Cost effectiveness of CO_2 reduction with hybrid and electric buses in developing countries

Summary

Hybrid and electric technologies may be the future of clean urban surface transport. However, it is unclear whether the cost effectiveness of CO_2 reduction through the use of these technologies justifies its implementation in developing countries. Data from 2014 suggest that hybrid buses are close to reaching acceptable cost-effectiveness levels, but they require further reductions in battery prices to achieve these levels. With regard to electric buses, acceptable cost-effectiveness levels are still far away. We recognize the need to foster the use of these technologies in order to go forward in the cost-reducing learning curve. However, in fiscally constrained developing countries with mainly private operations and no relevant national bus-manufacturing industry, we recommend that these countries (a) conduct a thorough analysis before these technologies are adopted, and (b) consider focusing on system sustainability or more cost-efficient measures to boost CO_2 emission reductions.

Methodology and assumptions on emission-reduction calculation

We use the method for calculating greenhouse gas (GHG) emissions for subprojects in the "Urban Transport Transformation Project" (Scorcia 2011). The model includes the calculation of four variables: (A) a dynamic baseline of the emissions generated by public transport in the intervention corridor, without project; (B) the estimated emissions generated by public transport in the corridor, with project; (C) the estimated avoided emissions linked to passengers who shift from cars to the new system, with project; and (D) the estimated emissions of the old fleet that continues operating after the project is implemented. Total GHG emissions reduced by the project correspond to: A + C - B - D. For a more detailed explanation of the method and additional resources, we recommend the economic analysis in the Implementation Completion Report on the P114012 GEF–STAQ Project (Perez-Prada 2016).

For purposes of comparing the potential CO_2 reductions of different measures, we have built on data in the feasibility study for the Ecovía BRT Corridor in Monterrey, Mexico. This is a 30-km feeder trunk corridor with 42 stops and an expected 130,000 daily passengers. The main assumptions we used in the model are:

- Old fleet daily vehicles-kilometers (veh-km): 175,893 veh-km.
- Old fleet emissions factor: 0.001521557 metric tonnes CO_2/km.[1]
- Traffic and public transport use–annual growth (with and without project): 1%.
- Number of days per year: 312.
- Private vehicle–average occupancy: 1.2.
- Average kms travelled by private vehicles, per year: 10,000.
- Number of trips per person in private vehicles, per day: 2.

Under these assumptions, we compare the potential CO_2 emissions in the corridor by achieving:

- A 10-percent modal shift from private cars to buses: Modal shift data as a percentage of total ridership—usually calculated with surveys of car-owner bus users—range from the 3 percent reported for the Metropolitano in Lima, Peru, or the 3.7 percent[2] for the Ecovía in Monterrey, to the 10 percent reported by Metrobus in Mexico City. We have chosen 10 percent as a desirable and potentially achievable percentage of modal shift for two reasons. First, because it is achievable in the proper context and with specific interventions and ancillary investments[3] (Wright and L. Fulton 2005). Second, because the data only accounts for users that stop using the cars. From a dynamic perspective, and taking into account motorization growth with income, it is

[1] This corresponds to a weighted average of 12-m diesel bus (70 percent), gasoline microbus (25 percent), and liquefied petroleum gas (LPG) microbus (5 percent) emission factors. The percentages reflect the fleet composition in Mexico City?. Emission factors per vehicle typeare from Mexico City (Metrobus 2010).

[2] Estimation from feasibility studies for Ecovia 2: Corredor Constitución – Morones Prieto. 2016

[3] Trasport demand management measures, proper intermodal integration, non-motorized transport interventions (pedestrian pathways, bike lanes)

realistic to assume that the new system will not only stop users from using cars, but also prevent current transport users from buying cars.
- 30-percent vehicles km rationalization: Inefficient systems can benefit from rationalization of fleet and routes. Although it is highly dependent on the context and efficiency of the system in the baseline scenario, there are examples in Mexico that justify this figure (e.g., Red Q in Querétaro).
- 30-percent reduction in emission factors: This corresponds to the average fuel-consumption reduction of hybrid technologies relative to equivalent diesel technologies (see References for data sources).

