ENVIRONMENT AND NATURAL RESOURCES

Environmental Implications and Policy Challenges for Bringing Long-Haul Electric Trucks into China

The Case of the Tesla Semi

Jonathan M. Moch

HARVARD Kennedy School
BELFER CENTER
for Science and International Affairs

PAPER
JULY 2019

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Cover photo: A prototype Tesla Semi truck at Tesla HQ in California, April 22, 2019. (Flickr/Steve Jurveston)

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About the Project

The Environment and Natural Resources Program at the Belfer Center for Science and International Affairs is at the center of the Harvard Kennedy School's research and outreach on public policy that affects global environment quality and natural resource management. Its mandate is to conduct policy-relevant research at the regional, national, international, and global level, and through its outreach initiatives to make its products available to decision-makers, scholars, and interested citizens.

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This paper is part of the Environment and Natural Resources Program's on-going paper series on China and climate. This series emphasizes the challenges and opportunities facing the power and transport sectors. Other papers can be found at www.belfercenter.org/program/environment-and-natural-resources

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A prototype Tesla Semi truck at Tesla HQ in California, April 22, 2019.
Flickr/Steve Jurveston

Executive Summary

The Tesla Semi is a battery powered electric long haul truck currently in the prototype phase. Since cost and technological barriers have prevented electric vehicles from making significant inroads into the market for long haul trucks, the announcement of the Tesla Semi marks one of the first major attempts to bring electrification to on-road long haul freight transport. China, as the world's largest carbon emitter, is an important market for truck electrification. China has a bourgeoning passenger electric vehicle market but, like the rest of the world, is reliant on heavily polluting diesel trucks for on-road freight transport.

This paper addresses two main questions:

1. What are the potential impacts on carbon emissions of electric long haul trucks in China?
2. What are the barriers to the adoption of electric long haul trucks in China?

Can the Tesla Semi cut costs and CO_2 in China?

For each standard diesel truck replaced, the Tesla Semi, as announced, would be able to reduce direct CO_2 emissions by up to a third over a 10 year period compared to what would have otherwise been emitted, despite a large percentage of coal in China's electricity generation mix. However, costs reductions depend on multiple factors including (1) diesel fuel costs, (2) the costs and utilization rates of the required charging infrastructure, and (3) whether or not the Tesla Semi is subject to a Chinese tariff on imported vehicles.

The charging infrastructure necessary to support long haul electric trucks is a major challenge to vehicle adoption, as it is with passenger electric vehicles. With only a few electric trucks on the road, the utilization rate of the charging infrastructure would be quite low and require high prices for the installers of the infrastructure to break even. But in order to reduce electricity prices and make electric trucks more economical, a high charger utilization rate is needed, implying large number of electric trucks already on the road. Therefore government subsidies or direct involvement in construction of charging infrastructure can provide an important boost to speed the adoption of electric long haul trucks by reducing costs for initial users.

If the electric truck charging infrastructure can achieve a utilization rate of 25% or greater, this paper estimates that the Tesla Semi can decrease costs to users given rising diesel prices in China between now and 2030, with increased savings possible if the charging infrastructure costs are kept low either by subsidies or by high utilization rates. If diesel prices in China fall from $4 per gallon in 2020 to $3 per gallon in 2030, the Tesla Semi would most likely increase user costs compared to a standard diesel truck. In all cases, if China's import tariff is waived, the Tesla Semi is much more likely to save Chinese users money over the truck's lifetime.

1. Introduction

China is the world's largest emitter of carbon dioxide (CO_2), with an estimated 9.4 Gton emitted in 2018, equivalent to 28% of global emissions.[1] The transport sector accounts for around 10% of these emissions,[2] and this percentage is projected to increase into the future even as other sources of CO_2 emissions are decreasing.[3,4] Reducing transport related CO_2 emissions in China is therefore essential to curbing total emissions.

One proposal for major reductions in transport related CO_2 emissions is the electrification of trucks.[5] Freight accounted for about half of China's transport CO_2 emissions in 2016,[6] with trucks generating the largest portion of those emissions.[7] Until recently, electrification of long haul trucks was not considered technologically feasible or cost effective. In addition, previous studies have shown that electrification of passenger vehicles, a first step in the conversion to electric vehicles (EVs), might only have a small impact on carbon emissions, while causing an increase in emissions of other air pollutants, such as NOx and SO_2, due to the large percentage of coal in China's electricity generation mix.[8,9,10]

1 BP Statistical Review, 2019. https://www.bp.com/en/global/corporate/energy-economics/statistical-review-of-world-energy/downloads.html

2 Li, W., Li, H., Zhang, H., & Sun, S. (2016). The Analysis of CO2 Emissions and Reduction Potential in China's Transport Sector. *Mathematical Problems in Engineering*, 2016, 12.

3 International Energy Agency. (2018). *World Energy Outlook 2018*. Paris. https://doi.org/10.1787/weo-2018-en

4 Wen, Z., Li, H., Zhang, X., Chi Kin Lee, J., & Xu, C. (2017). Low-carbon policy options and scenario analysis on CO2 mitigation potential in China's transportation sector. *Greenhouse Gases: Science and Technology*, 7(1), 40–52. https://doi.org/10.1002/ghg.1623

5 Moultak, M., Lutsey, N., Hall, D. (2017). Transitioning to zero-emissions heavy-duty freight vehicles. The International Council on Clean Transportation, Washington, DC. http://www.theicct.org/publications/transitioning-zero-emission-heavy-duty-freight-vehicles

6 Wen et al., 2017.

7 Ibid.

8 Shen, W., Han, W., & Wallington, T. J. (2014). Current and Future Greenhouse Gas Emissions Associated with Electricity Generation in China: Implications for Electric Vehicles. *Environmental Science & Technology*, 48(12), 7069–7075. https://doi.org/10.1021/es500524e

9 Huo, H., Zhang, Q., Wang, M. Q., Streets, D. G., & He, K. (2010). Environmental Implication of Electric Vehicles in China. *Environmental Science & Technology*, 44(13), 4856–4861. https://doi.org/10.1021/es100520c

10 Huo, H., Cai, H., Zhang, Q., Liu, F., & He, K. (2015). Life-cycle assessment of greenhouse gas and air emissions of electric vehicles: A comparison between China and the U.S. *Atmospheric Environment*, 108(Supplement C), 107–116. https://doi.org/10.1016/j.atmosenv.2015.02.073

1.1 The Tesla Semi and the future of battery electric trucks

Nevertheless, long haul truck electrification may arrive in the near future. On November 16th 2017, Tesla Inc., the electric car company founded by Elon Musk, unveiled the Tesla Semi, a fully electric heavy duty tractor trailer designed for medium to long haul jobs.[11] At the announcement, Musk said that the Tesla Semi would begin production by the end of 2019,[12] but during Tesla's 2019 annual shareholder meeting the company stated that production of the Tesla Semi would not begin until the end of 2020.[13] Several large companies, including Walmart and Pepsi, have placed preorders for the Tesla Semi as of April 2018.[14] Major truck companies, including Daimler[15] and Volvo,[16] are also preparing their own battery electric long haul trucks for release in the early 2020s.

