Robust Criteria for Sustainable Development: How to Lie with Transport Statistics

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Abstract: One of the difficulties in formulating effective residential sustainability policies is that it requires information on current resource consumption. It also requires predictions of future technological developments and the manner in which they may be used. These predictions facilitate the comparisons between competing policy scenarios. Much of the current discourse on developing more sustainable cities relies on current patterns of consumptions with little regard for the sensitivity of those results to very small changes in technology or behaviour. For example, the reported CO_2 emissions reduction by switching from car travel to light rail is negated with the recent availability of electric cars.

The apparent sustainability of competing alternative technologies may be erroneously reported because different forms of energy are often assumed to be comparable on their heating values alone, ignoring thermodynamic and practical limitations of converting between fuel types. Many authors have assumed that diesel (for transit buses) and electricity (for light rail) can be converted with 100% efficiency between each other based on heating energy content. They concluded that light rail was more energy efficient than buses. This paper questions those results.

The reported efficiency benefits of light rail over transit buses or cars are conflated by the higher efficiency of electric motors compared with combustion engines. A different result is found where electric versions of these modes of transport are compared. In the US, travel by light rail and trolley bus was found to use 210 and 236 watt-hours per passenger kilometre travelled (Wh/PKT), respectively. Travel by electric cars and electric buses were found to use approximately half: 118 and 132 Wh/PKT, respectively.

For the devious researcher, this paper shows the variation in US state averages allows the freedom to ‘find’ per capita greenhouse gas emissions of light rail travel between 0.1 and 697.7 gCO_2/PKT.

Introduction

The apparent sustainability of competing transport modes may be erroneously reported because different forms of energy are often assumed to be comparable on their heating values alone, ignoring thermodynamic and practical limitations of converting between fuel types. For example, Shapiro et al. (2002) states “The facts are clear and indisputable. For every passenger mile travelled by Americans, public transportation consumes about one-half the fuel and energy of private automobiles”, but O'Toole (2008) finds the opposite; “... most transit lines use more energy per passenger mile, and many generate more greenhouse gases than the average passenger automobile.” So which is more energy efficient? Both authors used data derived from the National Transit Database (US Department of Transportation, 2012). These opposing conclusions result largely from differences in the methods of comparing petrol energy for cars with electrical energy for rail.

This work focuses mainly on comparing light rail and inner-city buses because they can provide similar public transport service within a city and typically use different fuel types – electricity and diesel respectively. The area of study was the continental US because of the volume of public transport data available and because it minimises cultural, economic and environmental factors that affect inter-country comparisons.

The difficulty of comparing energy efficiency (or CO_2 emissions) of light rail with buses is that they use different fuel sources. Light rail uses electricity and most buses use diesel as their fuel source. The most common method of comparing these modes of transport is to convert both fuel types to a heating energy value (joules) assuming 100% efficient conversion (Potter, 2003, Shapiro et al., 2002, Vincent and Jerram, 2006, Kenworthy et al., 1999, Chester, 2008). They concluded that light rail was more energy efficient in moving passengers than diesel buses.

Comparing different fuels types is problematic because the efficacy of one unit of energy (joule) depends on the technology available to use that energy. Current technologies do not allow for equal conversion between fuel types. For example, petrol may be converted to electricity with approximately 30% efficiency but electricity cannot practically be converted to petrol. Electric motors are typically greater than 90% efficient (Chapman, 2007) but the efficiency of heat engines (diesel or petrol) is limited thermodynamically to approximately 50%. Petrol car engines typically achieve efficiencies of 14-30% (US Dept. of Energy, 2009). Diesel engines are limited beyond the maximum thermodynamic efficiency by the diesel fuel cycle (Holman, 1988). Furthermore, the most efficient technology may not be ubiquitously available, but vary spatially and temporally; for example, coal electricity generators in the US (discounting combined ‘heat and power’ models) vary between 18 and 39 percent efficient (Environmental Protection Agency (EPA), 2010). Analysis that relies on the resource efficiency in one location may be erroneously extrapolated to other times and other locations without considering such differences.

Comparing transport modes is further complicated because extrapolation of transport emissions to other areas or other periods involves the selection of a ‘suitable’ vehicle efficiency, occupancy rate and electricity emissions factor, among other factors. For example, the associated greenhouse gas (GHG) emission from light rail depends largely on the emissions factor of the locally generated electricity, which in the US in 2010 varied between 0.001 and 1.028 $kg{\cdot}CO_2{\cdot}kWh^{-1}$ (Environmental Protection Agency (EPA), 2010). Such freedom in selection without sensitivity analysis allows for a high variation in expected emissions per passenger kilometre travelled.

Comparing only modes of transport that use electric power for propulsion disentangles the often conflated differences in electric motor and diesel engine efficiency from differences in transport mode alone. To improve the comparison of different modes of transport, a first attempt is to compare only transport modes that use the same fuel source.

