Life Cycle Assessment of Shanghai Electric Vehicle Subsidy

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ABSTRACT

Rapid motorization is exacerbating China's growing greenhouse gas emissions from the transportation sector. To meet its target in abating greenhouse gas emissions, China promotes and subsidizes purchase of electric vehicles (EVs) as an alternative to conventional vehicles. This research assesses the environmental impact of the transportation subsidy policy in Shanghai, China. To model the effect of the policy, the life cycle emissions from different vehicle composition and electricity generation scenarios were calculated using the GREET model. Results indicate that encouraging the adaption of EVs via subsidy can reduce carbon emissions and air pollutants include violate organic compound (VOC), carbon monoxide (CO) and nitrogen oxide (NOx). However, it can increase air pollutants, such as particulate matter 10 (PM 10), particulate matter 2.5 (PM 2.5) and sulfur oxide (SOx). This suggests that while the policy has positive effect on mitigating emissions, it is worsening the already poor urban air quality. When coal powered energy is partially substituted with renewable energy sources, having more EVs is more effective in reducing carbon emission and all air pollution.

KEYWORDS

Life Cycle Assessment, GREET model, Carbon Emissions, Air Pollution, Transportation

INTRODUCTION

Increase in material wealth in China has resulted in a rapid rise in vehicle ownership (Chen and Zhang, 2012). Concurrently, Chinese motorization's negative environmental impacts are also growing steadily. Transportation is a major contributor to rising concentrations of anthropogenic greenhouse gases that affect global and regional climate patterns (IPCC, 2007). Problems related to road transportation are particularly pronounced in China. In the past two decades, China has experienced the most rapid economic growth, and has emerged as the world's second largest economy (Allen et al., 2005). China has also become the highest carbon emitting country (IEA, 2015). In 2013, the total number of vehicles on the road was approximately 13.7 million. This value has increased 13.7% in the past year (National Bureau of Statistics of People's Republic of China, 2014). Projections forecast that privately owned vehicles and gasoline demand will continue to increase and generate more greenhouse gas emissions and other pollution (Chen et al. 2007 and Gan, 2003). Therefore, it is important to find a sustainable transportation management method to deal with the rising demand for vehicle travel and its concerning environmental impacts, while maintaining this sector's economic value.

Chinese government has taken different measures to mitigate the environmental impacts of transportation. Aiming to improve air quality and traffic, the government implemented policies to restrict purchase of automobile by limiting the release of new license plates through lottery and to restrict the number of days the vehicles can be driven on the roads. The policies were successful in reducing pollution and carbon emissions in short run (Zhou et al., 2010 and Wang et al., 2009). However, research has found there is no significant in reducing fossil fuel consumption nor improving pollution reduction in the long run (Sun et al., 2014 and Yang et al., 2014). Therefore, restricting the number of on-road vehicles may not have the long-term desired result on emissions reductions in China. Big cities like Beijing and Shanghai have also implemented their own set of policies on transportation. In recent years, Shanghai has put a series of transportation subsidy policy into effect. Their intention is to reduce transportation sector emissions by promoting purchase of electric vehicles (EVs). Yet, the results of these programs are rarely monitored and evaluated; therefore, there is need to investigate the progress and current status of the programs and ensure they are effective in migrating transportation externalities as intended.

In theory, subsidy incentivizes consumers to purchase EVs instead of conventional vehicles, which will reduce reliance on gasoline, and thereby, carbon emissions and air pollutants in Shanghai; however, the story is much more complicated when we assess the whole life cycle of EVs in detail. Compared to conventional vehicles, EVs have zero tailpipe emissions, as they are powered by batteries rather than combustion engines (Michalek et al., 2011). This eliminates the mobile source of air pollution from driving. But based on differences in the sources that are used to generate electricity, the amount of life cycle emissions can fluctuate. EVs that rely on coal power do not have a significant effect on carbon emissions reduction compared to conventional vehicles (Hawkins, et al. 2013). However, when the coal power plants install carbon capture technologies, vehicle lifecycle emissions are reduced significantly (Ou et al., 2010). As a result, there is no concrete conclusion regarding whether EVs are effective in reducing both carbon and air pollution emissions. From this, a major concern around promoting EVs arise in China – China uses coal as the primary source to generate energy and these power plants release pollutants such as sulfur dioxide (SO2), nitrogen oxide (NOx) and particulate matter. However, the Chinese government has put substantial fund into subsidizing EVs to mitigate the negative externalities of vehicle travel. In another word, increasing the use of EVs in lieu of conventional vehicles may not be able to migrate the problem and meet the program objectives given the state of China's energy and charging infrastructure.