Methodology and assumptions on cost-effectiveness calculations

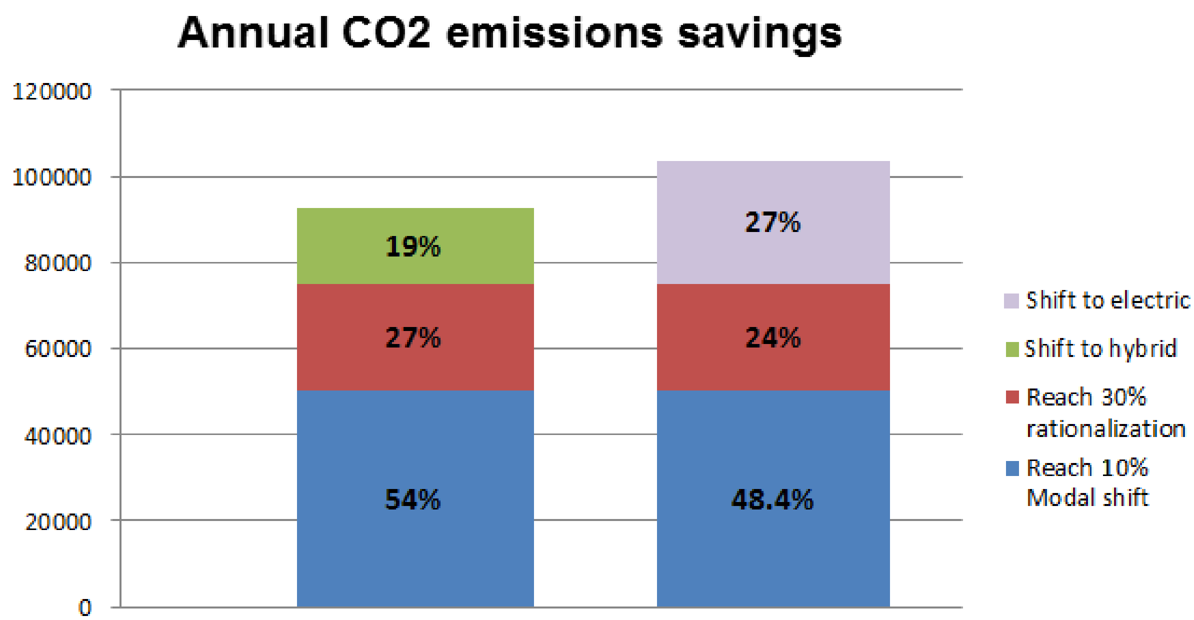
General Method. We have used a marginal abatement cost (MAC) approach to calculate the economic cost of reducing a tonne of CO_2e through the use of hybrid and electric bus technologies. The MAC is defined as the economic cost of reducing an additional tonne of pollutants: CO_2e in our case. First, we have calculated the difference between the net present value (NPV) of the total life-cycle cost of a hybrid bus and an electric 12-m bus, and that of an equivalent diesel bus. From the resulting value, we have subtracted the economic benefits of local pollutant emission reductions linked to hybrid and electric technologies: particulate matter (PM), nitrogen oxides (NOx) and carbon monoxide (CO). The resulting value is the economic cost of shifting from diesel to hybrid or electric, without taking into account CO_2 reductions. Finally, we have divided the economic cost of shifting from diesel to hybrid or electric by the associated total emission reductions associated with hybrid and electric technologies. The final result is the economic cost of reducing a tonne of CO_2e. We do not take into account any indirect or system level effect, such as the effect of supporting these technologies from an industrial strategy perspective. We have compared a model we developed with a model developed by Grütter and Dang,[4] which uses the same methodology with very similar assumptions.