The aim of this work was to demonstrate common erroneous conclusions in the literature on the efficiency of different transport modes. These errors arise largely because a) transport modes that use different forms of energy are compared on their heating energy use alone, assuming 100% conversion efficiency, and b) ignoring the variation in utilisation (occupancy rates) of different modes of transport. Firstly, the variation in US state-average light rail system efficiency, occupancy rate and electricity CO_2 emissions factor was documented. The high variation in these three factors allows the devious researcher the freedom to report a large range in potential CO_2 emissions per passenger kilometre travelled (PKT^{-1}). Secondly, the variation in US state-based average light rail and bus efficiency was documented and compared with the literature. A first attempt to reduce the erroneous conclusions of conflating fuel use efficiency with transport mode was to only compare transport modes that use the same energy source.

The energy efficiency of different transport modes was estimated for electric forms of light rail, buses, cars and trolley buses. In contradiction most of the literature, electric cars and buses were found to use half the energy per passenger kilometre as light rail or trolley buses.

Method

Light rail system energy efficiencies and occupancy rates were derived from the 2012 US National Transit Database (US Department of Transportation, 2012). It contained aggregated average data for 23, separately owned, light rail (LR) systems. In each US state there was usually only a single light rail operator. The reported electricity efficiencies and occupancy rates are the per passenger kilometre travelled weighted mean values because of the large variation in the number of passengers annually transported on different systems. The minimum and maximum values are reported directly.

Bus system energy efficiencies and occupancy rates were derived from the 2012 US National Transit Database (US Department of Transportation, 2012). The database contained data for 319 transit bus (MB) systems. The average bus occupancy rate was estimated from the per passenger kilometre travelled weighted mean values across all bus systems. To estimate average diesel fuel efficiency, the dataset was limited to those service that reported using more than 800 litres annually and provided more than 10,000 kilometres of annual travel service. There were 136 such bus systems. Most of the excluded services did not report any fuel use. The variation in fuel consumption reported was one standard deviation above and below the weighted mean for those services that consume more than one million litres of fuel. Diesel was assumed to have a heating energy content of 129,500 BTU/Gal. The efficiencies of US trolley bus systems was derived from the 2012 US National Transit Database (US Department of Transportation, 2012).

Electric bus energy consumption per passenger kilometre travelled was calculated from a real world trial in New York (Gehm, 2015), which reported an average 1.5 kWh per vehicle kilometre with air conditioner use, the most energy intensive use case. Average diesel bus occupancy rate was assumed (see above). This resulted in higher per capita energy consumption per kilometre travelled than if the mean New York occupancy rate of 15.8 were used.

Electric car energy consumption values were derived from a database of 26,427 vehicle trips in a 2012 model Nissan Leaf from across the US (CrossChasm Technologies Inc., 2015). The Nissan Leaf is currently the most popular electric car sold in the US (Voelcker, 2015). The national average car occupancy rate (load factor) of 1.55 was assumed (Davis et al., 2014).

The carbon dioxide (CO_2) emissions from electricity generation (emissions factor) were derived from the state-wide average 2010 values, the latest available (Environmental Protection Agency (EPA), 2010). The average values were weighted by the annual electricity generation per state. The variation reported is that between state averages.

The possible variation in GHG emissions of light rail was explored by combining the state-based average vehicle energy efficiency, occupancy rate and electricity CO_2 emissions factor. The highest possible emissions scenario was achieved by dividing the least energy efficient system by the lowest occupancy rate and multiplying by the highest emissions factor. Similarly, the lowest estimated emissions from light rail was achieved by dividing the most energy efficient vehicle system by the highest occupancy rate and multiplying by the lowest emissions factor.

To demonstrate the inconsistencies in the literature comparing buses with light rail, a brief review of the literature reporting the energy efficiency of light rail and diesel buses was conducted and compared with the US state averages and with a recent trial of electric buses. Diesel fuel was converted to kWh of electricity equivalent in keeping with the approach of most referenced authors. Mean values reported are the US state arithmetic mean.

To disentangle the efficiency of different modes of transport from the efficiency of using different fuels a first attempt was to compare only electric modes of transport. Light rail was compared with electric buses, cars and trolley buses. The travel weighted mean and weighted standard deviation energy consumption per passenger kilometre were calculated as a first approximation of the efficiency of each mode of transport.

Results

The Range in the Environmental Impacts of Light Rail

The apparent per capita emissions of light rail in the United States depends on the estimation of 1) vehicle efficiency, 2) occupancy rate and 3) emissions factor of the electricity used for propulsion. The large range in these values between US states contributes to an even larger range in reported per capita CO_2 emissions per passenger kilometre travelled, depending on the combination of factors selected.

The average light rail energy consumption was 5.1 kWh per vehicle kilometre (VKT^{-1}). The average city-wide variation was between 3.1 $kWh \cdot VKT^{-1}$ in San Diego, California and 9.1 $kWh \cdot VKT^{-1}$ in Pittsburgh, Pennsylvania. This was a variation from the average of between 60 and 178 percent.

The average occupancy rate (load factor) of light rail systems was 24.9 people but varied between 13.4 in Utah and 37.8 in Arizona. This was a variation from the average of between 56 and 157 percent. Inter-day variation (peak vs. off-peak) was not considered. Off-peak periods would likely be much lower than any state average and peak periods much higher.