This study will assess transportation subsidy policy in Shanghai. This site-specific study will allow me to be more accurate in quantifying the carbon and pollution emissions of Shanghai's current on-street fleet since lifecycle emissions can vary with different energy sources based on geographical locations. More importantly, small unit coal power plants in China emit higher level of pollutants because they do not have adequate emission control technologies (Zhao et al., 2008). And coal will remain a major source for power generation in China's foreseeable future because it is the cheapest source of electricity (Powers, 2009). These two factors might undermine the ability of EVs to reduce lifecycle vehicle emissions. Therefore, this research will evaluate the current status and the long-term effects of the policy – to ensure it is meeting the goal of mitigating transportation externalities. The project will also provide insight into which stages of the lifecycle of EVs require further technology improvements to reduce emissions. This, in turn, will allow me to propose alternative management methods that can migrate the negative externality of the transportation section.

BACKGROUND

Shanghai's Subsidy Policy

Road transportation emits carbon dioxide and other potent greenhouse gases including methane (CH_4), nitrogen oxide (NOx), nitrous oxide (N_2O), and sulfur dioxide (SO_2) (El-Fadel and Bou-Zeid, 1999). These particulate matters present are hazardous to public health (Kan et al., 2008). Recognizing the negative externalities related to increasing vehicle demand, The State Council of the People's Republic of China has announced the *Planning for the Development of Energy-Saving and New Energy Automobile Industry*. Under this plan, the central government has identified investing in alternative fuel vehicle technology as a means to ease the country's dependency of fossil fuel, reduce tailpipe emissions, improve the environment and promote technological progress of the auto industry (State Council).

I chose Shanghai as my study site because as one of the most developed cities in China and the role model of many developing cities, Shanghai is facing an unsustainable transportation issue. Shanghai is the most populous city in China, and is also a major global financial center. Job opportunities attract many people to move into the city; therefore, the population continues to grow (Shanghai Bureau of Statistics, 2015). Due to the population growth, income growth and urban expansion, the urban transportation demand is soaring (Chen and Zhang, 2012). The total amount of vehicles nearly doubled from 2004 to 2010 in Shanghai, which has exacerbated the negative environmental effects related to transportation (Shanghai Statistic Bureau, 2011 and Chan and Zhao, 2012).

In response to the *Planning for the Development of the Energy-Saving and New Energy Automobile Industry*, Shanghai implemented a EVs subsidy policy. Under this policy, the local government subsidizes consumers who purchase an EV with forty thousand RMBs and exempts the license-plate fees, which are worth sixty thousand RMBs (Shanghai Government, 2012). The goal of this policy is to replace the use of conventional vehicles by encouraging the adoption of EVs, which will reduce greenhouse gas emission and air pollution. Since the policy's implementation, the number of EVs on the roads has increased from 11,159 EVs in 2014 to 55,406 EVs in 2015 (Lai, 2016). Yet, no prior research has been performed to test the efficacy of this policy at reducing vehicle emissions.

Modeling Vehicle Emissions

Approaches to Modeling Vehicle Emissions

Vehicle Emission Inventory and Life Cycle Assessment are two methods that are commonly used in estimating vehicle emissions. The Vehicle Emission Inventory calculates fleet emissions based on the fleet composition and vehicle activity data. It only accounts for the emissions at the consumption phase and does not included those that are generated prior and after the consumption phrase. The International Vehicle Emission model is a model developed to calculate vehicle emission inventories (Liu, et al., 2007). A Life Cycle Assessment consists of a system boundary. Then, it will identify the material and energy input and output within the system, and calculate the greenhouse gas output from acquisition of raw material, production process, use of product, and recycling and disposal of a product (Owens, 1997). The Greenhouse Gases, Regulated Emission, and Energy Use in Transportation (GREET) model is built using the concept of Life Cycle Assessment, which calculates the environmental impact of a product from "Cradle to Grave".