Tesla claims that the Tesla Semi will have a maximum range of 500 miles on a single charge while capable of hauling up to 80,000 pounds.[17] This range makes the Tesla Semi adequate for long haul trucking, which is generally defined as trucking trips of more than 250 miles.[18] The Tesla Semi will be powered by a single large battery located beneath the truck cab, and will have four electric motors, two attached to each of two rear axles.[19] According to Musk, the Tesla Semi will be designed to be extremely aerodynamic, which reduces the amount of electricity needed to drive the vehicle and will have a drag coefficient of 0.36, which makes it slightly

11 Boudette, N. E. (2017, November 16). Tesla Unveils an Electric Rival to Semi Trucks. *The New York Times.* Retrieved from https://www.nytimes.com/2017/11/16/business/tesla-electric-truck.html

12 Ibid.

13 Kolodny, L. (2019, June 11). Elon Musk at Tesla shareholder meeting: "It won't be long before we have a 400-mile range car." CNBC.com. Retrieved June 12, 2019, from https://www.cnbc.com/2019/06/11/elon-musk-at-tesla-shareholder-meeting-promises-400-mile-range-car.html

14 Matousek, M. (2018, April 25). Tesla has a new customer for its electric Semi — here are all the companies that have ordered the big rig. *Business Insider*. Retrieved June 11, 2019, from https://www.businessinsider.com/companies-that-ordered-tesla-semi-2017-12

15 Coppola, G., & Kharif, O. (2018, June 6). Daimler Adds Two Electric Trucks in Race Against Tesla, VW. *Bloomberg.Com*. Retrieved from https://www.bloomberg.com/news/articles/2018-06-06/daimler-adds-two-electric-trucks-in-race-against-tesla-vw

16 Esha, V. (2018, September 27). Volvo aims to sell electric trucks in North America by 2020. *Reuters*. Retrieved from https://www.reuters.com/article/us-volvo-electric-idUSKCN1M72BJ

17 Boudette, 2017.

18 Urban Insurance Agency. (n.d.). Truck Insurance: Impact of Short vs Long Haul. Retrieved December 11, 2017, from http://www.urbaninsuranceagency.com/long-vs-short-haul-truck-insurance/

19 Boudette, 2017.

more aerodynamic than many sports cars.[20] Musk also claimed that the Tesla Semi would be able to charge to 400 miles of range in just 30 minutes from a specially designed direct current "Megacharger."[21,22]

At an announced price of $180,000 for the 500 mile range model, the Tesla Semi would come at a higher upfront cost than a conventional diesel truck, which costs around $125,000 in the United States[23] and around $90,000 in China.[24] However, since there will be fewer moving parts in the Tesla Semi than with a conventional diesel truck, the company claims that owners will save significantly on maintenance costs, in addition to savings on fuel.[25]

From an engineering perspective, there is skepticism of the claims by Tesla regarding the range and efficiency of the Tesla Semi. *Sripad and Viswanathan* (2017) calculated that the battery size needed to power an electric semi-truck would be both prohibitively heavy and expensive.[26] Similarly, industry analysts and Tesla competitors point out that the announced range and the announced cost of the Tesla Semi seem to be beyond the capability of existing battery technology.[27,28] One explanation is that Tesla may have had a breakthrough in battery technology that has not yet been announced. Another is that Tesla may be counting on the cost of batteries falling from levels of around $300 per kWh today.[29] It is also possible that Tesla has

20 Irfan, U. (2017, November 16). Tesla's electric semi truck: Elon Musk unveils his new freight vehicle. *Vox.com*. Retrieved November 29, 2017, from https://www.vox.com/2017/11/16/16665266/tesla-electric-truck-announced-self-driving-price

21 Ibid.

22 Pyper, J. (2017, November 17). Why Tesla's Electric Semi Truck Is the Toughest Thing Musk Has Attempted Yet. *Green Tech Media*. Retrieved November 29, 2017, from https://www.greentechmedia.com/articles/read/tesla-electric-semi-truck-toughest-musk

23 Stangel, L. (2017, November 27). Tesla reveals price of semi truck, and it's surprising competitive. *Silicon Valley Business Journal.* Retrieved December 9, 2017, from https://www.bizjournals.com/sanjose/news/2017/11/27/tesla-semi-truck-price-cost-fuel-tsla.html

24 Moultak et al., 2017.

25 Pyper, 2017.

26 Sripad, S., & Viswanathan, V. (2017). Performance Metrics Required of Next-Generation Batteries to Make a Practical Electric Semi Truck. *ACS Energy Letters*, *2*(7), 1669–1673. https://doi.org/10.1021/acsenergylett.7b00432

27 Randall, T., & Lippert, J. (2017, November 24). Tesla's Newest Promises Break the Laws of Batteries. *Bloomberg.com*. Retrieved from https://www.bloomberg.com/news/articles/2017-11-24/tesla-s-newest-promises-break-the-laws-of-batteries

28 Deutschland, J. K., Ruqayyah Moynihan, (2019, April 3). Business Insider. Electric trucks like the Tesla Semi are "pointless both economically and ecologically," according to a vehicle-tech expert. *Business Insider.* Retrieved May 26, 2019, from https://www.businessinsider.com/this-expert-says-tesla-semi-is-economically-and-ecologically-pointless-2019-2

29 Ibid.

over-promised in their initial announcement of the Tesla Semi. If Tesla is unable to achieve the promised range of 500 miles on a single charge, the Tesla Semi becomes a much less viable option for long haul trucking.

Another significant engineering challenge is being able to charge the battery of the Tesla Semi fast enough so that it is able to make long trips without spending significant time charging. The charging speed for the announced megacharger would require a charging technology that is much faster than anything currently available. Analysts suggest that Tesla might achieve the announced charging speeds by segmenting the battery and charging each segment simultaneously.[30] Regardless of how the battery is charged, in order to charge the Tesla Semi to 400 miles of capacity in just 30 minutes, the megacharger would need to be more than 10 times faster than the chargers used by Tesla today, which are already among the fastest in existence.[31] This fast a charging rate would require an output of more than 1200 kW and the power draw from the grid could be significant.[32] Some industry analysts project that charging a Tesla Semi would require power nearly equal to that consumed in 4,000 average European homes.[33]

For the analysis presented in this paper I take Tesla's technical claims at face value under the assumption that, even if the Tesla Semi itself does not quite live up to the announced price point and technical specifications, the claims are nevertheless indicative of the goal posts for what future electric trucks could look like.

1.2 Transportation sector emissions and electric vehicles in China

As part of its commitment for the Paris Climate Agreement, China pledged to peak its CO_2 emissions by 2030, as well as to increase the share of

30 Thomas, N., & Campbell, P. (2017, November 27). Tesla truck will need energy of 4,000 homes to recharge, says study. *Financial Times.* https://www.ft.com/content/f5593480-d29a-11e7-8c9a-d9c0a5c8d5c9

31 Randall and Lippert, 2017

32 Thomas and Campbell, 2017

33 Ibid.

non-fossil fuels in its primary energy mix to around 20%.[34] Energy and economic modeling studies have projected that it will be possible for China to achieve this target with existing policies; however, additional studies have also shown that further emissions reductions will require additional action.[35,36] Any significant effort to decrease emissions in China after 2030 will require a large expansion of electric passenger vehicles.[37,38] For example, in their "Accelerated Effort Scenario," Lawrence Berkeley National Laboratory's China Energy Group assumes that 70% of passenger vehicles in China would be electrified by 2050.

China has laid out ambitious goals for the expansion of EVs. Since 2015, China has manufactured more than 40% of the EVs produced globally.[39] It now also has over 100,000 public charging stations.[40] To promote the sale and adoption of EVs, China has offered significant tax breaks and subsidies, which in 2016 amount to 23% of the total vehicle price.[41,42] In September 2017, Xin Guobin, China's Vice Minister of Industry and Information Technology, announced that the government was debating a timetable to phasing out the sale and manufacture of fossil-fuel powered cars.[43] Going forward, however, the government is also planning to

34 Department of Climate Change, National Development and Reform Commission of China, (2015). Enhanced Actions on Climate Change: China's Nationally Determined Contributions. http://www4.unfccc.int/ndcregistry/PublishedDocuments/China%20First/China%27s%20First%20NDC%20Submission.pdf

35 Zhou, N., Fridley, D., Khanna, N. Z., Ke, J., McNeil, M., & Levine, M. (2013). China's energy and emissions outlook to 2050: Perspectives from bottom-up energy end-use model. *Energy Policy*, 53(Supplement C), 51–62. https://doi.org/10.1016/j.enpol.2012.09.065

36 Zhang, X., Karplus, V. J., Qi, T., Zhang, D., & He, J. (2016). Carbon emissions in China: How far can new efforts bend the curve? *Energy Economics*, 54(Supplement C), 388–395. https://doi.org/10.1016/j.eneco.2015.12.002

37 Zhou et al., 2013.

38 Zhang et al., 2016.

39 Hertzke, P., Müller, N., & Schenk, S. (n.d.). China's electric-vehicle market plugs. *McKinsey Quarterly* July 2017. McKinsey & Company. https://www.mckinsey.com/global-themes/china/chinas-electric-vehicle-market-plugs-in