There was a large variation in state-wide average emissions factors across the US. The average emissions factor was 0.56 $kg \cdot CO_2$ per kilowatt-hour (kWh^{-1}) of gross electricity generated (line losses not included). It varied between 0.001 in Vermont and 1.028 in Washington DC. This was a variation from the average of between 0.2 and 184 percent.

Light rail transport emissions were between 0.1 and 697.7 grams of carbon dioxide per passenger kilometre travelled, using US state-wide averages of vehicle efficiency, occupancy rate and electricity emissions factor. The lowest CO_2 emissions per passenger kilometre for light rail could be achieved by combining an occupancy rate of light rail in Arizona, an emissions factor of Vermont and vehicle efficiency of San Diego, California. The highest could be achieved by combining an occupancy rate of light rail in Utah, an emissions factor of Washington DC and a vehicle efficiency of Pittsburgh, Pennsylvania. Combining vehicle efficiency, occupancy rates and electricity emissions factors of different US states occurs in the literatures: Puchalsky (2005) combined the light rail vehicle efficiency of Denver, Colorado, with an estimated ‘bus adjusted’ occupancy rate and an emissions factor of Rhode Island. Extrapolation of light rail energy efficiency to other cities or countries requires the selection of those factors. The freedom to select the most ‘suitable’ factors allows one to lie with statistics; to ‘find’ the benefits of light rail over buses, for example.

Figure 1 shows how the variation in light rail vehicle efficiency, occupancy rate and emissions factor are combined and result in an even larger variation in per capita emissions per light rail kilometre travelled. The variation was found to be between 0.1 and 610 % of the mean weighted value of 114.4 $g \cdot CO_2 \cdot PKT^{-1}$. O'Toole (2008), Shapiro et al. (2002) and Vincent and Jerram (2006) reported 101, 127 and 130 $g \cdot CO_2 \cdot PKT^{-1}$, respectively. Chester (2008), however, considered only two US light rail systems and reported emissions from operational energy of approximately 49 % of the national average (56 $g \cdot CO_2 \cdot PKT^{-1}$).