Review of Vehicle Emissions Models

Comparing the Vehicle Emission Inventory and Life Cycle Assessment, both exhibit some limitations in determining a precise measure of greenhouse gas emissions due to the variability of the data (Van Mierlo et al. 2011, and Delucchi, 2004). For example, Vehicle Emission Inventory's calculation depends on the vehicle activity. However, it is difficult to get the precise data on distance travelled by every vehicle and therefore, the accuracy of the Emission Inventory calculation is heavily based on the approximation of the vehicle activities (Liu, et al., 2007). On the other hand, Life Cycle Assessment model also has uncertainty. Since the emission factors vary at different areas; therefore, without accurate emission factors based on the geographic location, the accuracy of the calculation can be affected (Mullins et al. 2010). In this research, I seek to understand the emissions for shifting from conventional vehicles to EVs, which provides a better understanding of the impact of the subsidy policy. Life Cycle Assessment is a better model than Vehicle Emission Inventory for estimating environmental impact because it encapsulates the pollutants that are emitted during the production, maintenance and end-of-life phase of the vehicle (Nordelof et al., 2011). Therefore, the GREET model will be used for this study in evaluating the policy implications of alternative fuel and transportation by assessing the life-cycle greenhouse gas emissions of Shanghai's on-street fleet.

The GREET Model

The Greenhouse Gases, Regulated Emissions, and Energy use in Transportation (GREET) Model is used in this research (Argonne National Lab, 2015). It was first developed by the Argonne National Laboratory in 1986 to calculate transportation life cycle emission. The model contains data on more than a hundred fuel and production pathways. Each pathway refers to the energy used and emissions associated with a single input product, such as a certain type of fuel. This allows users to make adjustment to the inputs and generate the life cycle impact for conventional vehicles and alternative fuel vehicles. The data are derived from the Environmental Protection Agency, Energy Information Administration and other creditable sites (Argonne National Lab, 2015). Since there are many products included with this model, I will use the GREET.net Model to calculate the life-cycle emissions for this study.

GREET.net Structure

GREET.net consists of two stages: Well to Pump and Pump to Wheel. Well to Pump contains emission data for different the fuel pathways and Pump to Wheel contains emission data for different vehicle technologies. The fuel pathway measures emissions from the energy input starting from feedstock extraction to the form that is ready to use. It also includes the emission from transporting the feedstock and fuel. While, the Pump to Wheel measures the emissions at the vehicles operation stages when different vehicle technology is used. Each part of these stages can be modified and customized in the model. The data from these two stages combined will generate the carbon emission and air pollutants outputs that I need for calculating the emission from conventional vehicles and EVs.

Data and Assumptions

Since GREET is a model that was developed based on United States data, I need to modify the pathway data to better fit scenarios in China. The input data required for this model includes the electricity mix, average fuel economy of the fleet, average vehicle emissions and annual vehicle mileage. These data will be taken from research papers that based their study in China (Huo et al., 2013, Huo et al., 2015, Liu et al., 2007 and Wang et al., 2008). Emission factors that may vary in China include:

Electricity Mix. Electricity Mix refers the portions of natural gas, coal, renewable and nuclear being used in electricity grid. China used 75.79% of coal, 1.72% Natural Gas, 1.95% nuclear Power and about 17.46% of hydropower. The mix will after the emission factor of each kWh of electricity.

Vehicle Emissions. The vehicles in Shanghai has an average age of 3.61 years old (Wang et al., 2008). Since the vehicles are relatively new, the vehicle emissions are tended to be lowered than the older generation vehicles. In addition, newer vehicles also have higher mileages; as a result, they require less energy input to operate.

Annual Vehicle Mileage. The road characteristics is different in each city. Such characteristics directly affect the driving pattern. In Shanghai, 68% of the travel distances were driven on residential roads and only 6.4% were driven on highways (Liu et al., 2007).

METHODS

Data Collection Methods

To calculate carbon emission and pollution emission from conventional vehicles and EVs, I need the following data: emissions from electricity mix and gasoline, vehicle emissions, number of vehicles, annual vehicle travel mileage and fuel economy. All these data were collected from sources listed in Table 1.

Table 1. Summary of input. A summary that includes the description and sources of all the input data.