40 Ibid.

41 Gao, P., Sha, S., Zipser, D., & Baan, W. (n.d.). Finding the fast lane: Emerging trends in China's auto market. April 2016. McKinsey & Company. https://www.mckinsey.com/industries/automotive-and-assembly/our-insights/finding-the-fast-lane-emerging-trends-in-chinas-auto-market

42 Feng, E., Clover, C., & Ju, S. F. (2017, June 27). China puts a stop to electric-car gold rush. *Financial Times*. https://www.ft.com/content/891d8264-5016-11e7-bfb8-997009366969

43 Ya, Z., & Yang, G. (2017, September 13). News Analysis: China mulls fossil fuel car ban, boosts electric vehicles. *Xinhua—English.cn* http://news.xinhuanet.com/english/2017-09/13/c_136606474.htm

phase out subsidies for EVs by 2020 and replace them with regulatory initiatives.[44]

The transportation sector can be divided into two sub sectors: passenger transport and freight transport. In past estimates, the majority of passenger transport emissions have been attributed to cars, while the majority of freight transport emissions are attributed to trucks.[45,46] The remainder of freight emissions is due to planes, ships, and trains.[47]

Estimated truck emissions in China in 2016 were around 420 Mton of CO_2, about 10% higher than estimated CO_2 emissions from passenger vehicles.[48] Emissions in China from trucks have been growing in recent years and are expected to show continuous annual increases at least until 2030.[49,50] These increases are driven by increasing demand for trucking services; from 1995 to 2012, truck freight volume in terms of ton-kilometers increased by over 16 times,[51] with an 81% increase just between 2008 and 2012.[52] These trends are projected to continue, with estimates showing truck freight volume doubling by 2030 from 2010 levels.[53]

Electric trucks are beginning to build a presence in China, but mostly for short haul deliveries within cities. Several Chinese companies are already producing light duty trucks for sale within China and are looking to expand.[54] BYD, a Chinese EV company with a presence in both China and

44 Feng et al., 2017.

45 W. Li et al., 2016.

46 Wen et al., 2017.

47 Ibid.

48 Wen et al., 2017.

49 Ma, L., Liang, J., Gao, D., Sun, J., & Li, Z. (2012). The Future Demand of Transportation in China: 2030 Scenario based on a Hybrid Model. *Procedia - Social and Behavioral Sciences*, 54(Supplement C), 428–437. https://doi.org/10.1016/j.sbspro.2012.09.761

50 W. Li et al., 2016.

51 Ibid.

52 Li, Y., Bao, L., Li, W., & Deng, H. (2016). Inventory and Policy Reduction Potential of Greenhouse Gas and Pollutant Emissions of Road Transportation Industry in China. *Sustainability*, 8(12). https://doi.org/10.3390/su8121218

53 Ma et al., 2012.

54 Shirouzu, N. (2018, November 15). A slew of electric truck plans may deliver the goods for China's EV ambitions. *Reuters*. Retrieved from https://www.reuters.com/article/us-china-autos-trucks-electric-focus-idUSKCN1NK35I

in the United States,[55] is working on several medium haul electric trucks with ranges in excess of 100 miles per charge.[56] Chinese regulators are also considering long term plans to phase out 1 million diesel trucks with mandated cleaner alternatives, with some Chinese ports going further and considering a complete ban on diesel trucks.[57]

1.3 **Tesla, Inc.'s presence in China**

No planned purchases of the Tesla Semi have been announced by Chinese companies, but Tesla does already have a presence in China, with $2 billion in revenue in 2016.[58] The company also enjoys good brand recognition compared to other EVs, and market analysts say that Tesla's electric cars are far ahead in terms of quality compared to those manufactured by Chinese companies.[59,60] Tesla has also installed over 1,000 superchargers in China along with 3 of the world's largest charging stations.[61]

On the production side, Tesla broke ground on a factory in the Shanghai free trade zone in January 2019.[62] According to their deal with the Chinese government, Tesla will be the sole owner of their manufacturing facility and will be allowed to keep company intellectual property secret. This contrasts with most foreign car companies that establish manufacturing facilities in China through joint partnerships with a Chinese company, and are usually

55 Hagstrom, A. (2018, January 18). BYD leads US market for electric trucks. *Chinadaily.Com.Cn*. Retrieved from www.chinadaily.com.cn/a/201801/18/WS5a5f8067a310e4ebf433e611.html

56 BYD: ELECTRIC TOUGH. (n.d.). Retrieved May 26, 2019, from https://en.byd.com/truck/

57 Carey, N. (2018, October 22). Truck makers rev up for rollout of electric big rigs. *Reuters*. Retrieved from https://www.reuters.com/article/us-autos-trucks-electric-idUSKCN1MW0NB

58 Xinhua. (2018, August 23). China becomes Tesla's fastest growing market in 2017 - *Xinhua* | *English.news.cn*. Retrieved February 8, 2019, from http://www.xinhuanet.com/english/2018-03/23/c_137060428.htm

59 Mullaney, T. (2017, October 23). Musk moves: Tesla deal to make cars in Shanghai, China's new EV rules. *CNBC.com*. https://www.cnbc.com/2017/10/23/musk-moves-tesla-deal-to-make-cars-in-shanghai-chinas-new-ev-rules.html

60 Kim, T. (2017, October 17). Analyst says "nobody can compete" with Tesla in China. *CNBC.com* https://www.cnbc.com/2017/10/17/analyst-says-nobody-can-compete-with-tesla-in-china.html

61 Xinhua, 2018.

62 Iyengar, R. (2019, January 7). Tesla starts building its huge Shanghai factory to make cars for China. *CNN*. Retrieved February 8, 2019, from https://www.cnn.com/2019/01/07/business/elon-musk-tesla-gigafactory/index.html

required to surrender some control over intellectual property.[63] Tesla's deal may allow it to avoid a 15% foreign car import tariff,[64] which is usually compounded with a 17% value added tax, meaning that imported cars are over 30% more expensive than the manufacturer's sales price.[65,66] For Tesla, one of the benefits of establishing a factory in China is access to EV components. For example, currently China produces about 25% of the world's lithium ion batteries.[67] Tesla plans to manufacture its Tesla Model S and Model X passenger cars at the Shanghai facility,[68] but this same supply chain for electric passenger could be adapted to the production of electric trucks.

1.4 The uncertain benefits of electric vehicles in China

Whether or not EVs will have a positive environmental impact is far from certain. Coal comprised 72% of China's total generation in 2015.[69] By 2040, U.S. Energy Information Agency (EIA) and International Energy Agency (IEA) projections show this percentage decreasing to around 47%.[70] This change in the percentage of coal-fired electricity generation will have a dramatic effect on the environmental friendliness of EVs. *Huo et al. (2010)* examined the effect of using EVs for each of China's six interprovincial power grids, which in 2008 varied from 65% to 98% coal. They found that EVs could significantly increase NO_x and SO_2 emissions compared to gasoline power vehicles, but would only have minor effects on CO_2 emissions in 2030.[71]

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63 Bradsher, K., & Kitroeff, N. (2017, October 22). Tesla Plant in China May Be a First. *The New York Times.* Retrieved from https://www.nytimes.com/2017/10/22/business/tesla-plant-in-china-may-be-a-first.html

64 Cheng, E. (2019, January 6). Elon Musk breaks ground on Tesla Shanghai factory. *CNBC.Com.* Retrieved February 12, 2019, from https://www.cnbc.com/2019/01/07/tesla-shanghai-factory-ground-breaking.html

65 Ibid.

66 Trivedi, A. (2018, December 5). A Win on China Car Tariffs Is Irrelevant for Automakers. *Bloomberg*. Retrieved from https://www.bloomberg.com/opinion/articles/2018-12-05/china-car-tariff-win-would-be-irrelevant-for-u-s-automakers

67 Hertzke et al., 2017.

68 Iyengar, 2019.

69 U.S. Energy Information Administration (EIA). (2017, September 27). Chinese coal-fired electricity generation expected to flatten as mix shifts to renewables. *Today in Energy.* https://www.eia.gov/todayinenergy/detail.php?id=33092

