Cost effectiveness of CO₂ 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 CO₂ 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 CO₂ 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 CO₂ 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 CO₂/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 CO₂ 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 percent² 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 investments³ (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?.
² Estimation from feasibility studies for Ecovia 2: Corredor Constitución – Morones Prieto. 2016
³ Transpor 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$_2$e 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$_2$e 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$_2$e. 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$_2$e/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 CO₂e emission reduction potential.** The first result we obtained is that modal shift has greater potential to achieve CO₂e emission reductions. As shown in the image below, we estimate that achieving a 10-percent modal shift can triple the CO₂e reduction when compared to shifting to hybrid buses, and nearly double it when compared to electric buses.

![Annual CO2 emissions savings](chart.png)

**Reducing CO₂e 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 CO₂ ton. This same figure can reach US$750 for electric buses. Both are over the US$100 threshold of acceptable cost efficiency⁶ for GHG emission reductions.

**Hybrid battery prices must decrease by 27 percent to achieve CO₂ 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).

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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 reduction. 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 CO₂e/kWh generated, while that of Spain is 0.3 kg of CO₂e/kWh. An electric bus consumes 1 kWh per km traveled, so that kilometer would be emitting 0.6 kg of CO₂ if it operated in Mexico and 0.3 kg of CO₂e 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. 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 operators.

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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.

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