Assumptions. For purposes of the analysis, we have made the following assumptions:
- No marginal cost of public funds.
- No penalization on availability linked to electric batteries because of limited battery life.
- Diesel, electric and hybrid buses' operation and maintenance (O&M) costs are the same, except for fuel consumption.
- Lifespan of a bus: 10 years.
- Lifespan of a battery: 6 years.
- Diesel cost: US$1/liter.
- Km per year per vehicle: 75,000.
- Hybrid fuel efficiency relative to diesel equivalent: 31.29%.
- Market interest rate: 8 percent.
- Cost of a 12-m diesel bus: US$150,000.
- Premium[5] acquisition cost of hybrid bus relative to equivalent diesel bus: 60%.
- Premium acquisition cost of electric bus relative to equivalent diesel bus: 100%.
- Battery replacement cost for hybrid bus: 15% of vehicle's initial value.
- Battery replacement cost for electric bus: 50% percent of vehicle's initial value.
- Electricity consumption of electric bus: 1 kilowatt hour (kWh)/km.
- Emission factor of grid: 0.60 kg of CO_2e/kWh.
- Fuel consumption of 12-m diesel bus: 2 km/l.
- PM economic value: US$20,000 per tonne.
- NOx economic value: US$1,500 per tonne.
- CO economic value: US$500 per tonne.
- Electricity price: US$0.03/Kwh

Results

[4] (Grütter and Dang 2014)
[5] Although prices differ in various countries and regions, premiums for hybrid and electric buses are similar.

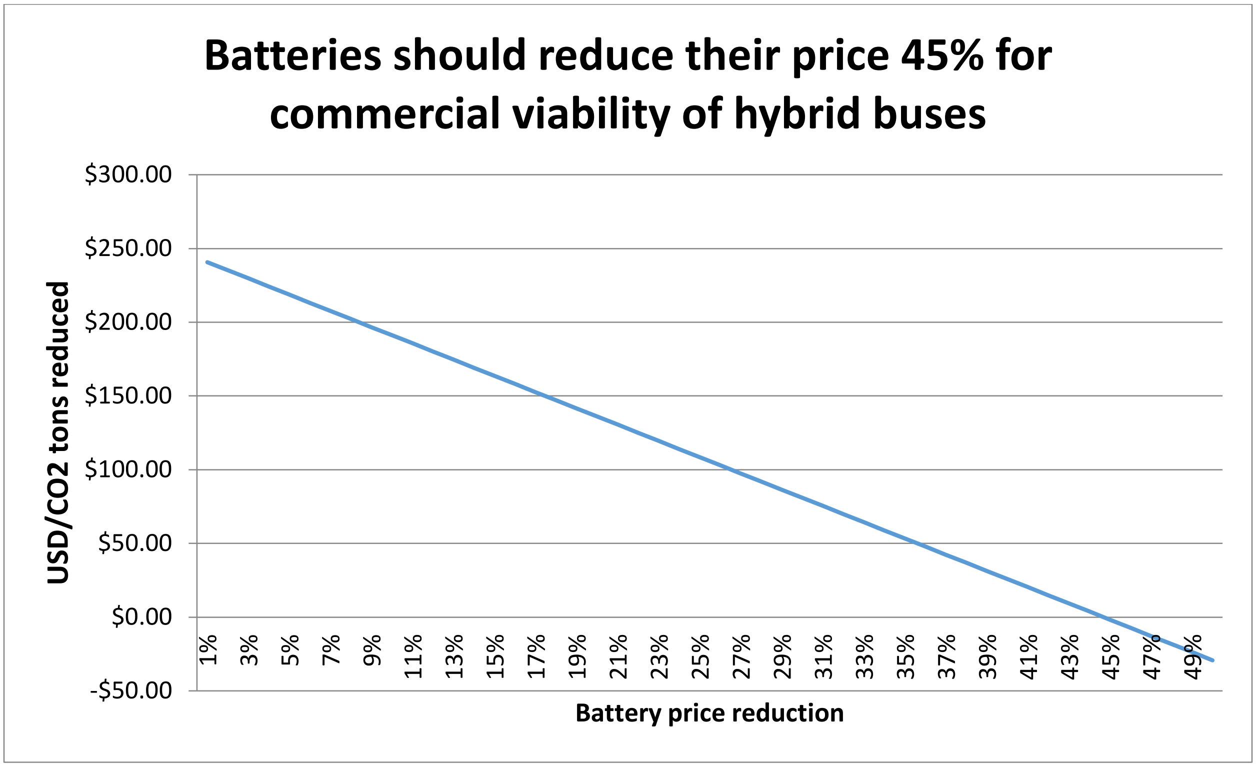
Modal shift has the greatest CO_2e emission reduction potential. The first result we obtained is that modal shift has greater potential to achieve CO_2e emission reductions. As shown in the image below, we estimate that achieving a 10-percent modal shift can triple the CO_2e reduction when compared to shifting to hybrid buses, and nearly double it when compared to electric buses.