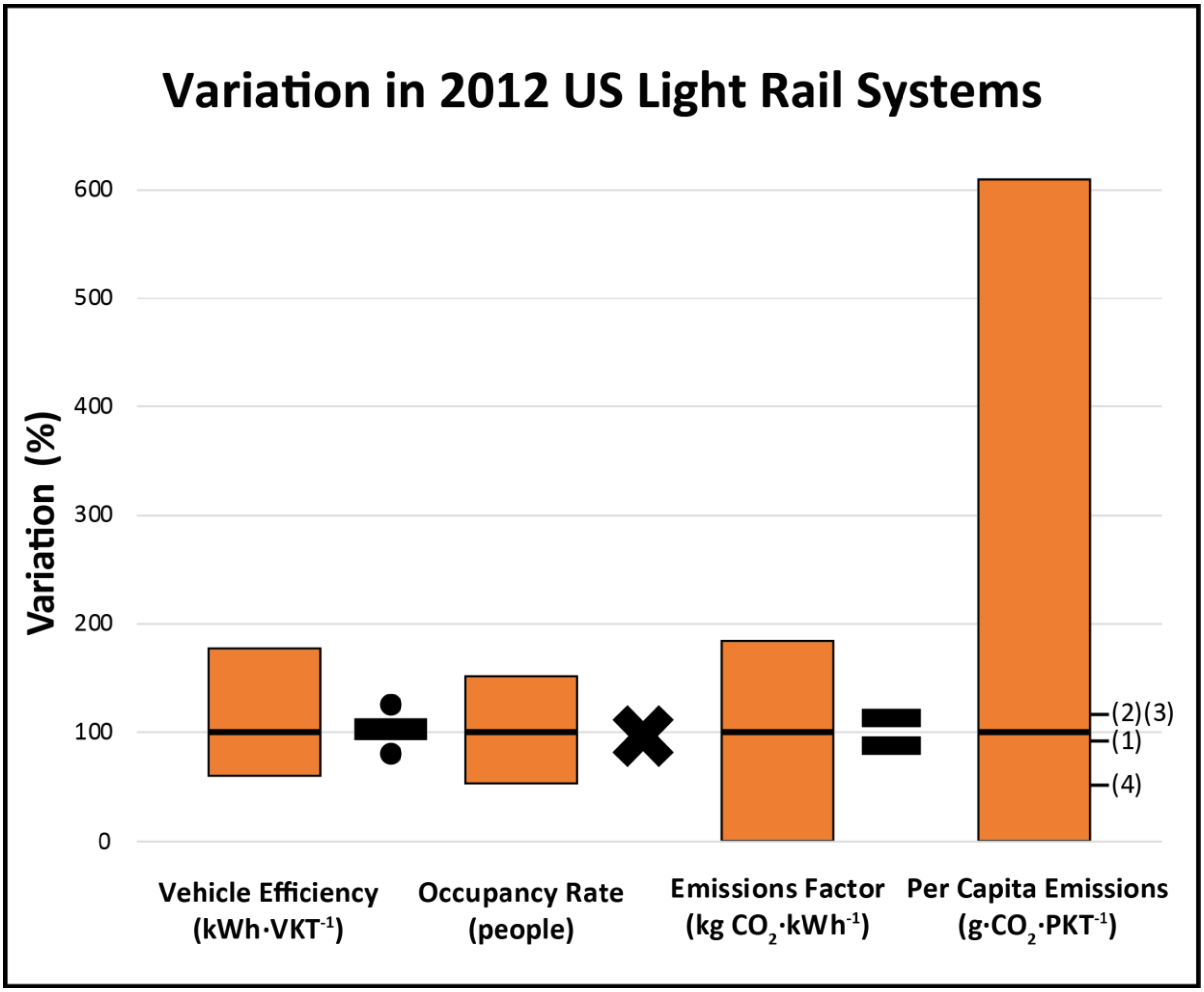

Figure 1 Variation in light rail efficiency, occupancy rate and electricity emissions factor combine into a large variation in reported CO_2 emissions per passenger kilometre travelled (PKT^{-1}). Maximum and minimum vehicle efficiencies and occupancy rates are 2012 US State-wide averages (US Department of Transportation, 2012). Electricity generation emissions factors were derived from 2010 US State-wide average 2010 values (Environmental Protection Agency (EPA), 2010). Four papers that use the same data are also shown: (1) O'Toole (2008) 101 g CO_2·PKT^{-1}; (2) Shapiro et al. (2002) 127 g CO_2·PKT^{-1}; (3) Vincent and Jerram (2006) 130 g CO_2·PKT^{-1}; (4) Chester (2008) 56 g CO_2·PKT^{-1}.

Comparing Transport Modes that Use Different Fuels

Comparing modes of transport that use different fuel types is likely misleading because it conflates differences in the mode of transport with differences in the efficiency with which that form of energy can be used.

The per capita light rail and diesel bus energy efficiency values reported by seven authors were compared with the average energy consumption of such systems across the United States. Figure 2 shows the per capita energy consumption reported by: (1) O'Toole (2008); (2) Shapiro et al. (2002); (3) Vincent and Jerram (2006); (4) Potter (2003); (5) Chester (2008); (6) Davis et al. (2014); (7) Kenworthy et al. (1999). The average occupancy rates across the US were found to be 11.4 people for buses and 24.9 people for light rail. The average energy consumption of light rail users was found to be 210 Wh per passenger kilometre travelled (PKT^{-1}). At the city-wide average, it varied between 126 Wh·PKT^{-1} in San Diego and 557 Wh·PKT^{-1} in Pittsburgh. The average energy consumption of bus users was found to be 752 Wh·PKT^{-1} varying between 488 and 1017.

Light rail is often cited as more efficient than buses in moving passengers: Shapiro et al. (2002), Vincent and Jerram (2006) and Chester (2008), ((2), (3) and (5) in Figure 2, respectively) reported that light rail used between one half and one quarter the energy. However, O'Toole (2008) and Davis et al. (2014) reported higher energy consumption by light rail than the other authors ((1) and (6) in Figure 2, respectively) because they attempted to account for different fuel types by adding an electricity generation efficiency factor. They multiplied all light rail electricity consumption values by 3 to account for the average US grid electricity generation and distribution efficiency. This partially reduced the error in comparing electricity with diesel on heating content. The majority of the electricity generation was from coal, the burning of which has a similar thermodynamic efficiency to diesel. Their comparisons of different modes of transport still conflate the differences in mode with fuel conversions efficiencies, but the differences are partially accounted for.

The problem of comparing different modes of transport that use different fuel types is not confined to the US. Potter (2003) used available seat kilometres during estimated peak and off-peak periods in the UK. The results were difficult to compare with other studies, but nonetheless indicate light rail was more energy efficient. The range showed in Figure 2 indicates how a change in estimated occupancy rates (peak vs. offpeak) changed the apparent energy efficiency; the results were not robust to small changes in model assumptions. Kenworthy et al. (1999) was included for comparison because their work was referenced in Australia as evidence that public transport is more energy efficient than private car use (Rickwood et al., 2007, Newman and Kenworthy, 2001, Kenworthy, 2007). They, however, also compare diesel buses with electric trains on heating energy content alone. Figure 2 shows their reported values for transit buses and light rail for Melbourne in 1991. They also conclude that trains are more energy efficient than buses.

If buses were powered by the same fuel source (electricity) as the light rail, then a different result is found. Electric buses were found to use 132 $Wh \cdot PKT^{-1}$. This is similar to the most efficient light rail systems (126 $Wh \cdot PKT^{-1}$) and 37% less than the average (Figure 2).

By comparing modes of transport using the same type of energy for propulsion, the variation in emissions factors and efficiency in converting between fuel types is removed. Only then does the result reflect transport modes. No formal statistical test was performed because of the small sample of electric buses. However, the lower national average bus occupancy rate was assumed rather than that of New York trial which reduced the apparent per capita energy efficiency. Furthermore, the most energy intensive results are reported, where the air conditioning was running. Care should be taken extrapolating these values to other locations because battery electric vehicles are more energy efficient in warmer climates (CrossChasm Technologies Inc., 2015).