Data Source/Model	**Description**	**URL/Citation**
GREET.net model	Life Cycle Assessment Model that calculates the life cycle carbon emission and pollutants of gasoline and different electricity mixes.	https://greet.es.anl.gov/net
Shanghai Statistics Yearbook	A yearbook that contains all the statistical information about Shanghai. This yearbook includes data on fleet information such as number of passenger vehicles	http://www.stats-sh.gov.cn/data/toTjnj.xhtml?y=2015
Vehicle Emissions	This research studied the emission from Shanghai vehicles' on-road activities. The average vehicles' CO, VOC, NOx, PM and carbon emission are taken from this paper to calculate the Pump to Wheel emission.	Wang, H., C. Chen, C. Huang, and L. Fu. 2008. On-road vehicle emission inventory and its uncertainty analysis for Shanghai, China. Science of the Total Environment 398:60-67.
Annual Vehicle Mileage	This research measured the average total distance travelled by the vehicles in Shanghai using GPS and survey. This should provides an accurate proximately of my model.	Liu, H., K. He, Q. Wang, H. Huo, J. Lents, N. Davis, N. Nikkila, C. Chen, M. Osses, and C. He. 2007. Comparison of vehicle activity and emission inventory between Beijing and Shanghai. Journal of the Air & Waste Management Association 57:1172-1177.
EV Fuel Economy	The research showed that the fuel economy of the electric vehicles in 100 (mi/gasoline eq. gal)	Huo, H., Q. Zhang, F. Liu, and K. He. 2013. Climate and environmental effects of electric vehicles versus compressed natural gas vehicles in China: A life-cycle analysis at provincial level. Environmental science & technology 47:1711-1718.
Conventional Vehicles' Fuel Economy	I am using California average fuel economy of conventional vehicles to proximate the average fuel economy in China.	Benjamin, M., J. Taylor, P. Hughes. Comparison of Greenhouse Gas Reductions Under CAFE Standards and ARB Regulations Adopted Pursuant to AB 1493. California Air Resources Board. 2008.
Current and Future Electric Mix	A report on China's future energy characteristics. It included the percentage of each source of fuel China is anticipating to use to generate electricity.	Song,R., W. Dong, J. Zhu, X. Zhao and Y. Wang. Assessing Implementation of China's Climate Policies in the 12th 5-Year Period. World Resource Institute. 2015.

Data Analysis Methods

The subsidy on EVs, sponsored by the government, will affect the proportion of on-street fleet by increasing the numbers of EVs drastically. By comparing the emissions of different fleet proportions and energy generation methods in the future, I am able to determine the effect of policy on carbon and air pollution emissions. To model such effect, I set up six scenarios (Table 2), which comprised of three fleet compositions scenarios in 2020 and two energy sources scenarios. I selected the year of 2020 as target year because 2020 is only 5 years ahead; therefore, the assumed variables such as vehicle mileages are unlikely to vary a lot from the current statues, which makes the assumptions more more reliable. The three future compositions are modeled after three future EVs adoption rate: 1) Low – the EVs are replacing conventional vehicles at 1.4% per year 2) Medium – the EVs are replacing conventional vehicles at 2.5% per year 3) High – the EVs are replacing conventional vehicles at 4% per year. I determined the growth rate of the EVs based on the China's State Council's proposal, which proposed to accumulate five millions EVs sale by 2020 (China's State Council, 2012). To calculate the vehicle stocks in 2020, I projected the total vehicle growth rate using the total passenger vehicle stocks in Shanghai over the past 14 years. All the projected vehicle stock values can be found in Appendix A.

The two energy sources scenarios represent a Business As Usual (BAU) scenario and an optimistic scenario. BAU means there are no changes in the source of electricity production in the future; coal is still the dominating source (EIA, 2015). The optimistic scenario, alternatively, simulated an increase of renewable energy source replacing the fossil fuel use in the electricity mix because China has committed to reduce its carbon emission and peak CO2 emissions around 2030 (Ohshita et al., 2015). To better reflect the future of energy composition of China, for the optimistic scenario, I used 50% coal, 20% natural gas, 2% nuclear and 28% renewable energy. I came up with this percentage to try reflecting China plans to increase the capacity of natural gas and renewable energy to replace coal (Song et al., 2015). Finally, I calculated the emission from the fleet each scenario to create graphs, which compare and illustrate emission trends considering differential EVs adoption. By comparing the fleet emission from each scenario, I was able to draw conclusions about the policy's effect on reducing emission and pollutions.