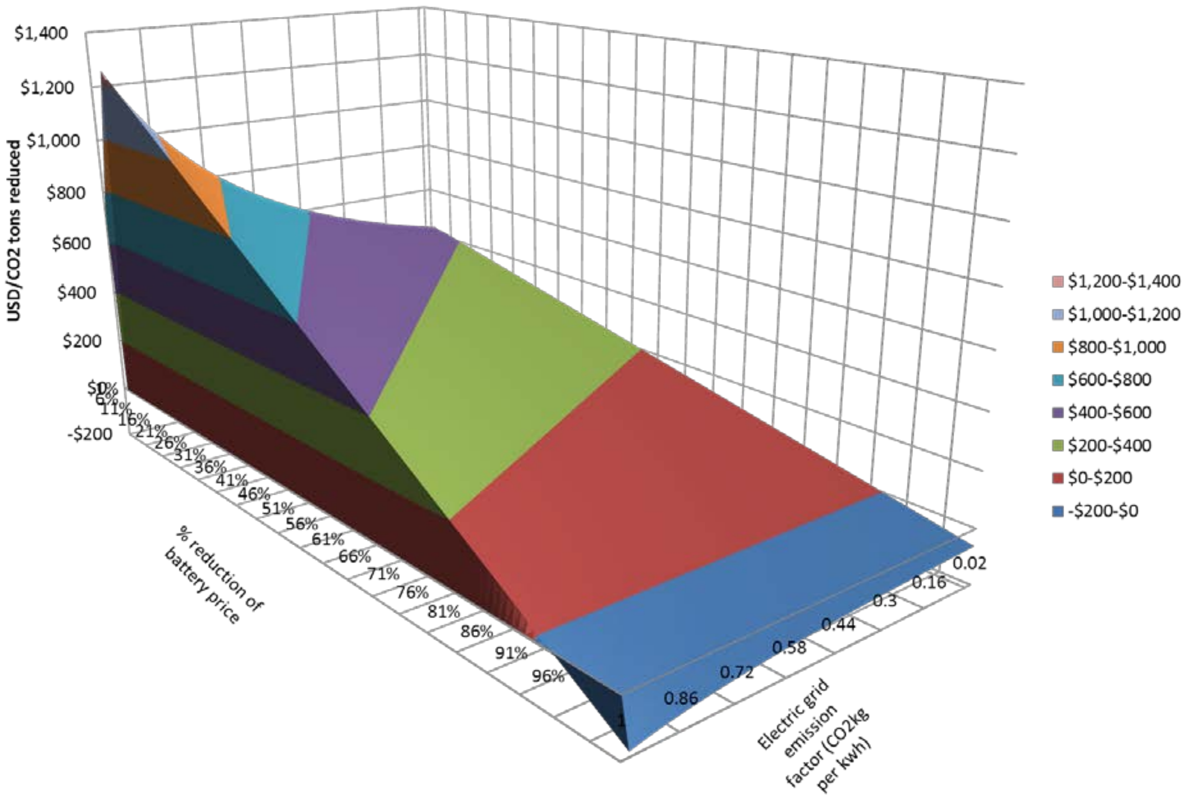
Reducing CO_2e by shifting to hybrid or electric technologies may not yet be cost efficient. Subsidizing hybrid buses results in costs of US$100 to US$250 per CO_2 ton. This same figure can reach US$750 for electric buses. Both are over the US$100 threshold of acceptable cost efficiency[6] for GHG emission reductions.