Only by considering different modes of transport (e.g. light rail and buses) powered by the same fuel source (e.g. electricity) can the energy efficiency of both be accurately compared because the variations in thermodynamic efficiency and emissions factor are removed.

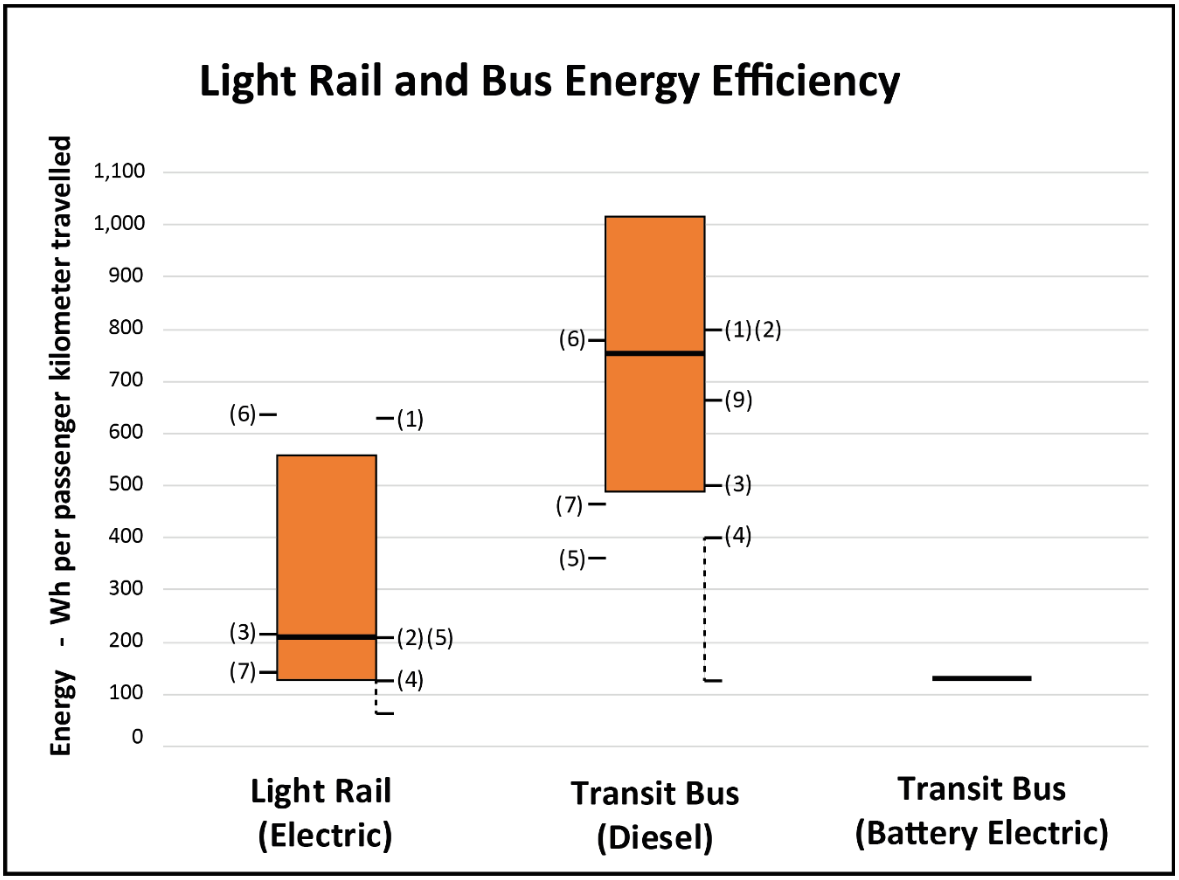

Figure 2 Energy consumption per passenger kilometre for electric light rail and diesel and electric buses. Comparisons based on heating energy consumption. Numbering indicates other authors values: (1) O'Toole (2008); (2) Shapiro et al. (2002); (3) Vincent and Jerram (2006); (4) Potter (2003); (5) Chester (2008); (6) Davis et al. (2014); (7) Kenworthy et al. (1999).

Energy Efficiency of Selected Transport Modes

To disentangle the energy efficiency of different modes of transport from differences in their fuel sources, only modes that used electrical energy were considered. Figure 3 shows four modes of transport all powered by electrical energy; light rail, cars, battery buses and trolley buses.

Light rail used 210 ± 94 $Wh{\cdot}PKT^{-1}$, the electric cars used 118 ± 37 $Wh{\cdot}PKT^{-1}$, the electric buses used 132 $Wh{\cdot}PKT^{-1}$ and trolley buses used 236 ± 213 $Wh{\cdot}PKT^{-1}$. Travel by light rail and trolley buses were found to use a similar quantity of energy. Travel by electric cars and electric buses were also found to use a similar quantity of energy. Per passenger kilometre travelled, electric buses used approximately half that of light rail. A formal statistical test was not conducted because of the limited sample of the electric buses and trolley buses and because the method of aggregation of light rail travel and electric car travel were not identical.