Table 2. Six Scenarios. The two energy source scenarios and three EVs and PHEVs adoption are combined to create the six scenarios.

	Low EV Adoption	**Medium EV Adoption**	**High EV Adoption**
BAU Energy Scenario	Scenario 1	Scenario 3	Scenario 5
BEST Energy Scenario	Scenario 2	Scenario 4	Scenario 6

RESULTS

Carbon Emissions

I found that the scenario combining the high EVs Adoption and the renewable energy source generated the lowest lifecycle carbon gas emissions (see Figure 1). While, the life cycle carbon emissions decreased as the numbers of EVs on roads increased in both energy scenarios, the lifecycle carbon emissions were always lower and decreased more rapidly when renewable energy was used. I also found that the differences in carbon emissions reduction became larger when the numbers of EVs goes up. Comparing Scenario 1 (BAU with Low EV Adoption) and Scenario 5 (BAU with High EV Adoption) with Scenario 2 (Best Energy Scenario with Low EV adoption) and Scenario 6 (Best Energy Scenario with High EV Adoption), the emissions reduced by 8.9% and 9.8% representatively.

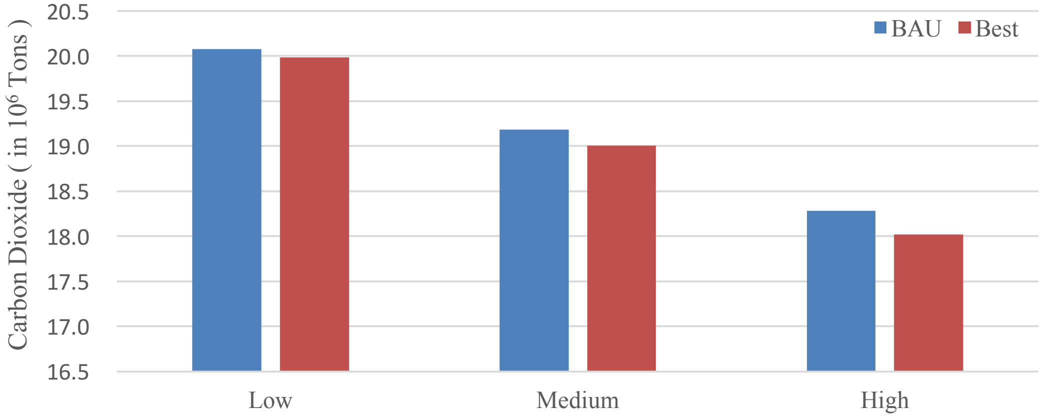

Figure 1. **Life Cycle Carbon Emissions**. The graph is the life cycle emission of each of the six scenarios in million short tons. The scenarios are ordered from left to right.

VOC, NOx and CO Emissions

The lifecycle VOC, NOx and CO emissions decreased as the adoption of EVs increased in both energy scenarios (see Figure 2a, 2b and 2c). Similar to the carbon emissions, the emissions were always when renewable energy was used and the differences in emissions reduction became larger when the numbers of EVs goes up. However, the reduction was insignificant in VOC and NOx even in Best energy scenarios. Comparing Scenario 5 with 6 in VOC and NOx, the emissions reduced by 0.031% and 0.084%. While, the CO emissions reduction was much more significant; the reduction is 8.4% between Scenario 5 and 6.

PM10, PM2.5 and SOx Emission

In both BAU and Best energy scenario, the lifecycle emissions of PM10, PM2.5 and SOx emission increased as the adoption of the EVs increased (see Figure 2d, 2e and 2f). However, the emissions increased as the number of EVs increased, the emissions were always lower and increased in a much slower rate in the Best energy scenario. Overall, when comparing Scenario 1 and Scenario 5 with Scenario 2 and Scenario 6, the PM 10, PM 2.5 and SOx emissions increased by 38% and 32%, 14% and 6% and 1.9 times and 1.8 times respectively.