70 Ibid.

71 Huo et al., 2010.

Recent studies using more up to date projections show that EVs might not be as harmful to the environment as calculated in 2010 but, in the short run, they are unlikely to provide large reductions in CO_2 emissions. A regional analysis by *Shen et al.* (2014) calculated that in Beijing, Shanghai, and Guangzhou, EV's would need to have an efficiency of 13-20 kWh per 100 miles to result in reduced CO_2 emissions, which is lower than the 24-32 kWh per 100 km efficiency of EVs currently demonstrated in China.[72] A second regional analysis by *Huo et al.* (2015) found that by 2025 EVs could provide reductions in CO_2 emissions, but could increase emissions of SO_2 and primary particulate matter.[73] The study also calculated that CO_2 emissions from passenger vehicles could be reduced by 60-85%, but only if at least 80% of electricity in China came from renewable sources over the fuel life cycle.[74] Estimates show the greater Beijing region being powered by 85% coal in 2025, the Yangtze River Delta Region by 72% coal, and the Pearl River Delta region by 50% coal.[75]

Along with the large percentage of coal in China's grid, passenger EVs offer only minor reductions in CO_2 because relatively efficient gasoline powered cars are available, with efficiency expected to further improve over time. China has announced a target for new passenger vehicles to reach an efficiency standard of 5 liters (L) per 100km (around 46 miles per gallon, by 2020).[76] Diesel trucks are significantly less efficient, and their target is 6.3 miles per gallon by 2020.[77] Given these fuel standards and an average emission factor of around 8 kg of CO_2 per gallon of gasoline burned and 10.1 kg of CO_2 per gallon of diesel burned,[78] a passenger car would emit around 0.17 kg CO_2 per mile traveled, while a diesel truck would emit around 1.6 kg CO_2 per mile traveled.

72 Shen et al., 2014.

73 Huo et al., 2015.

74 Ibid.

75 Ibid.

76 He, H., and Bandivadekar, A. (2013). Passenger car fuel-efficiency standards in China and the US: Stringency and technology, 2020–2025. The International Council on Clean Transportation, Washington, DC. http://www.theicct.org/publications/passenger-car-fuel-efficiency-standards-china-and-us-stringency-and-technology-2020

77 Moultak et al., 2017.

78 U.S. Energy Information Administration (EIA). (n.d.). How much carbon dioxide is produced from burning gasoline and diesel fuel? - FAQ -. https://www.eia.gov/tools/faqs/faq.php?id=307&t=11

2. Methods

To examine the potential impact of electric trucks on CO_2 emissions in China, this paper uses the Tesla Semi as a case study to build on the analysis of Moultak et al. (2017).[79] It analyzes the net savings of CO_2 over 10 years by comparing electric trucks with a standard diesel truck for long haul jobs. I also calculate the net present value (NPV) of a diesel truck and the Tesla Semi assuming the same 10 year truck lifetime. Despite the delay in the production of Tesla Semi until 2020, this analysis uses 2020 as a starting year and assumes that the initial truck purchases occur in 2020 while operation does not begin until 2021 and continues through the end of 2030. In calculating the net present value (NPV) of a Tesla Semi, this analysis considers initial capital costs, maintenance costs, fuel costs, and additional infrastructure costs. Other challenges to the adoption of the Tesla Semi and other plug-in electric trucks are discussed separately after the quantitative analysis.

2.1 Calculating carbon emissions for the Tesla Semi and a standard diesel truck

The difference in net CO_2 emissions between a Tesla Semi and a standard diesel truck is calculated using the following equation:

$$Net\ CO_2 difference = \sum_{n=1}^{10} (\gamma_{diesel} - \gamma_{tesla}) \times VDT_n$$

where *n* is the year, *VDT* is the vehicle distance traveled per year in km, and γ is the CO_2 produced per km of travel by the truck. *VDT* follows the assumptions for China made in Moultak et al. (2017), where a truck travels slightly over 150,000 km in the first year with *VDT* decreasing by around 10% annually for each year after that. *VDT* for each of the 10 years can be found in Table A1.

79 Moultak et al., 2017.

The calculation of γ is different for diesel trucks and the Tesla Semi. The calculation of CO_2 produced per km of diesel truck travel, γ_{diesel}, is a constant value for this analysis determined by the diesel truck fuel efficiency, the amount of energy per gallon of diesel fuel, and the CO_2 emitted from diesel combustion per unit of energy:

$$\gamma_{diesel} = \frac{1}{\beta_d/\rho_d/\varepsilon_d}$$

where β_d is the fuel efficiency of the diesel truck, ρ_d is the energy density of diesel fuel, and ε_d is the kg of CO_2 produced from diesel fuel per unit of energy. β_d, ρ_d, and ε_d are all constants leading to a constant γ_{diesel} of 1 kg CO_2 per km of diesel truck travel. This is assuming a fuel efficiency (β_d) of 10.1 km per gallon for diesel trucks according to the Stage 3 fuel consumption standards that are planned to be put in place by 2020, and the same standard used in Moultak et al (2017).[80,81] This analysis also assumes an energy density (ρ_d) for diesel fuel of 145 MJ per gallon,[82] and emissions of 69.3 kg CO_2 per GJ of energy (ε_d).[83]

For the Tesla Semi, γ depends on the efficiency and composition of the electric grid as well as the efficiency of the vehicle itself. Assuming that electricity is generated either from coal or from non-fossil sources, γ_{tesla} follows the equation:

$$\gamma_{tesla} = \frac{\tau}{(1-\alpha)} \times \kappa \times \beta_c \times \rho_c \times \varepsilon_c$$

where τ is the end use efficiency of the Tesla Semi in terms of kWh per km, α is the percentage of electricity lost in the transmission of power, κ is the percentage of electricity generated from coal, β_c is the fuel efficiency of a coal fired power plant in terms of kg coal equivalent per kWh, ρ_c is the energy density of coal, and ε_c is the kg of CO_2 produced from coal per unit

80 Ibid.

81 This analysis assumes 100% compliance with the Stage 3 fuel consumption standard. If actual compliance does not reach this level it would increase the CO_2 emissions from a standard diesel truck.

82 U.S. Energy Information Administration (EIA). (n.d.). Energy Units - Energy Explained, Your Guide To Understanding Energy - Energy Information Administration. Retrieved June 11, 2018, from https://www.eia.gov/energyexplained/index.php?page=about_energy_units

83 U.S. Energy Information Administration (EIA). (n.d.). How much carbon dioxide is produced when different fuels are burned? - FAQ. https://www.eia.gov/tools/faqs/faq.php?id=73&t=1 1

of energy. This analysis assumes that from 2020 onward, coal fired power plants meet an efficiency standard of 310 grams of coal equivalent per kWh as mandated by regulations scheduled to go into effect in 2020.[84,85] The energy density of coal (ρ_c) is constant at 29 GJ per ton of coal equivalent,[86] and 5.4% of electricity put into the grid is lost during transmission based on data from 2014.[87] This analysis also assumes that the majority of coal used in power plants is near sub-bituminous quality, and has emissions of 92.1 kg of CO_2 per GJ (ε_c).[88,89] Tesla announced that the Tesla Semi would have an efficiency (τ) of less than 2 kWh per mile (1.24 kWh per km),[90] but this analysis assumes 2 kWh per mile as an upper limit. I assume percentage of electricity generation from coal (κ) is 64% in 2020 and 56% in 2030 as in the U.S. EIA's International Energy Outlook 2017 Reference Case.[91] I also examine a scenario where falls to 49% by 2030, based off of the IEA's World Energy Outlook 2018 New Policies Scenario, which assumes countries successfully live up to their stated climate and energy goals.[92] Further details of how changes between 2020 and 2030 are in Table A1 in the Appendix.

84 Hart, M., Bassett, L., & Johnson, B. (2017, May 15). Everything You Think You Know About Coal in China Is Wrong. Center for American Progress. Washington, DC. https://www.americanprogress.org/issues/green/reports/2017/05/15/432141/everything-think-know-coal-china-wrong/

85 This analysis assumes 100% compliance with coal fired power plant efficiency standards. If actual compliance does not reach this level it would increase the CO_2 emissions of a Tesla Semi.

