WORKING PAPER 2020-07

MARCH 2020

Environmental impacts of modal shift to rail in Tangshan

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Keywords: modal shift, truck to rail, air pollution, life-cycle emissions, diesel consumption

Summary

Driven by severe air pollution in the Beijing-Tianjin-Hebei region, known as Jing-Jin-Ji, and the State Council's requirement to increase the amount of freight transported by rail, the key industrial city of Tangshan has required that all iron ore imports be shipped by rail. In particular, this modal shift from truck to rail seeks to help Tangshan and the Jing-Jin-Ji area reach the particulate matter ($PM_{2.5}$) concentration target of 50–54 micrograms per cubic meter ($\mu g/m^3$) set by the Tangshan government for 2020, and eventually meet the national standard of 35 $\mu g/m^3$.

But while rail transport is typically more efficient for bulk transport, the climate and air quality impacts of using it are dependent on the emissions associated with a given rail system. Therefore, this analysis models the fuel life-cycle environmental impacts and the energy use of the current approach of transporting iron ore from the Tangshan port to nearby steel manufacturers via truck and compares it with alternative methods of transport via rail and truck. For the 220 million tons of iron ore shipped in 2018, modal shift to rail would eliminate about 30,000 truck trips daily, and this would significantly reduce the on-road vehicle congestion around the Tangshan port. This modal shift also results in significant savings of diesel fuel and potential reductions in air pollution. However, we find that requiring stringent emission control technologies in addition to modal shift, including cleaner diesel combustion engines and rail electrification powered by a cleaner grid and renewable energy, is required to achieve the reduction in pollution sought.

Policy background

In 2012, China limited annual average particulate matter concentration ($PM_{2.5}$) to 35 micrograms per cubic meter ($\mu g/m^3$) in ambient air quality standards for the first time and required key cities to monitor and report air quality data (Ministry of Ecology and Environment, 2012). Severe air pollution problems were by then well known. Hebei province in particular was later identified, in 2013, as the most polluted province in China,

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Acknowledgments: This study was sponsored by Energy Foundation China. The author thanks all internal and external reviewers for their guidance and constructive comments, with special thanks to Honglei Xu of Transportation Planning and Research Institute, Shaojun Zhang and Jingran Zhang of Tsinghua University, Junfang Wang of the Vehicle Emission Control Center, Huiming Gong of Energy Foundation China, Cristiano Façanha of CALSTART, and Hongyang Cui, Kate Blumberg, Josh Miller, Dale Hall, and Hui He of the International Council on Clean Transportation.

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and it contained six of the top 10 cities with the highest annual $PM_{2.5}$ concentration. As illustrated in Figure 1, the average annual $PM_{2.5}$ concentration in these cities was about 3–4 times higher than the national limit. The pollution significantly worsened the overall air quality in the Beijing-Tianjin-Hebei region, known as Jing-Jin-Ji.