Hybrid battery prices must decrease by 27 percent to achieve CO_2 reduction cost effectiveness below US$100, and 45 percent to achieve commercial viability. In the case of hybrid buses, our simulation estimates that battery prices should drop by 45 percent in order to achieve higher profitability than that of their diesel equivalents. There is a linear relationship between the cost of batteries and the cost-efficiency of hybrid vehicles. We estimate that for each percentage point to reduce the cost of batteries, reducing one ton of carbon will be approximately US$5 cheaper (see chart below).

[6] For instance, the Clean Technology Fund considers US$100 as a threshold for acceptable cost efficiency.



With regard to electric buses, achieving acceptable cost effectiveness levels would require 75 percent of battery prices reductions, and commercial viability would require 90 percent redictopm.The effect of the energy grid's efficiency on commercial viability is practically negligible. The analysis is slightly more complex because in the case of electric buses, in addition to the price of batteries, we must take into account the efficiency level of the country's or region's electricity production (the kilograms of carbon that electricity generators emit to produce 1 kWh of electricity, with which we charge the batteries). A standard order of magnitude for the emissions of an energy grid in Mexico is 0.6 kg of CO_2e/kWh generated, while that of Spain is 0.3 kg of CO_2e/kWh. An electric bus consumes 1 kWh per km traveled, so that kilometer would be emitting 0.6 kg of CO_2 if it operated in Mexico and 0.3 kg of CO_2e in Spain. The relatively large reduction in the price of batteries to achieve commercial viability leads to the not-very-intuitive result that the effect of the energy grid's efficiency on the cost of the buses is not very relevant. The figure below is a graphic example of this approach.



Political economy implications

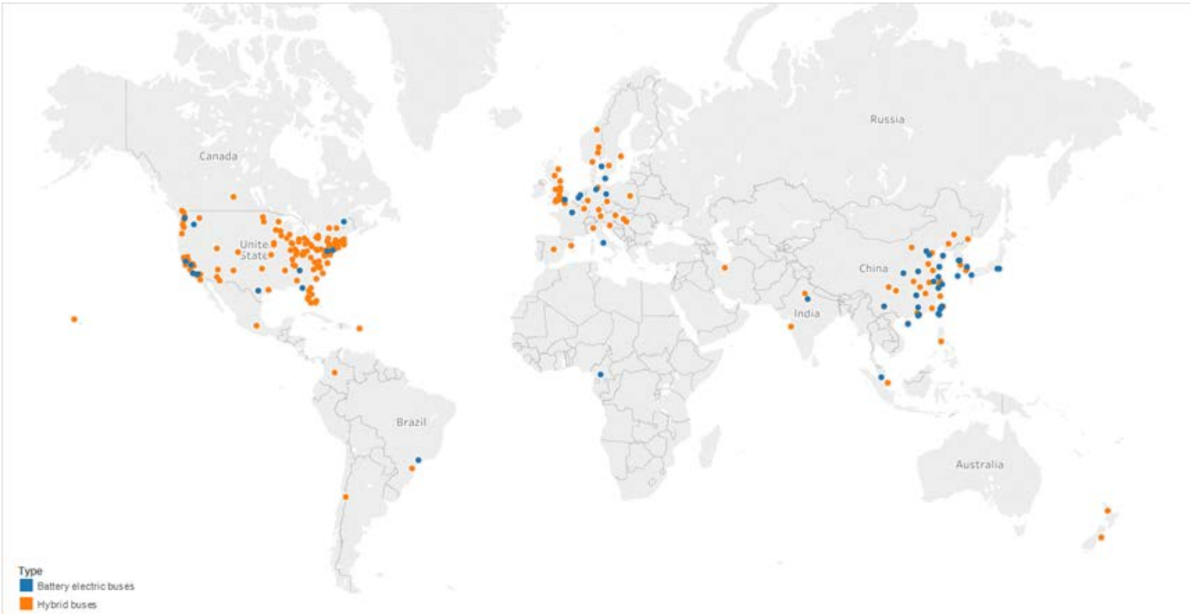
For systems in developing countries with large fiscal constraints and private operations, the additional resources required to introduce hybrid and electric technologies can be much better utilized by supporting the systems' sustainability or more efficient complementary investments. In contexts such as private bus concessions in Latin America, many systems that operate with diesel buses have major liquidity problems which endanger these systems. Fiscal constraints and/or tradition prevent many governments from providing much needed subsidies. In addition, even in places with subsidies for public transport, the systems lack efficiency due to inefficient projects and markets structures. In these cases, any available resources must be used to safeguard the systems' sustainability and, once this is achieved, be used in a way that presents the greatest cost efficiency for reducing emissions.