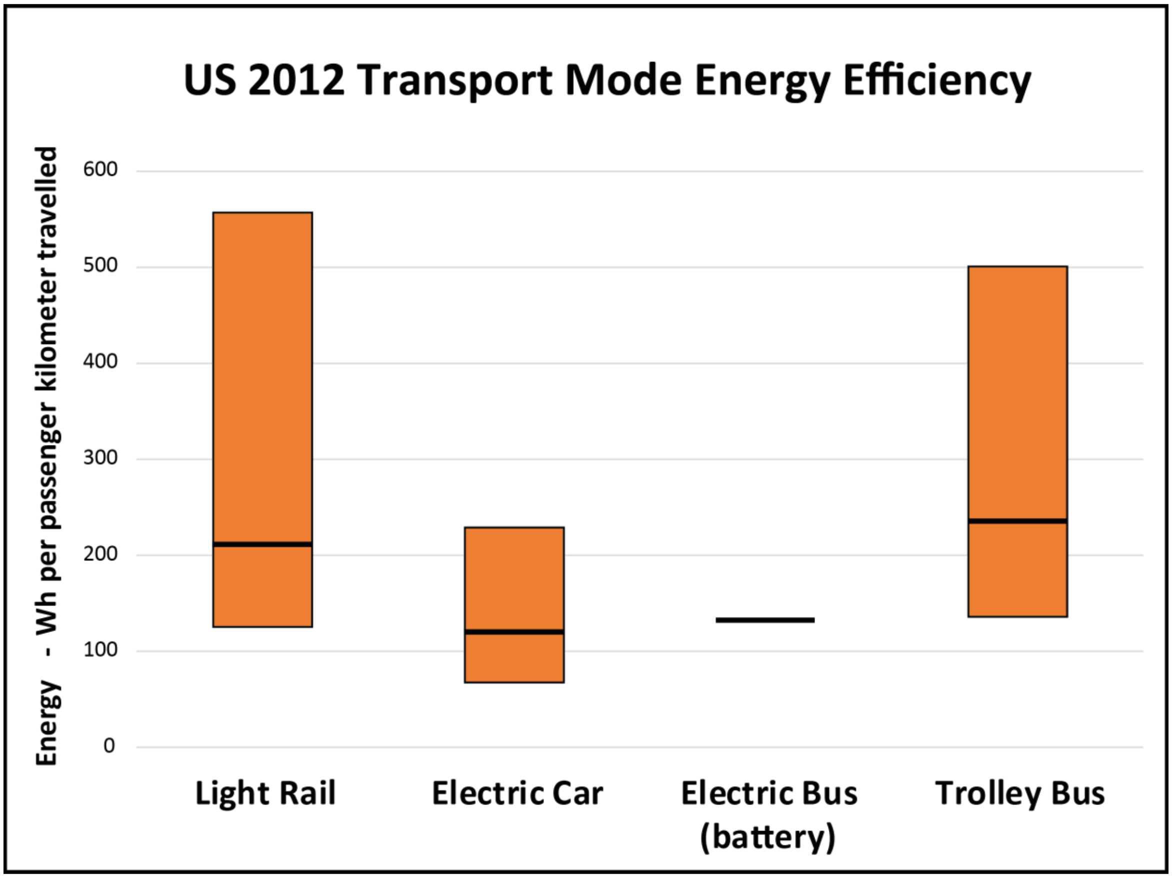

Figure 3 Comparison of four modes of transport based on energy required per passenger kilometre travelled; electric light rail, car, bus and trolley bus. The range in light rail and trolley buses are the range in 2012 US-Sate averages. The range in electric cars is the range in individual trips. No range was reported for the electric bus trial.

Discussion

The work shows that energy efficiency comparisons between modes of transport that do not consider difference in fuel types may lead to erroneous results. Such comparisons conflate modes of transport with other factors such as the efficiency of small internal combustion engines vs an electric motor, or the greenhouse gas (GHG) intensity of different fuel sources (electricity vs liquid fuel).

While the benefits of rail over buses or cars are sometimes pronounced because steel wheels on steel rails are more energy efficient than rubber wheels on roads (Bonnafous and Raux, 2003), such considerations ignore real world variations in occupancy rates. In the data presented, larger vehicles had lower average occupancy rates than small vehicles: Light rail had an average occupancy rate of 24.9 of approximately 200 possible sitting and standing positions (~10%), buses had an average occupancy of 11.4 of approximately 50 possible sitting and standing positions available (~20%) and cars had an average occupancy rate of 1.5 of approximately 5 sitting positions (~30%). Push bikes or motor bikes would have close to 100% occupancy. Moriarty and Honnery (2008) suggested that average occupancy rates are difficult to change and should not be a major focus in reducing transport greenhouse gas emissions. A more complete comparison of modes of transport requires consideration of real world occupancy rates. These vary significantly even for the same transport modes, as demonstrated for light rail in the US.