86 Fridley, D., Lu, H., & Liu, X. (2017). Key China Energy Statistics 2016. Berkeley, CA: Lawrence Berkeley National Laboratory. https://china.lbl.gov/publications/key-china-energy-statistics-2016

87 The World Bank, O. 2014. (2014). Electric power transmission and distribution losses (% of output). *IEA Statistics.* Retrieved December 12, 2017, from https://data.worldbank.org/indicator/EG.ELC.LOSS.ZS?locations=CN

88 U.S. Energy Information Administration (EIA).

89 Chen, X., Huang, J., Yang, Q., Nielsen, C. P., Shi, D., & McElroy, M. B. (2018). Changing carbon content of Chinese coal and implications for emissions of CO2. *Journal of Cleaner Production*, *194*, 150–157. https://doi.org/10.1016/j.jclepro.2018.05.128

90 Semi | Tesla. (n.d.). Retrieved November 29, 2017, from Tesla.com. https://www.tesla.com/

91 U.S. Energy Information Administration (EIA), 2017. International Energy Outlook 2017. Reference Case. Retrieved December 13, 2017, from https://www.eia.gov/outlooks/aeo/data/browser/#/?id=30-IEO2017&cases=Reference&sid=Reference-d082317.18-30-IEO2017~Reference-d082317.18-33-IEO2017&sourcekey=0

92 International Energy Agency, (2018).

2.2 Calculating the cost effectiveness of the Tesla Semi compared to a standard diesel truck

To calculate the NPV of a new diesel truck or Tesla Semi purchased in 2020 for use in 2021-2030, this analysis adds the capital costs, maintenance costs, and fuel costs over 10 years for the two different trucks and uses a discount rate of 7%, based on previous analyses of renewable energy, environmental, and economic impacts in China.[93,94] I assume that a standard diesel truck will cost $91,500 in 2020 in China,[95] and the Tesla Semi will have a base price of $180,000.[96] As previously discussed, both a standard diesel truck and Tesla Semi are subject to a 17% value added tax, but the Tesla Semi is also subject to an additional 15% tariff on imported vehicles.[97] The actual value of the Chinese tariff on imported vehicles has oscillated with the ongoing trade dispute and negotiations between the US and China, and it is unclear at what level the tariff will be set to at the conclusion of negotiations.[98] To account for the lower bound of this uncertainty, the effect of a total removal of the imported vehicle tariff is also considered.

Little information is available regarding the cost of building a megacharger network to charge the Tesla Semis, although it has reported that Tesla is working in conjunction with companies to build on-site megachargers with price estimates for a station ranging from several hundred thousand to several million dollars.[99] To account for the capital costs associated with constructing a megacharger station, this analysis prices the capital cost associated with a megacharger as an added surcharge on electricity prices. I

93 Chen, X., Lu, X., McElroy, M. B., Nielsen, C. P., & Kang, C. (2014). Synergies of Wind Power and Electrified Space Heating: Case Study for Beijing. *Environmental Science & Technology*, 48(3), 2016–2024. https://doi.org/10.1021/es405653x

94 Lu, X., McElroy, M. B., Chen, X., & Kang, C. (2014). Opportunity for Offshore Wind to Reduce Future Demand for Coal-Fired Power Plants in China with Consequent Savings in Emissions of CO2. *Environmental Science & Technology*, *48*(24), 14764–14771. https://doi.org/10.1021/es503767x

95 Moultak et al., 2017.

96 Stangel, 2017.

97 Bradsher & Kitroeff, 2017.

98 Wang, O., Ren, D., & Xin, Z. (2018, December 14). China agrees to lower import tariff on US cars for three months. *South China Morning Post*. Retrieved from https://www.scmp.com/economy/china-economy/article/2178081/china-roll-back-extra-tariff-us-car-imports-three-months

99 Johnson, E. M. (2018, February 2). Exclusive: How Tesla's first truck charging stations will be built. *Reuters*. Retrieved from https://www.reuters.com/article/us-tesla-trucks-charging/exclusive-how-teslas-first-truck-charging-stations-will-be-built-idUSKBN1FM0I9

assume a megacharger station capital cost of between $500,000 and $5 million, and calculate a capital recovery factor of 0.14 based on a payback time of 10 years and a discount rate of 7%. The electricity surcharge price at which the megacharger operator can break even is dependent on the utilization rate of the megacharger.[100] I examine how the breakeven surcharge price is dependent on the megacharger utilization rate, but assume a constant utilization rate of 25% for the NPV analysis. Assuming the 25% utilization rate, a two unit megacharger station totaling 4 MW would have an electricity surcharge of $0.008-$0.08 per kWh depending on the capital cost.

I follow the assumptions of Moultak et al. (2017) for base electricity costs and truck maintenance costs, and assume maintenance costs are $0.12 per km for diesel trucks and $0.11 for electric trucks.[101] Electricity prices in China are assumed to be $0.10 per kWh in 2020, $0.11 per kWh in 2025, and $0.12 per kWh in 2030.[102] For diesel prices in China I assume as an upper bound that diesel will be $4 per gallon in 2020, $5 per gallon in 2025, and $5.73 per gallon in 2030.[103] To examine the effect of diesel prices, I also consider as a lower bound a scenario in which diesel falls from $4.00 per gallon in 2020, to $3.50 per gallon in 2025, and $3.00 per gallon in 2030. In calculating net present value (NPV) I assume a linear change in diesel and electricity prices between 2020 and 2025 and between 2025 and 2030.

To calculate annual maintenance costs, the maintenance costs per km are multiplied by the *VDT* for each year. For annual diesel costs, I divide the annual diesel cost by the fuel efficiency of the diesel truck and multiply the annual *VDT*. For annual electricity costs for the Tesla Semi, I multiply the annual electricity cost by the Tesla Semi efficiency in terms of kWh per km and multiply by the annual *VDT*. Lastly, to calculate the NPV, the initial capital investment in the truck and the discounted annual fuel and maintenance costs for the truck are summed.

100 Lee, H., & Clark, A. (2018). *Charging the Future*. Environment and Natural Resources Program, Belfer Center. Retrieved from https://www.belfercenter.org/publication/charging-future

101 Moultak et al., 2017.

102 Ibid.

103 Ibid.

3. Results

This section estimates how different percentages of coal in China's power sector affect CO_2 emissions per kilometer from diesel trucks as compared to the Tesla Semi. It next estimates the cumulative CO_2 emissions between a standard diesel truck and the Tesla Semi for 2021 to 2030. This paper then estimates how electricity prices are affected by megacharger utilization and costs. Lastly, results are shown for how the net present value of a Tesla Semi and diesel truck purchased in 2020 and operated from 2021 through 2030 changes for each year of operation. Net present value for the Tesla Semi is calculated for both a scenario with and a scenario without the 15% import tariff.

3.1 The carbon emissions benefits of a Tesla Semi

As shown in Figure 1, the relative CO_2 per km results for the Tesla Semi is highly dependent on the percentage of electricity generated from coal. When coal makes up less than 90% of generation, the Tesla Semi has less CO_2 emitted per km of travel than a standard diesel truck, which is 1 kg CO_2 per km. Since China electricity generation consisted of 72% coal in 2014, the Tesla Semi would on average emit less CO_2 than a diesel truck driven the same distance. Since some regional electricity grids have higher percentages of coal generation than others, driving the Tesla Semi in certain regions may still result in higher CO_2 emissions than that emitted by a standard diesel truck. However, according to the Chinese National Bureau of Statistics, as of 2017 the North China Grid, which is the grid serving the Beijing-Tianjin-Hebei region, got 93% of its power from thermal sources, which includes coal and gas.[104] Taking into account that thermal power within the boundaries of Beijing is now entirely natural gas,[105] the North China Grid had a maximum of 90% coal generation in 2017. Since thermal generation for other provinces connected to the North China Grid is not

104 Chinese National Bureau of Statistics. Electricity production data. Provided courtesy of Michael Davidson.

105 Chen, S. (2017, March 19). Beijing shuts last coal-fired power plant in bid to clear air. *South China Morning Post*. Retrieved from https://www.scmp.com/news/china/society/article/2080270/beijing-shuts-down-its-last-coal-fired-power-plant-part-bid-clear

entirely coal, it is likely that the percentage of coal generation for the North China Grid has already fallen below this 90% threshold. This means that Tesla Semis which start operation in 2021 would begin with slight emissions benefits over standard diesel trucks even in one of the most coal-heavy grids in China. At a nationwide level, given the changing composition of the electricity sector from 2020 to 2030, γ_{tesla} is calculated to be 0.70 kg CO_2 per km in 2021 when coal makes up 63% of generation and 0.62kg CO_2 per km in 2030 when coal makes up 56% of generation.

