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Long term energy and emission implications of a global shift to electricity-based public rail transportation system

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HIGHLIGHTS

- Economy wide carbon price policy will have little impact on transportation emissions.
- Focused energy and emission mitigation policies required for transportation sector.
- Large global shift towards electric rail based public transport is one possible option.
- Transport sector focused policy will have marginal impact on total global emissions.
- A combined transport sector and economy wide policy can reduce costs significantly.

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ABSTRACT

With high reliance on light-duty vehicles in the present, the future of global transportation system is also geared towards private modes, which has significant energy and emission implications. Public transportation has been argued as an alternative strategy for meeting the rising transportation demands of the growing world, especially the poor, in a sustainable and energy efficient way. The present study analyzes an important yet under-researched question – what are the long-term energy and emission implications of an electric rail based passenger transportation system for meeting both long and short distance passenter transportation needs? We analyze a suite of electric rail share scenarios with and without climate policy. In the reference scenario, the transportation system will evolve towards dominance of fossil based light-duty vehicles. We find that an electric rail policy is more successful than an economy wide climate policy in reducing transport sector energy demand and emissions. Economy wide emissions however can only be reduced through a broader climate policy, the cost of which can be reduced by hundreds of billions of dollars across the century when implemented in combination with the transport sector focused electric rail policy. Moreover, higher share of electric rail enhances energy security for oil importing nations and reduces vehicular congestion and road infrastructure requirement as well.

1. Introduction

Transport sector was highlighted in the Kyoto Protocol as one of the key sectors to be tackled for meeting ambitious global greenhouse gas emission reduction targets (Chapman, 2007). Between 1970 and 2010, global transport sector CO_2 emissions increased by 250% growing at significantly higher rate compared to other sectors (IPCC, 2014), while final energy consumption in this sector increase by 220% between 1973 and 2010 (IEA, 2012). By 2010, the transport sector accounted for 23% of global carbon dioxide (CO_2) emissions from fossil fuel combustion with 80% of increase coming from road vehicles (IPCC, 2014). Contrary to what was the global priority highlighted in the Kyoto Protocol, carbon intensity of energy consumed in the transport sector has not decreased in the last two decades, even though energy efficiency of this sector has increased significantly.

Reducing emissions from the transportation sector has been seen as a more costly option due to distributed emission sources, high dependence on liquid hydrocarbon fuels where emission mitigation options are limited, and low responsiveness of passenger service demand to fuel price increases (Kyle and Kim, 2011). Different strategies for reducing energy demand and emissions from the transportation sectors have been discussed

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and debated by researchers and policy makers. Some key strategies discussed in the literature are (i) Land use and urban planning for reducing passenger travel demand (van Wee, 2002; Brommelstroet and Bertolini, 2008; Bartholomew and Ewing, 2009; Limtanakool et al., 2006); (ii) Fuel switching to electric, biofuel and hybrid vehicles (Litman, 2007; Bayindir et al., 2011; Zheng et al., 2012; Kyle and Kim, 2011); and (iii) Improving vehicle fuel efficiency[1] which varies widely across regions (An and Sauer, 2004).

Shifting towards a higher share of public and mass rapid transportation system has been proposed and discussed as another important strategy for mitigating emissions from the transport sector (Hensher, 2007; GEF-STAP, 2010; The World Bank, 2012). Currently, private vehicles are a dominant provider of passenger service demand globally (IPCC, 2014). A vast difference can be observed in the regional patterns, with the richer countries more dependent on private modes while non-motorized and public transportation modes being dominant in the developing nations. UITP (2009) shows that cities where modal share of private motorized vehicles is above 75% produce 2.5 t more CO_2 per passenger per year, or more than four times, than cities where the share of public transport, cycling and walking together is more than 55%. However, in developing countries, where most of the future transportation growth and infrastructure investments will occur, it is expected that the future share of public transport and non-motorized transport will decrease (GEF-STAP, 2010).

Rail based urban passenger transport system is an important element in the public transportation strategy of many countries and cities (Priemus and Konings, 2001; Phang, 2002; Cascetta and Pagliara, 2008), including many cities in Brazil, Canada, China, India and the USA.[2] Electric rail technology is increasing its presence in many urban centers around the world as multiple benefits of electric rail systems, such as reliable and safe transportation service to commuters, higher energy efficiency compared to other modes of travel (Electris et al., 2009), reduced local air pollution and carbon emissions (IIMA et al., 2009), reduced congestion, and improved energy security by reducing oil dependence-make it an attractive investment option.