However, it is advisable to continue to support new technology production in order to go forward in the learning curve and maintain the downward trend in battery prices. Although we are still far from a 90-percent reduction in battery prices that will make electric buses viable, a 45-percent reduction is just around the corner. In the last 10 years, battery prices have collapsed, with reductions of up to 90 percent. Although the drop in prices has begun to slow down, the trend indicates that we are most likely to achieve reductions, such as those needed, between 2020 and 2025.[7] Therefore, it may make sense to use public funds to support hybrid and electric technologies in regions with public operators. The existence of such operators makes it possible to reduce the transaction cost/inefficiency associated with the subsidy which, in this case, would constitute a higher cost to public operators.

The existence of a national industry and public operators are factors that can favor support to new technologies. A national bus-manufacturing industry can justify the subsidies to strategically go forward the learning curve and position the national industry at the forefront of the production of technologies of the future. Moreover, the existence of public operators makes it possible to reduce the transaction cost/inefficiency associated with the subsidy which, in this case, would constitute a higher cost to public

[7] Nature Climate Change (2015). Available at http://www.nature.com/nclimate/journal/v5/n4/pdf/nclimate2564.pdf.

operators. According to the map below (presented by the WRI at the 2017 Transforming Transportation Conference), it seems that the market is already positioning itself in this way by concentrating the production of these technologies in the U.S., China and Europe where there are public operators and local bus-manufacturing industries.



Source: Xiangyi Li /WRI

Next steps

Due to fast-changing figures in terms of battery prices and the age of data, we plan to update this report in the following months with data from after 2014. We will also refine the emissions model by adapting the United Nations-approved emissions reduction estimation model for Metrobus Line 1 (Insurgentes Corridor) in Mexico City.

Acknowledgements

Prepared in March 2017 by Alejandro Hoyos Guerrero. Peer Reviewed by Yang Chen. Emission calculations based on the Urban Transport Transformation Project Emissions Reduction Model developed originally by Harvey Scorcia and reviewed and improved by Leonardo Canon, Alejandro Hoyos Guerrero, Yang Chen, and Fiamma Perez-Prada. Cost-effectiveness calculations based on the model developed by Grütter Consulting (Grütter and Dang 2014) and the model developed by Alejandro Hoyos Guerrero.

References and Data Sources

Hybrid-Diesel vs. CNG (An updated comparison of transit fleet alternatives), Steve Richardson, President, Public Solutions Group, Ltd. (January 2013).

Rio de Janeiro. Low-carbon technologies can transform Latin America's bus fleets. C40 Cities Initiative. April 25, 2013.

Low-carbon technologies can transform Latin America's bus fleets. C40 Cities initiative. April 25, 2013.

USA. DOE/FTA Fuel Cell Research Priorities Workshop. Bart W. Mancini. June 7, 2010.

USA. Tech Brief, October 2012. Assessing the Costs for Hybrid versus Regular Transit Buses

USA. Clean Diesel versus CNG Buses: Cost, Air Quality, and Climate Impacts. Dana Lowel to Conrad Schneider, Clean Air Task Force. February 22, 2012.

USA. New York City Transit Hybrid and CNG Transit Buses: Interim Evaluation Results. K. Chandler and E. Eberts Battelle L. Eudy National Renewable Energy Laboratory. 2006.

USA. NREL Technical Report NREL/TP-540-40125. Barnitt and Chandler. November 2006.

Estudios de factibilidad del Corredor Lincoln Ruiz Cortines en México Monterrey.

Tech Brief (Chandler and Walkowicz 2006 NYCT).