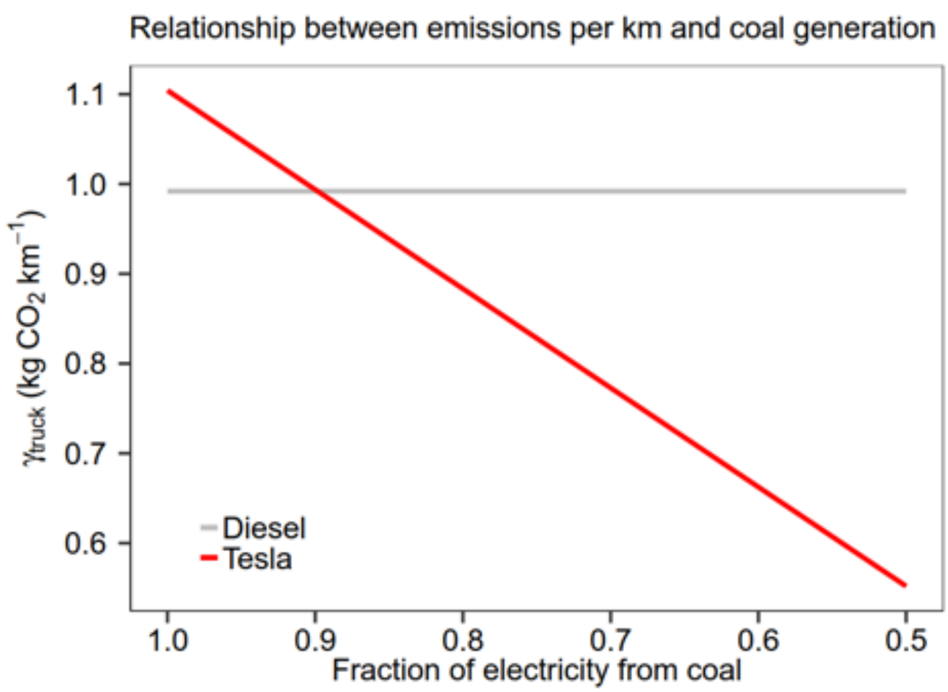

Figure 1: Dependence of γ_{truck}, kg CO_2 emitted per km traveled, on the fraction of electricity generated in China from coal for a standard diesel truck and for a Tesla Semi.

Figure 2 shows the cumulative CO_2 emissions for a standard diesel truck and for a Tesla Semi. For the US EIA scenario, the gap between the cumulative emissions from the standard diesel truck and a Tesla Semi grows with each year reaching 331 tons of CO_2 saved per Tesla Semi on the road from 2021 to 2030. If coal use in China follows the faster decline outlined in the IEA's World Energy Outlook,[106] an additional 45 tons of CO_2 are saved per Tesla Semi over the same time period. The annual CO_2 emissions for a Tesla Semi and for a standard diesel truck decrease each year due to declining *VDT* over

106 International Energy Agency, 2018.

the course of the truck lifetime, leading a reduction in annual truck emissions. However, since the national average percent of electricity generation from coal is also decreasing over the same time period, the annual average CO_2 emissions for the Tesla Semi are decreasing even faster than those of the standard diesel truck, leading to an even greater difference in cumulative emissions over time than would occur if the percentage of coal generation in the electricity mix had remained constant.

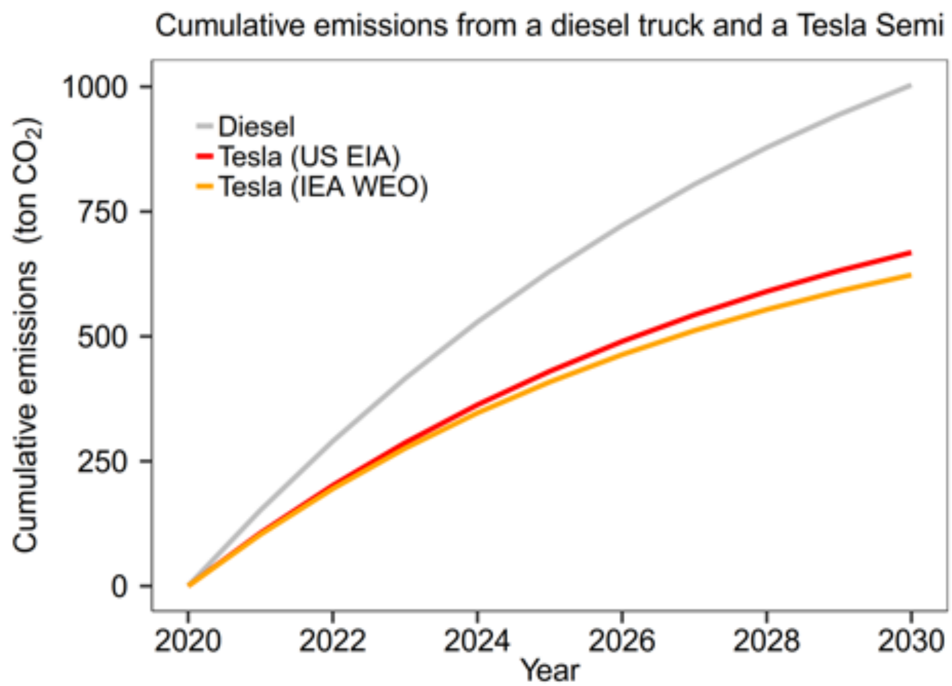

Figure 2: Cumulative CO_2 emissions from a standard diesel truck and a Tesla Semi for 2020 through 2030.

3.2 Cost uncertainty associated with charging infrastructure utilization rates

Assuming that costs are passed through to the owners of the electric vehicles, the uncertainty regarding megacharger costs is a major factor on whether a Tesla Semi saves money over time compared to a standard diesel truck. Figure 3 shows the price of electricity, including both the base electricity price and an added surcharge to recoup infrastructure costs, at which the megacharger installers would be able to break even on their investment. This figure is a direct function of the utilization rate of the magacharger. The shaded range in Figure 3 is a function of the additional uncertainty from increases in electricity prices between 2020 and 2030. The equivalent cost for a standard diesel truck to travel 2 miles, the distance the Tesla Semi can travel on 1 kWh, is shown for various diesel price scenarios.

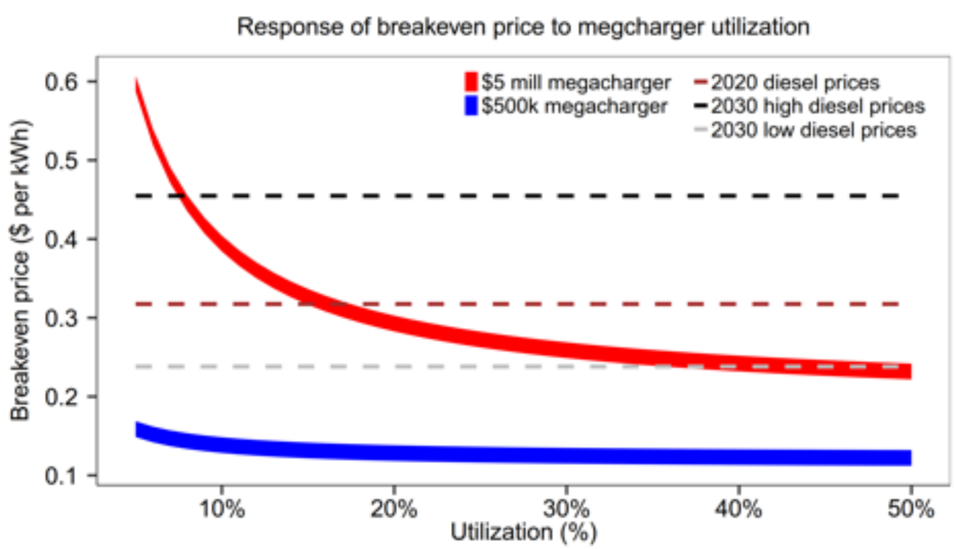

Figure 3: Breakeven price versus utilization rate for a 4 MW megacharger with a discount rate of 5%. The shaded range indicates variation in electricity prices between 2020 and 2030.