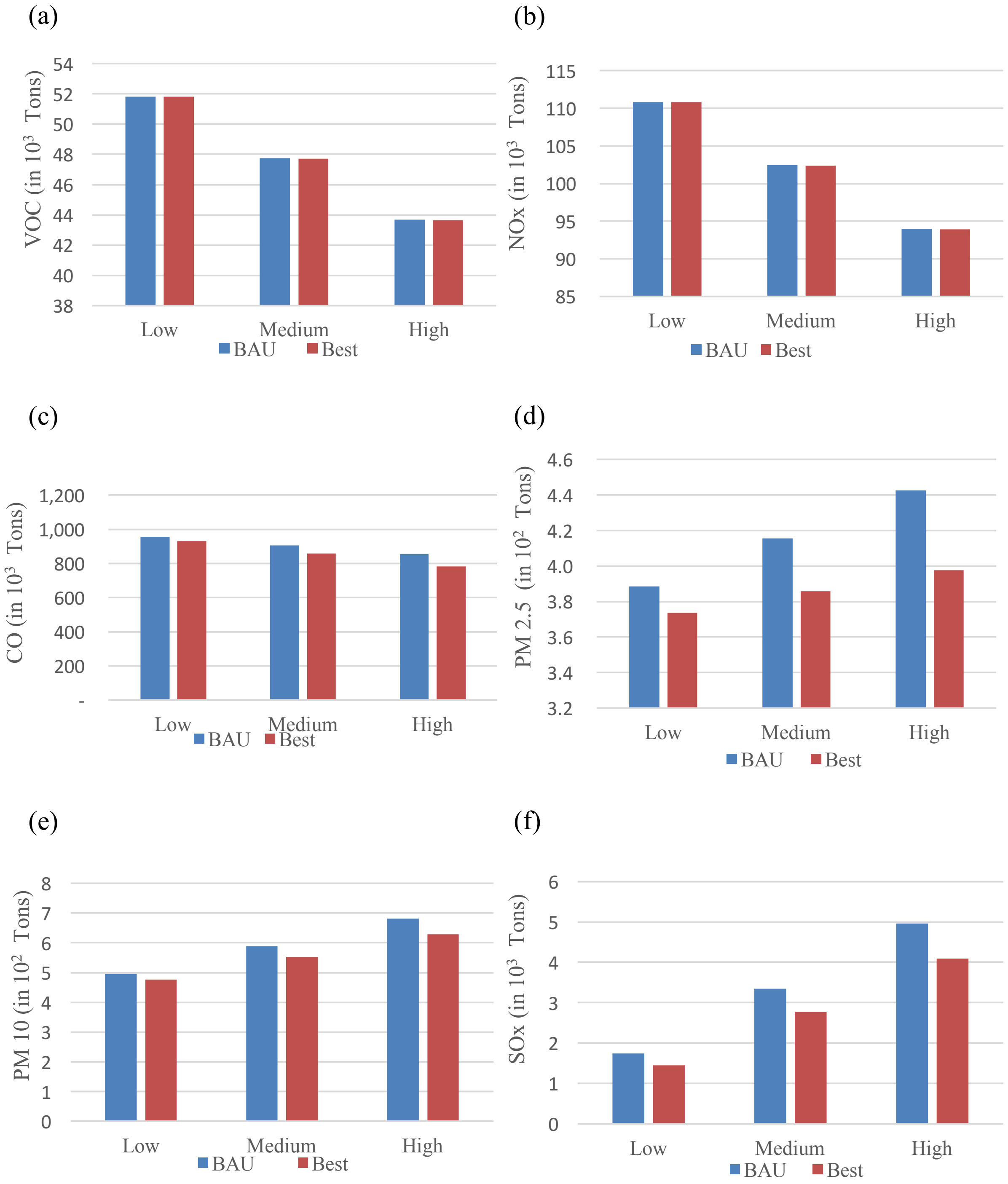

Figure 2. Air Pollutant Results. The graphs are the life cycle emission of each of the pollutants: (a) VOC, (b) NOx, (c) CO, (d) PM 2.5 (e) PM 10 and (f) SOx. The scenarios are ordered from left to right. VOC, NOx, CO and SOx are measured in 10^3 tons, while PM2.5 and PM 10 are measured in 10^2 tons.

