
| Average distance $\beta_2$ | -0.229 | (-11) | | |
| Business jets $\beta_3$ | 0.677 | (4.5) | | |
| Regional jets $\beta_4$ | -0.120 | (-3.5) | | |
| Widebody jets $\beta_5$ [(1)] | 0.519 | (19) | | |
| B747 aircraft $\beta_6$ | 1.270 | (16) | | |

**Table Notes:** [(1)] except B747.