For a $500k megacharger, the breakeven price for electricity is below the equivalent cost for diesel fuel even in 2030 in the low diesel price scenario. For a megacharger station with a utilization of at least 7%, electricity costs will be less than the low estimate for diesel fuel costs if the megacharger cost is below $1.5 million. The same electricity costs can result from a 13%

utilization rate if the breakeven capital cost is $2.5 million. In the high cost scenario, where the 4 MW megacharger stations cost $5 million, utilization rates need to reach ~50% for the breakeven price to equal the equivalent diesel price in the low prices scenario in 2030. With these high megacharger costs, a 15% utilization rate is required to have the breakeven price equal the 2020 diesel fuel price, and an ~8% utilization rate is needed to keep the breakeven price below the equivalent diesel fuel costs in 2030 for the high diesel prices scenario.

3.3 The net present value of a Tesla Semi compared to a standard diesel truck

Figure 4 shows how the NPV in 2020 of a Tesla Semi and of a standard diesel truck changes based on how many years are used in the calculation, taking into account the uncertainty surrounding diesel and megacharger infrastructure cost estimates. Year 1 corresponds to 2021 and year 10 corresponds to 2030. Because the diesel truck has higher fuel costs and maintenance costs than the Tesla Semi, the NPV for the diesel truck rises faster than the Tesla Semi for each addition year of operation. For a full 10 years of operation, the NPV of a diesel truck is $455k-$545k, while the NPV of the Tesla Semi is $434k-$502k and thus the net benefits of a Tesla Semi compared to a standard diesel truck are between -$46k to +$111k. If the tariff on imported vehicles is waived, the NPV of the Tesla is $402k-$470k for 10 years of operation and net benefits of a Tesla Semi compared to a standard diesel truck are between -$15k to +$143k.

The potential for negative net benefits of a Tesla Semi compared to a diesel truck is driven primarily by the possibility of low diesel fuel costs. In the scenario with falling diesel fuel prices, the net benefits of a Tesla Semi are -$46 to +$22k, depending on assumptions regarding megacharger costs. If the import tariff is waived, the net benefits of a Tesla Semi compared to a standard diesel truck in the low diesel prices scenario range from -$14k to +$53k.

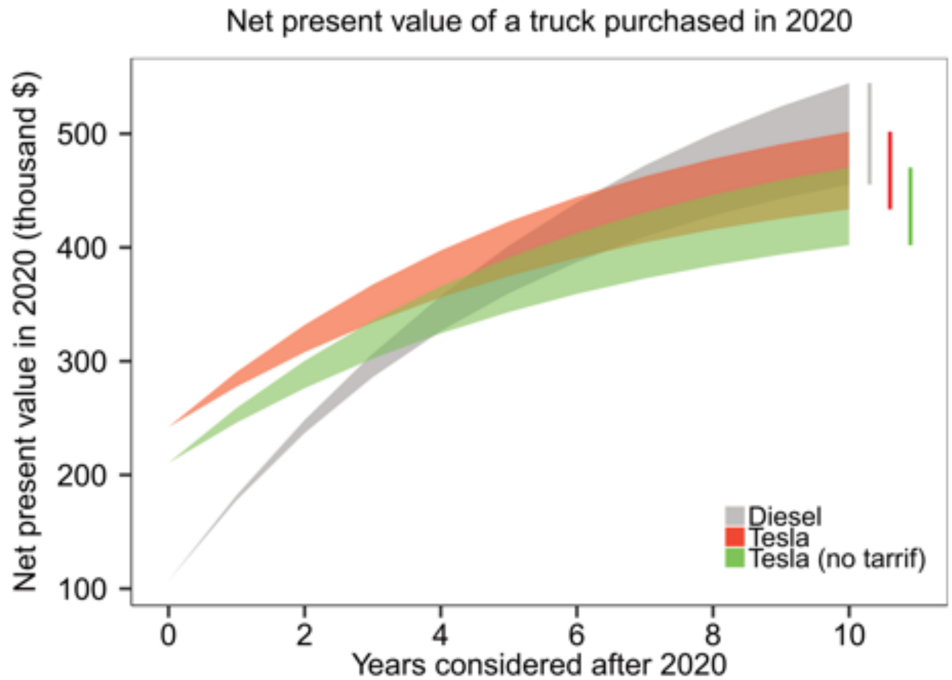

Figure 4: Net present value of a diesel truck or Tesla Semi purchased in 2020 considering 0-10 years of operation. The shaded area represents the range of possible net present value due to uncertainty from diesel costs for diesel trucks or from uncertainty in megacharger costs for the Tesla Semi assuming a 25% megacharger utilization rate. The vertical bars after year 10 show the range of possible net present value when considering the entire time period.

At the time of purchase, the Tesla Semi is ~2.3 times more expensive than a standard diesel truck with the import tariff and ~2 times more expensive at purchase if the existing tariff is waived. For the high diesel prices scenario, a Tesla Semi has positive net benefits after 4-7 years, depending on megacharger infrastructure costs. If the import tariff is waived, a Tesla Semi would have positive net benefits after 3-5 years depending on megacharger infrastructure costs. For a low diesel fuel costs scenario, a Tesla Semi would have positive net benefits after 7 years, if megacharger costs are just $500k for 4 MW, but would always have negative net benefits, if megacharger costs are above ~$2 million. If diesel fuel costs are low and the import tariff is waived, the Tesla Semi would have positive net benefits after approximately 4 years depending on assumptions about megacharger costs, but the net benefits are always negative if the 4 MW megacharger station costs are above ~$4 million.

All of these NPV calculations do not consider benefits from reductions in carbon emissions, so the actual net benefits to broader society will be higher than the values presented in this paper. However, since there is also uncertainty regarding how electric trucks will affect local air pollution, there is also the possibility that truck electrification could lead to an increase in conventional air pollution related deaths and illnesses even as CO_2 emissions are reduced, which could partially or fully counteract the additional benefits from CO_2 reductions.

4. Discussion

Using the Tesla Semi as a case study, results show that electric trucks could reduce carbon emissions when used in China during the 2020-2030 time frame. However, whether or not an electric semi truck would also save money is dependent on assumptions about future diesel fuel prices and the cost of developing the charging infrastructure required to power an electric truck fleet. Waiving the import tariff can also cause foreign-produced electric trucks, such as the Tesla Semi, to have positive net benefits where they otherwise would not have. The electric truck charger utilization rate remains a major source of uncertainty in any NPV calculation.

4.1 Variations in CO_2 savings derived from the Tesla Semi

Replacing a standard diesel truck with a Tesla Semi could reduce average emissions per replaced truck in China over the 2020-2030 timeframe by about a third. Regardless of where in China the Tesla Semi is charged, it should save CO_2 emissions over the course of the truck lifetime, since even in the North China Grid, China's most coal intensive electric grid, the percentage of coal has likely recently dropped below 90%. The magnitude of the CO_2 savings will vary significantly between electric grids in China, which as of 2017 derived between 52-90% of annual generation from thermal power sources.[107] Because I only look at the national electricity generation mix, my analysis obscures large differences in the CO_2 emissions benefits across different regions of China. Electric trucks operated in northeastern China will have less of an emissions reduction impact than the national average, and Tesla Semis operated in Southern China will have more of an emissions reduction on average.