Comparing different modes of transport that use different fuel types based on their heating energy content alone can be partially but not completely improved by increasing the system boundary. O'Toole (2008) multiplies electricity consumption by 3 to account for the efficiency of the US national electricity grid in converting fossil fuels (mostly coal) to electricity. This increase in the system boundary allows for a more accurate comparison between transport modes because the fuel sources (coal for grid and diesel for buses) have similar thermodynamic efficiencies. The results are still misleading. O'Toole (2008) aimed to compare transport modes but the results were devalued by differences in efficiency of burning coal versus diesel, and differences in efficiency of large coal generators versus small diesel engines in vehicles.

In considering proposals for light rail in cities or countries that don't have light rail, the estimated occupancy rates, emissions factors and vehicle efficiency must be estimated or selected from other 'similar' cities. The apparent sustainability of this transport mode is highly sensitive to these assumptions. Selecting other cities for comparison also ignores historical, technological, and cultural differences between the cities. To inform long term public transport policy some (Flannery et al., 2015) consider it useful to draw on data from other cities around the world, but this may lead to erroneous conclusions. Some recent public transport policies (Capital Metro Agency, 2014) report that light rail will reduce CO_2 emissions related to public transport based on analysis of light rail in other countries and compared with existing diesel buses. This paper questions those conclusions. The high variability in factors used to compare different modes of transport mean extrapolations to other locations are likely inaccurate. This paper has found that in the US, electric buses or cars are twice as energy efficient at moving people as light rail or trolley buses but more work is required to investigate the difference in transport modes in different countries.

This paper is a first step towards increasing the robustness of comparing different modes of transport, but does not constitute a complete sensitivity analysis, see for example (Saltelli et al., 2008). The paper shows how case-study-based analysis of transport modes in particular is highly sensitive to small changes in technology, for example the replacement of diesel buses with electric buses. Life-cycle analysis (LCA) aims to expand the boundary of analysis. It does not directly consider thermodynamic efficiency. LCA can be useful for case based comparisons, but may have limited application without comprehensive sensitivity analysis, including allowing for possible future changes in technology. A more complete sensitivity analysis might include differences in topography, climate, network age, safety, economic, environment or other historic or cultural factors. Loukaitou-Sideris (2010) showed that even within the same city (Los Angeles) cultural and socio-economic variation on different rail lines may have a large impact on the success of light rail.

Chester and Horvath (2009) were among a few authors who conducted a sensitivity analysis, albeit limited in scope. They considered occupancy rates ranging from the driver only to 'full capacity' which included all sitting and standing spaces in cars and light rail. This simple sensitivity analysis showed their results were highly sensitive to variation in occupancy rates. Chester (2008) also considered the sensitivity of their results but did not consider the range in values across the US, and has limited application as it cannot be extrapolated to other locations or periods.

New light rail installations may require additional electricity generation which may have a different emissions factor from the grid average. The emissions factor of newly built generators is known as the marginal emissions factor (Puchalsky, 2005). The marginal electricity emissions factor is an important consideration for newly built electric transport modes for estimating the sustainability of those transport modes.

The marginal emissions factor may be lower or higher than that of the current grid. It may be lower where renewable energy constitutes the bulk of new electricity generation. In 2014, 53 % of newly installed electricity generation in the United States was from renewable sources (Hales, 2015) compared with 13.9 % of current generation (Environmental Protection Agency (EPA), 2010). The marginal emissions factor may also be greater than the current grid. In Australia, for example, a renewable energy target (RET) policy has displaced fossil-fuelled generation capacity with renewable generation capacity. There is currently between 7,650 MW and 8,950 MW of idle fossil-fuelled capacity (Australian Energy Market Operator, 2014). A new light rail may bring these idle fossil fuel generators back online. The marginal GHG emissions factor of this electricity would be greater than the current grid.

This work focuses on analysis of transport modes but is equally applicable to analysis involving multiple fuel sources. The paper focuses on transport because of the volume of literature available comparing different transport modes, and the differing methodologies employed in accounting for conversion between electricity and petrol or diesel are easily identifiable. This paper is also applicable to analysis of per capita energy consumption in different types of dwellings where multiple types of energy are consumed, such as solar, gas, electricity and wood (Talent et al., 2013).

Conclusion

The common conclusion that light rail is more energy efficient than buses may be erroneously reported because the results conflate difference in the transport modes with differences in the types of energy they use for propulsion; electricity and diesel, respectively. Only by comparing modes of transport using the same fuel source can accurate comparisons be made between competing transport modes. In the US electric cars and buses were found to use half the energy per passenger kilometre travelled as light rail or trolley buses.

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References

AUSTRALIAN ENERGY MARKET OPERATOR 2014. Electricity Statement of Opportunities for the National Electricity Market.

BONNAFOUS, A. & RAUX, C. Transport energy and emissions: rail. Handbook of Transport and Environment, 2003. Elsevier, pp. 293-307.

CAPITAL METRO AGENCY 2014. Capital Metro Full Business Case. Camberra: ACT Goverment.

CHAPMAN, L. 2007. Transport and climate change: a review. *Journal of transport geography,* 15**,** 354-367.