DISCUSSION

Many cities around the globe subsidize clean vehicles, such as EVs, in an effort to abate greenhouse gas emissions and air pollution generated by the transportation sector. Accordingly, Shanghai implemented subsidy of EVs to cut down its GHG emissions and improve air quality. In this research, I modeled the effect of the Shanghai subsidy policy by comparing the amounts of carbon and air pollutant emissions resulting from different fleet composition and energy mix. I used a lifecycle assessment tool to assess the amounts emitted. Results indicated that increasing EV adoption in Shanghai through subsidy policy would result in less carbon emissions. In term of air pollutants, the levels of VOC, NOx and CO decreased as the amount of EVs increased. In contrast, Particulate Matters and SOx increased significantly as EVs increased. This suggests that although the subsidy is abled to migrate the greenhouse gas emission generated in transportation sector, it is actually harming the public's health by increasing potent air pollutants. However, when cleaner energy was used instead of coal, the result suggested an 88 thousand tons of cutback in carbon emission even with the lowest level of EV adoption. In addition, there were less air pollutants emitted.

EVs' Emission Analysis

Encouraging adoption of EVs has both negative and positive environmental outcomes. The amount of emissions heavily depends on the energy mix employed for vehicle use. EVs, which are powered by electricity, potentially generate less greenhouse gas emissions and air pollution than conventional gasoline vehicles. However, I found in this study that even though EVs using electricity that is generated are emitting less GHGs, CO, VOC and NOx, they are emitting more certain kind air pollutants (PM10, PM2.5 and SOx). In Figure 1 and 2, which compared the two energy mix scenarios at three different fleet compositions, there is a distinct trend — the carbon emissions and air pollutants from different fleet composition are always higher if coal is the dominant energy source. Overall, the emissions were strongly influenced by the energy sources that were used to produce the electricity. This suggests EVs release more greenhouse gas and pollutants if coals remain China's main energy source.

Transportation Policy

The subsidy policy meets the objective to reduce carbon emission; however, it will not lead to an improvement in air quality. As Graphs d, e and f in Figure 2 demonstrate, with the current energy generating sources (majority of energy is generated by coal), increased EVs will simply shift vehicle pollution to centralized coal power plant pollution which explained why the PM10, PM 2.5 and SOx emissions increased as the number of EVs increased. The data also revealed that even through the pollution emissions also increase in Best energy scenario, they were increasing in a slower rate. For example, comparing Scenarios 1 (BAU and Low EV adoption) and 4 (Best Energy Scenario and Medium EV adoption) in Figure 2d, Scenario 4 has a lower emission.

While it is important to migrate the GHG emission, preserving the air quality is as important. In Shanghai, the Particulate Matters and SOx air pollution has led to adverse health effects, such as higher rate of asthma attack, heart disease and mortality (Lu et al., 2015). Therefore, the government should reconsider the subsidy and balance the tradeoff. In addition, many cities in China besides Shanghai are promoting the same subsidy policy aiming to improve air quality and reduce GHG emissions. However, as the Shanghai results suggest, increasing the number of EVs on the roads does not inherently result in positive environmental externalities relative to alternative on-street fleet condition. Compared to other cities and provinces, Shanghai has a higher renewable electricity mix in general. The less developed regions mainly use coal as the primary source of electricity generation. Therefore, increasing the number of EVs in the less developed regions may also lead to increase air pollution such as PM10, PM2.5 and SOx that is worse than Shanghai's fleet.

Recommendations

In order to reduce the transportation sector's carbon footprint and air pollution through adoption of EVs, shifting to low-carbon and renewable energy sources is necessary in China. As Scenarios 2, 4, and 6 in Figures 1 and 2 demonstrate, the carbon emissions and air pollution lower as the number of EVs increased when cleaner energy (natural gas and renewable energy) was used. Therefore, government should take into consideration subsidizing renewable energy before subsidizing EVs. This is most cost effective solution to both reduce the carbon emission and improve the air quality. Besides, it will also provide more benefits than just subsidizing EVs alone. It is because even though the transportation sector contributes a significant amount of emissions, other sectors, such as the residential sector and industrial sector, are still responsible for much greater amounts of emission in China. Therefore, if the electricity is generated from a cleaner source by installing carbon capture technology or adopting renewable energy, it will further reduce the overall emissions from the other sectors that also consume electricity and not just the transportation sector.