Along with uncertainties in the fraction of coal in the grid wide generation mix, a small decrease in the efficiency of the Tesla Semi could have large impacts. As shown in the equation for γ_{tesla}, percentage changes in the efficiency of the Tesla Semi have a corresponding percentage change in the

107 China National Bureau of Statistics

amount of CO_2 emitted per mile of travel. According to an independent analysis from engineers at Carnegie Mellon University, the best estimate for the efficiency of an electric truck similar to the Tesla Semi is 2.2 to 2.9 kWh per mile, with an optimistic scenario estimate of 1.6 to 2.2 kWh per mile.[108] If the Tesla Semi has an efficiency of 2.9 kWh per mile instead of 2 kWh per mile, the grid wide percentage of coal generation would need to fall below around 61% before driving a Tesla Semi would provide a CO_2 emissions benefit when compared to a standard diesel truck. Although some regional grids may have below 61% coal generation by 2020, the national average percentage of coal generation for China is not expected to drop below 61% until 2024 according to the US EIA.[109]

On the other hand, Tesla claims that the Tesla Semi will have an efficiency of "< 2 kWh / mile energy consumption,"[110] which would still be in line with the optimistic scenario of *Sripad and Viswanathan* (2017). It is therefore also possible that the use of a Tesla Semi in China could have a greater savings in CO_2 emissions per km driven than calculated in this paper. A more efficient Tesla Semi will also have benefits in terms of improving local air quality, as there will be lower emissions of SO_2, NO_x, or other pollutants emitted from the power sector. However, the relative effects of the Tesla Semi versus a standard diesel truck on local air pollution are not addressed in this paper.

4.2 **Cost concerns and the need for charging infrastructure**

The charging needs and requisite infrastructure mean that bringing the Tesla Semi to China is not as simple as just having truck operators purchase the vehicles. In order for it to be viable for long haul trucking, there will need to be megacharging stations deployed along whatever route the trucks will be driving. Another option would be to locate megachargers at the endpoints of different trucking routes, as long as the route endpoints

108 Sripad & Viswanathan (2017).

109 U.S. Energy Information Administration (EIA), 2017. International Energy Outlook 2017. Reference Case.

110 Semi | Tesla. (n.d.). Tesla.com. https://www.tesla.com/semi

are less than 400 miles apart, so drivers do not have to worry about running out of power mid trip. However, in this situation the Tesla Semi might be operating more as a medium-haul truck. In either instance, in order for electric trucks to become viable in China, a network of charging stations need to be sited and built either by the Chinese government or by third party corporations. For passenger EVs, third party corporations with subsides from the Chinese government are already working on establishing a robust national charging infrastructure.[111,112] In the U.S., a network of over 1000 supercharging stations is owned and operated by Tesla for use by their passenger vehicles, a large portion of which are in California.[113] However it is currently unknown how much the megacharger technology will cost and Tesla has not released any details.

Even if a network of megachargers is successfully deployed in China, there will still be concerns around the upfront cost of the Tesla Semi. For scenarios in which the life cycle cost of a Tesla Semi is cheaper than a diesel truck, the initial cost of the Tesla Semi including the value added tax and the import tariff on foreign vehicles is still ~2.3 times more expensive than a standard diesel truck. This higher initial price could discourage potential purchasers, who might experience 'sticker shock.' The Chinese government could reduce this risk by waiving the import tariff, which would encourage adoption and cause the Tesla Semi to save owners money compared to a standard diesel truck after fewer years of operation. However, the presence of the import tariff gives a significant advantage to domestically produced electric trucks and the Chinese government may therefore decide to keep the tariff in place.

111 Jing, S. (2018, December 24). China's largest electric vehicle charging operator launched. *China Daily*. Retrieved from //www.chinadaily.com.cn/a/201812/24/WS5c204569a3107d4c3a0026a8.html

112 He et al., "Assessment of Electric Car Promotion Policies in Chinese Cities," White Paper (Washington, DC USA: International Council on Clean Transportation, October 2018), https://www.theicct.org/publications/assessment-electric-car-promotion-policies-chinese-cities.

113 Supercharger | Tesla. (n.d.). https://www.tesla.com/supercharger

5. Summary

I show in this analysis that, if Tesla is able to deliver the Tesla Semi at an efficiency close to what the company has advertised, the Tesla Semi will provide net CO_2 benefits compared to a standard diesel truck in China. Given the advertised cost, the Tesla Semi would also save money over the truck's lifetime compared to a standard diesel truck unless diesel fuel prices fall between 2020 and 2030 and megacharger infrastructure costs more than $500k per MW. The main technical barrier for the Tesla Semi is designing a battery that will be able to provide 500 miles of range on a single charge and also be able to recharge to 400 miles in just 30 minutes. This is a technical challenge that all truck electrification efforts will face. If Tesla is able to follow through on its claims, it could herald a significant advance in vehicle electrification technology.

From a policy perspective there are two major challenges. First, depending on the circumstances an electric long haul truck modeled after the Tesla Semi might not save purchasers money over a 10 year period. Furthermore, even if an electric long haul truck would save money in the long term, potential purchasers may be deterred by high upfront costs . Second, a charging infrastructure for electric trucks will need to be created and, since the trucks will need to charge rapidly, that system will need to be specifically designed for large long haul EVs. As with passenger EVs, the deployment of a charging network suffers from a 'chicken and egg' problem, where owners of charging stations cannot recuperate their investments without selling prohibitively expensive electricity or having a large number of vehicles utilizing the station, but a large number of vehicles will not be deployed unless there is some ability for the vehicles to be charged economically. However, since electric truck charging stations would be used by smaller number of commercial vehicles as opposed to a larger number of individual users the benefits of establishing a changing network are more concentrated than with passenger EVs. Individual companies that hope to operate a fleet of electric trucks, or a consortium of companies, may be willing to absorb the initial costs of the development of a charging network as long as the companies are still generate net savings over the long term.

If the Chinese government wishes to accelerate the deployment of electric long haul trucks in China, there are two main options which they could pursue:

- **Waive the imported vehicle tariff on the Tesla Semi or provide direct subsidies for electric long haul truck purchases.** This would have the effect of reducing the upfront cost of the vehicle and reducing the chance of 'sticker shock' among potential purchasers. Waiving the tariff or providing initial subsidies also makes it more likely that the Tesla Semi or a similar electric long haul truck will save users money over the truck's lifetime.
- **Work with Tesla or other corporations to develop a network of megachargers along a few initial trucking routes.** This could be done by subsidizing the construction of the megachargers or by having them be wholly government owned. The megachargers could be designed to charge Tesla Semis as well as any other comparable brand of electric long haul truck. This would allow Chinese policy makers and the trucking industry to test out electric trucks on just a few routes and determine whether and how the use of electric long haul trucks should be expanded nationwide. The development of an initial set of megachargers would also create demand for electric trucks and could help spur development of China's domestic electric truck manufacturing industry.

Because no market currently exists for long haul electric trucks, this paper focuses on the Tesla Semi as a possible harbinger for the electric truck technologies of the next decade. By focusing on China, the world's largest emitter of CO_2, the paper zooms in on one of the regions where truck electrification can have the biggest impacts. However, the lessons learned from an examination of the Tesla Semi in China are also applicable to the introduction of electric trucks broadly. High upfront costs and the need for higher charging infrastructure utilization rates are barriers to any effort to bring electrification to the on-road freight sector. The fact that the Tesla Semi could reduce CO_2 emissions per standard diesel truck replaced in China, despite the large percentage of coal in China's electricity generation mix, is an encouraging sign for the potential emissions benefits of truck electrification. As this technology develops, further CO_2 emissions and cost reductions may become possible. But regardless of whether or not the Tesla Semi itself meets stated performance and cost goals, this paper shows the potential for long haul truck electrification, as already envisioned, to reduce freight related CO_2 emissions and to do so while also reducing costs.

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7. Appendix

Table A1: VDT and α from 2020 to 2030

	Vehicle Distance Traveled (km year^{-1})	κ (fraction of electricity generation from coal, US EIA)	κ (fraction of electricity generation from coal, IEA)
2020	0	0.639445	0.6267388
2021	153175	0.627309	0.6109019
2022	139324	0.619974	0.5950651
2023	126636	0.611863	0.5792282
2024	114082	0.602728	0.5633914
2025	102415	0.593998	0.5475545
2026	92409	0.585998	0.5363444
2027	83055	0.579455	0.5251343
2028	74314	0.572655	0.5139243
2029	66576	0.564101	0.5027142
2030	59577	0.555526	0.4915041

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