CHESTER, M. 2008. Life-cycle environmental inventory of passenger transportation modes in the United States PhD Dissertation University of California, Berkeley, CA, online, h ttp. *repositories. cdlib. org/its/ds/UCB-ITS-DS-2008-1*.

CHESTER, M. V. & HORVATH, A. 2009. Environmental assessment of passenger transportation should include infrastructure and supply chains. *Environmental Research Letters,* 4**,** 024008.

CROSSCHASM TECHNOLOGIES INC. 2015. *Real world vehicle mileage reports: 2012 Nissan Leaf* [Online]. Available: http://www.fleetcarma.com/Real-World/Gas-Mileage-MPG/Nissan-Leaf/2012 [Accessed 1/6/2015.

DAVIS, S. C., DIEGEL, S. W. & BOUNDY, R. G. 2014. Transportation energy data book: Edition 33.

ENVIRONMENTAL PROTECTION AGENCY (EPA). 2010. *Emissions & Generation Resource Integrated Database (eGRID)* [Online]. Available: http://www.epa.gov/cleanenergy/energy-resources/egrid/ 2015].

FLANNERY, D., DUARTE, R., NORMAN, B., O'DONNELL, T., SINCLAIR, H. & STEFFEN, W. 2015. Light rail transit and residential density in mid-size cities Canberra Urban and Regional Futures.

GEHM, R. 2015. *BYD electric bus provides 30-h service on single charge* [Online]. SAE International. Available: http://articles.sae.org/12804/ [Accessed 1/6/2015.

HALES, R. 2015. *Solar & Wind = 53% Of New US Electricity Capacity In 2014* [Online]. CleanTechnica. Available: http://cleantechnica.com/2015/02/03/solar-wind-53-new-us-electricity-capacity-2014/ [Accessed 10/6/2015.

HOLMAN, J. 1988. Thermodynamics. McGraw-Hill, New York.

KENWORTHY, J. 2007. Urban planning and transport paradigm shifts for cities of the post-petroleum age. *Journal of Urban Technology,* 14**,** 47-70.

KENWORTHY, J. R., LAUBE, F. B., NEWMAN, P., BARTER, P., RAAD, T., POBOON, C. & GUIA JR, B. 1999. *An international sourcebook of automobile dependence in cities 1960-1990*.

LOUKAITOU-SIDERIS, A. 2010. A new-found popularity for transit-oriented developments? Lessons from Southern California. *Journal of Urban Design,* 15**,** 49-68.

MORIARTY, P. & HONNERY, D. 2008. The prospects for global green car mobility. *Journal of Cleaner Production,* 16**,** 1717-1726.

NEWMAN, P. & KENWORTHY, J. Transportation energy in global cities: sustainable transportation comes in from the cold? Natural resources forum, 2001. Wiley Online Library, 91-107.

O'TOOLE, R. 2008. Does Rail Transit Save Energy or Reduce Greenhouse Gas Emissions? *Cato Policy Analysis*.

POTTER, S. 2003. Transport energy and emissions: urban public transport.

PUCHALSKY, C. 2005. Comparison of emissions from light rail transit and bus rapid transit. *Transportation Research Record: Journal of the Transportation Research Board***,** 31-37.

RICKWOOD, P., GIURCO, D., GLAZEBROOK, G., KAZAGLIS, A., THOMAS, L., ZEIBOTS, M., BOYDELL, S., WHITE, S., CAPRARELLI, G. & MCDOUGAL, J. Integrating population, land-use, transport, water and energy-use models to improve the sustainability of urban systems. State of Australian Cities Conference, 2007.

SALTELLI, A., RATTO, M., ANDRES, T., CAMPOLONGO, F., CARIBONI, J., GATELLI, D., SAISANA, M. & TARANTOLA, S. 2008. *Global sensitivity analysis: the primer*, John Wiley & Sons.

SHAPIRO, R. J., HASSETT, K. A. & ARNOLD, F. S. 2002. Conserving energy and preserving the environment: The role of public transportation. *American Public Transportation Association,* 9.

TALENT, M., TROY, P. & DOVERS, S. 2013. *Canberra Residential Energy and Water Consumption Baseline Report,* Canberra, Australia, Australian National University.

US DEPARTMENT OF TRANSPORTATION. 2012. *National Transit Database* [Online]. Available: http://www.ntdprogram.gov/ntdprogram/.

US DEPT. OF ENERGY 2009. Where the Energy Goes: Gasoline Vehicles. *Advanced technologies and energy efficiency, Fuel Economy Guide.*

VINCENT, W. & JERRAM, L. C. 2006. The Potential for Bus Rapid Transit to Reduce Transportation-Related CO 2 Emissions. *Journal of Public Transportation,* 9**,** 12.

VOELCKER, J. 2015. *Plug-In Electric Car Sales In June: Leaf, Volt Wane After May Surge: FINAL UPDATE* [Online]. Available: http://www.greencarreports.com/news/1098948_plug-in-electric-car-sales-in-jun-leaf-volt-wane-after-may-surge [Accessed 1/6/2015.