That said, to reduce emissions in transportation, merely increasing EVs is not enough. Altering the social behavior of drivers can make a significant difference in the emissions (Sager et al., 2011). These social behavior includes reducing travel distance and increasing the number of occupants per vehicle. However, to achieving these types of changes in travel distance and occupant numbers require a long term planning that will include changes to urban design. Transit oriented development refers to mix-use communities that are characterized by its compact land use and walkability. This design allows residents to shorten their habitual trips, and has been found to have a positive reduction on transportation-sector emissions (Dou et al., 2016 and Cervero and Sullivan, 2011). In addition, the government should promote public transportation use and increase its coverage.

Limitations and Future Directions

In this research, I calculated the lifecycle carbon and air pollutant emission from different fleet composition and energy scenarios. This calculation required inputs such as emission factors, distance traveled per vehicle and the fuel efficiency. However, many of these inputs are only estimations of the average in the region due to the limited available data. For further investigation, local data are needed to calculate accurate life cycle emissions. Future research can also investigate high resolution (daily) travel patterns, which include consumption and emissions patterns during congestion events. This approach will provide a better understanding how traffic can affect life cycle emissions calculations, as congestion tends to increase the greenhouse gas emissions.

Conclusions

Facing the pressures of a growing motorization rate, the Chinese government has identified the development and adoption of EVs as a means to abate the negative externalities of on-road transportation. The lessons offered by a case study of Shanghai show that EVs are more beneficial when low carbon energy is used for electricity generation. Therefore, although it is crucial to reduce emissions from the transportation sector, it is more reasonable to subsidize the energy sector before subsidizing the adaption of EVs. This also implies that in order for China to achieve the commitment to peak the nation's emissions by 2030 and improve air quality, China should prioritize increasing the use of cleaner and renewable energy over coal.

ACKNOWLEDGEMENTS

Thanks to Patina Mendez, Kurt Spreyer, Abby Cochran and ESPM 175 cohort, for the efforts and support provided to me on this project. I would especially like to thank Abby Cochran for patiently editing and giving valuable feedback on my work. Special thanks to Chi-Chung Tsao for providing endless guidance in formulating the thesis and developing the methods and analysis of my research. This project would not have happened without these generous supporting efforts.

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Appendix A.

Table 3. Projected Vehicle Stocks. The table summarized the total passenger vehicle stocks in Shanghai over the past 14 years. The data were collected from Shanghai Statistics Yearbooks. To calculate the future vehicle stocks, I used power regression to find the fitting function which is 1.3036*(x)^-0.929 with R² = 0.91503. Then, I calculated calculated from the growth rate.

Year	Number of CV (20% of EV)	Number of CV (40% of EV)	Number of CV (60% of EV)	Fleet Total
2001	47,500	47,500	47,500	47,500
2002	143,600	143,600	143,600	143,600
2003	221,300	221,300	221,300	221,300
2004	314,700	314,700	314,700	314,700
2005	410,000	410,000	410,000	410,000
2006	509,100	509,100	509,100	509,100
2007	612,500	612,500	612,500	612,500
2008	719,900	719,900	719,900	719,900
2009	849,500	849,500	849,500	849,500
2010	1,035,700	1,035,700	1,035,700	1,035,700
2011	1,195,700	1,195,700	1,195,700	1,195,700
2012	1,408,400	1,408,400	1,408,400	1,408,400
2013	1,628,800	1,628,800	1,628,800	1,628,800
2014	1,828,100	1,816,941	1,816,941	1,816,941
2015	2,033,244	1,977,995	1,977,995	1,977,995
2016	2,247,243	2,186,334	2,137,039	2,081,769
2017	2,470,001	2,379,433	2,288,282	2,197,152
2018	2,701,432	2,569,340	2,436,401	2,303,500
2019	2,941,457	2,761,646	2,580,685	2,399,787
2020	3,190,005	2,955,969	2,720,438	2,485,003
2021	3,447,013	3,151,935	2,854,976	2,558,156
2022	3,712,420	3,349,179	2,983,627	2,618,265
2023	3,986,172	3,547,344	3,105,726	2,664,361
2024	4,268,219	3,746,077	3,220,618	2,695,487
2025	4,558,516	3,945,034	3,327,657	2,710,695
2026	4,857,018	4,143,874	3,426,201	2,709,044
2027	5,163,688	4,342,261	3,515,617	2,689,605
2028	5,478,487	4,539,863	3,595,276	2,651,453
2029	5,801,383	4,736,354	3,664,555	2,593,669
2030	6,132,342	4,931,408	3,722,836	2,515,342