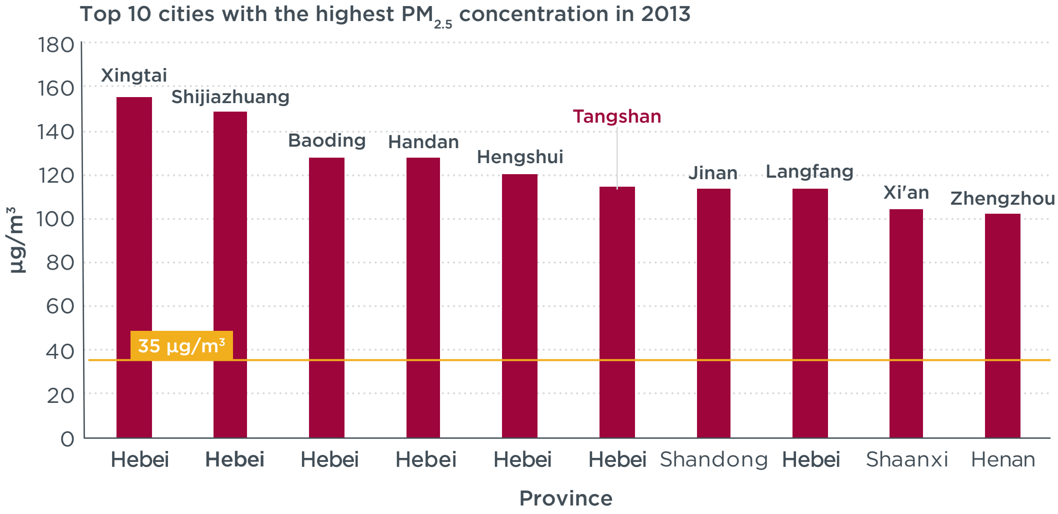

Figure 1. Top 10 cities with the highest average $PM_{2.5}$ concentration in 2013. Source: Greenpeace (2014).

Elevated $PM_{2.5}$ concentrations are associated with premature mortality from lung cancer, cardiopulmonary disease, and acute respiratory infection, as well as many other acute and chronic health impacts. The State Council released the Air Pollution Prevention and Control Action Plan in 2013 and it contains aggressive measures to reduce reliance on coal energy; these include increasing the share of renewable energy sources, reducing tailpipe emissions from motor vehicles, and strengthening regulatory enforcement and monitoring systems for motor vehicles. All of this is aimed at improving air quality and dramatically reducing heavily polluted days (State Council, 2013). After identifying Jing-Jin-Ji as the most polluted region in China, the plan also set a target of a 25% decrease of $PM_{2.5}$ concentration by 2017 when compared with the 2012 level for the area; this was more aggressive than the targets set for the other two economic centers for which air pollution strategies were also adopted—the Yangtze River Delta (target of 20% decrease of $PM_{2.5}$ concentration by 2017) and the Pearl River Delta area (15% decrease of $PM_{2.5}$ concentration by 2017). The plan proved to be effective, as the annual average $PM_{2.5}$ concentration in Jing-Jin-Ji in 2017 was about one-third lower than in 2013 (Figure 2). However, the average $PM_{2.5}$ concentrations monitored were still higher than the national standard of 35 µg/m³ and far above World Health Organization's (WHO) recommended limit of 10 µg/m³. This suggested that further action was needed to address air pollution in the region.

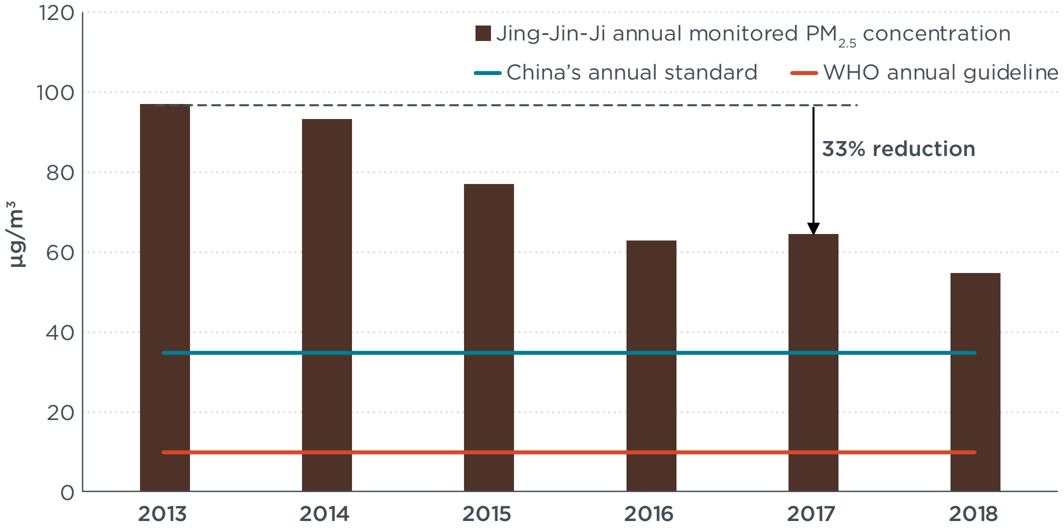

Figure 2. Monitored $PM_{2.5}$ in Jing-Jin-Ji. Source: China Air Quality Monitoring and Analysis Platform (n.d.).