IADB. Análisis de buses de bajas emisiones de CO_2 en el marco del "Sistema Integrado de Transporte" de la ciudad de Bogotá. Daniel Magallon. 2013.

Global Environment Facility. Manual for Calculating Greenhouse Gas Benefits of Global Environment Facility Transport Projects. Available at: http://www.unep.org/stap/Publications/AdvisoryProductsofSTAP/ManualforCalculatingGHGBenefits/tabid/52256/Default.aspx

The Fuel Economy of Hybrid Buses: The Role of Ancillaries in Real Urban Driving. Francesco Bottiglione, Tommaso Contursi, Angelo Gentile and Giacomo Mantriota. July 1, 2014.

Duluth Transit Authority. 2014. http://www.duluthtransit.com/green/hybrid Michigan

Metro Transit Authority Minneapolis 2013. http://www.metrotransit.org/super-hybrids-KFAI

Hybrid–Electric Bus Test Program in Latin America. Final Report, International Sustainable Systems Research Center–ISSRC. January 2013 (Euro IV vs Parallel).

Análisis de buses de bajas emisiones de CO_2 en el marco del "Sistema Integrado de Transporte" de la ciudad de Bogotá. BID. Daniel Magallon. 2013

New York City Transit (NYCT) Hybrid (125 Order) and CNG Transit Buses. R. Barnitt National Renewable Energy Laboratory. K. Chandler Battelle. Technical Report NREL/TP-540-40125. November 2006.

King County Metro Transit Hybrid Articulated Buses: Final Evaluation Results. K. Chandler Battelle, K. Walkowicz. National Renewable Energy Laboratory Technical Report NREL/TP-540-40585. December 2006.

New York City Transit Hybrid and CNG Transit Buses: Interim Evaluation Results. K. Chandler and E. Eberts Battelle L. Eudy National Renewable Energy Laboratory Technical Report NREL/TP-540-38843. January 2006.

Case Study: Ebus Hybrid Electric Buses and Trolleys. R. Barnitt. Technical Report NREL/TP-540-38749. July 2006.

Pruebas a autobuses de bajas emisiones para la Ciudad de México 2011. Developed by Balam for Metrobus.

Grütter, Jürg, and Ly Dang. Comparison of Hybrid and Electric with Diesel Bus, version 1.1. Model, Grütter Consulting, 2014.

Metrobus. Reporte de Reducción de Emisiones Metrobus 2009–2010. Mexico City: Metrobus, 2010.

Nature Climate Change (2015). Available at

http://www.nature.com/nclimate/journal/v5/n4/pdf/nclimate2564.pdf

Perez-Prada, F. Implementation Completion and Results Report, Mexico GEF Sustainable Transport and Air Quality Project. Project Document, World Bank, 2016.

Scorcia, H. Metodología para el cálculo de reducción de emisiones de gases de efecto invernadero para subproyectos del Proyecto de Transformación del Transporte Urbano. Project Document, unpublished manuscript, 2011.

World Bank. Natural Hazards, Unnatural Disasters: The Economics of Effective Prevention. Washington DC: The World Bank, 2010.

Wright, L., and L. Fulton. Climate Change Mitigation and Transport in Developing Nations. Transport Reviews, Vol. 25, No. 6, 2005.

Dargay et al. Vehicle Ownership and Income Growth, Worldwide: 1960–2002. 2007. Available at: http://www.econ.nyu.edu/dept/courses/gately/DGS_Vehicle%20Ownership_2007.pdf

Federal Transit Administration. Applicability of Bogota's Transmilenio in the United States. 2006. Available at: http://www.nbrti.org/docs/pdf/Bogota%20Report_Final%20Report_May%202006.pdf

Global Environment Facility. Manual for Calculating Greenhouse Gas Benefits of Global Environment Facility Transport Projects. Available at: http://www.unep.org/stap/Publications/AdvisoryProductsofSTAP/ManualforCalculatingGHGBenefits/tabid/52256/Default.aspx

Inter-American Development Bank. CTF – Investment Plan. Integrated Transport System Projects GHG Emission Reduction Potential, 2011