In our study we focus on this under-researched subject of electricity rail based public transportation system (both for long distance as well as short distance commuting) for meeting energy and climate mitigation objectives. A recent study by McCollum et al. (2014) highlights the importance of transport electrification for energy system transformation and climate stabilization. However the McCollum et al. study only captures fuel switching and price elastic demand response at the aggregate level of the entire transport sector and individual transport modes are not explicitly modeled. On the other hand our model explicitly models different modes and allows us to specifically model electric rail scenarios for meeting future passenger transportation service demands. We ask the following research questions: (i) How would transportation sector evolve in the future under a business as usual scenario and a climate policy scenario, with specific reference to light duty vehicles (LDVs) versus public transportation; (ii) What are the long term energy and emissions implications of an electric rail based global transportation system and its role in a climate policy world?, and (iii) What is the economic value of including an electric rail push policy as a part of broader economy-wide emission mitigation effort? We address these important yet under-researched questions within an integrated assessment energy and climate change modeling framework. We model scenarios of varying share of electric rail in meeting all long and short distance passenger travel service demands to find its impact under the business as usual as well as under a climate policy scenario. The next section describes the modeling framework followed by the scenario design. The results and discussions are presented next, and finally the conclusions are presented. It should be noted that the aim of the analysis is to investigate the impact of higher share of electric rail technology on global energy and emission mitigation efforts and not how such high shares are to be achieved. We provide potential motivations for the increased investment in public electric rail systems from a global perspective. The realistic implementation of such efforts will depend on the transportation sector policies of each country as well as local governments.

2. Methodology

We use the Global Change Assessment Model (GCAM) for exploring the implications of a higher share of electric rail in global passenger transportation service. GCAM is an integrated assessment model that has a particularly rich representation of the overall energy system. It accounts for GHG emissions from the energy sectors, as well as from agriculture and land use change. GCAM disaggregates the world into 14 regions, and represents economic markets for fossil fuels, renewables, as well as biofuels, synthetic fuels and agricultural commodities. GDP, population and prices drive energy service demands in the end-use sectors; services are provided through the suite of end-use and energy conversion technologies. Additional information on GCAM can be found in Edmonds and Reilly (1983), Edmonds et al. (1996), Clarke and Edmonds (1993), Kim et al. (2006), Clarke et al. (2008), Chaturvedi et al. (2013, 2014).

Transportation sector is one of the three end-use energy sectors modeled in GCAM, along with industry and buildings. Within the transportation sector, energy consumption is modeled for three transport services—freight, international shipping, and passenger. Within passenger transport, which is the focus of our study, there are a variety of modes (light-duty vehicles, trains, buses, airplanes) that compete for service. Within each mode, alternative vehicle technologies (e.g. electric, biofuel, hydrogen fuel cell, and fossil-fuel based vehicles) compete for service.

More broadly, transportation service demand in GCAM is dependent on the GDP, population, and the price of transportation service aggregated across all modes. The transportation service price of a given mode is dependent on fuel price, vehicle fuel intensity, vehicle non-fuel price (representing the capital cost, maintenance cost and others such as insurance cost), and load factor. Additionally, GCAM includes the value of time spent in transit as part of the service cost in competing alternative modalities. The fuel price, and the variable component of the service price, is determined endogenously while all other parameters are exogenous to the model. The market share captured by each modality is determined by a logit formulation and the cost of each mode for providing transport services (Clarke and Edmonds, 1993). Fuels supplied to vehicle technologies include refined liquid fuels, natural gas, electricity and hydrogen. Detailed structure of the transportation sector in GCAM and the relevant algebraic relationships can be found in Kyle and Kim (2011). Please refer Appendices 1 and 2 for details related to all the passenger transport modes and technologies modeled within GCAM, the assumed fuel intensities, as well as load factors for different modes.

The present study focuses on the implications of modal shift towards electric rail based passenger transportation system. It is important thus to discuss the modal choices available for passengers in GCAM. The freight transportation sector is not discussed

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[1] Schipper (2011), and Litman (2005). and however argue that this strategy is overvalued.

[2] http://www.world-metro.org/en/; http://www.lightrailnow.org/news/n_newslog002.htm; http://www.lightrail.com/; http://indiatoday.intoday.in/story/metro-rail-intra-city-commuting/1/160680.html.