Motor vehicles, particularly heavy-duty vehicles (HDVs), are a major source of urban air pollution, greenhouse gas (GHG) emissions, and congestion. Although HDVs make up just 10% of the total vehicle fleet in China, they are responsible for more than 80% of particulate emissions and consume nearly 50% of on-road fuel; they are also a major source of CO_2 emissions (Kodjak, 2015; Yang, Delgado, & Muncrief, 2019). Diesel vehicles are the third largest contributor to Jing-Jin-Ji's local $PM_{2.5}$ pollution (Xue, 2018), and as a result, the three-year National Plan of Blue-Sky Defense requires early adoption of the China 6/VI vehicle emission control standards in the area along with sufficient supply of ultralow-sulfur diesel fuel in 2019 and the removal of more than 1 million China III or older HDVs by the end of 2020 (State Council, 2018a). China VI emission standards are expected to reduce more than 80% of PM and NO_x pollutants and reduce the annual average $PM_{2.5}$ concentration for Jing-Jin-Ji by 1.46 µg/m³ by 2030 (Cui, Posada, Lv, Shao, Yang, & Liu, 2018).

In addition to regulating diesel HDVs, the State Council requires that freight shipping be restructured. The goal of the National Plan of Blue-Sky Defense is to significantly shift bulk freight transport from on-road HDVs to railroads and waterway (State Council, 2018a). Additionally, the Three-year Action Plan on Promoting Shipping Structure Adjustment targets increasing the volume of goods shipped by railroads to 1.1 billion tons by 2020, a 30% increase from 2017 levels (State Council, 2018b). For Jing-Jin-Ji, the railroad shipping volume was expected to increase more, to 40%; the plan called for an extensive of expansion of dedicated tracks connecting major industry and logistic parks, and of on-dock tracks connecting port terminals. The State Council (2018a; 2018b) and Ministry of Ecology and Environment (2019a) required that outbound shipping from ports of all coal products be done via railway and/or waterway instead of diesel trucks by the end of 2018; they also suggested expanding this modal shift strategy to the shipment of all bulk products.

Tangshan, as one of the most polluted cities in the Jing-Jin-Ji area, has mandated the use of railway for all iron ore imports from the Tangshan port (Vehicle Emission Control Center [VECC], 2018; VECC, 2019). Given Tangshan's decision to use rail, this study evaluates the environmental and energy performance of the modal shift strategy from truck to rail and offers key insights for policy implementation that would help reach desired benefits. We compare the expected impacts from the use of various truck and railway technologies to ship the iron ore. While rail transport is generally more efficient for bulk transport, the climate and air quality outcomes of this strategy can vary greatly depending on the emissions associated with rail systems. Indeed, as new standards dramatically reduce truck emissions, moving to rail can actually increase air pollution if the engines are highly polluting or, in the case of an electrified rail system, if upstream emissions are high. The results are also relevant for other ports and policymakers considering a modal-shift strategy.

About Tangshan and Tangshan port

Tangshan is a key industrial city in the Jing-Jin-Ji economic center, which surrounds the capital Beijing and is one of the country's economic megalopolis regions (Figure 3). Despite having less than 2.5% of China's land area, and less than 7.5% of its population, Jing-Jin-Ji contributes about 10% of the national gross domestic product (GDP), and about 40% of this comes from Hebei province (National Bureau of Statistics of China, 2019). One of the dominant industries in Hebei is steel production; it contributes more than 20% of China's total production, and half of that comes from the city of Tangshan (National Bureau of Statistics of China, 2019; China Industry Information, 2018). Tangshan's leading role in China's steel industry stems from its unique geographic location, rich mineral resources, and from the large amounts of iron ore imports that come through the Tangshan port.

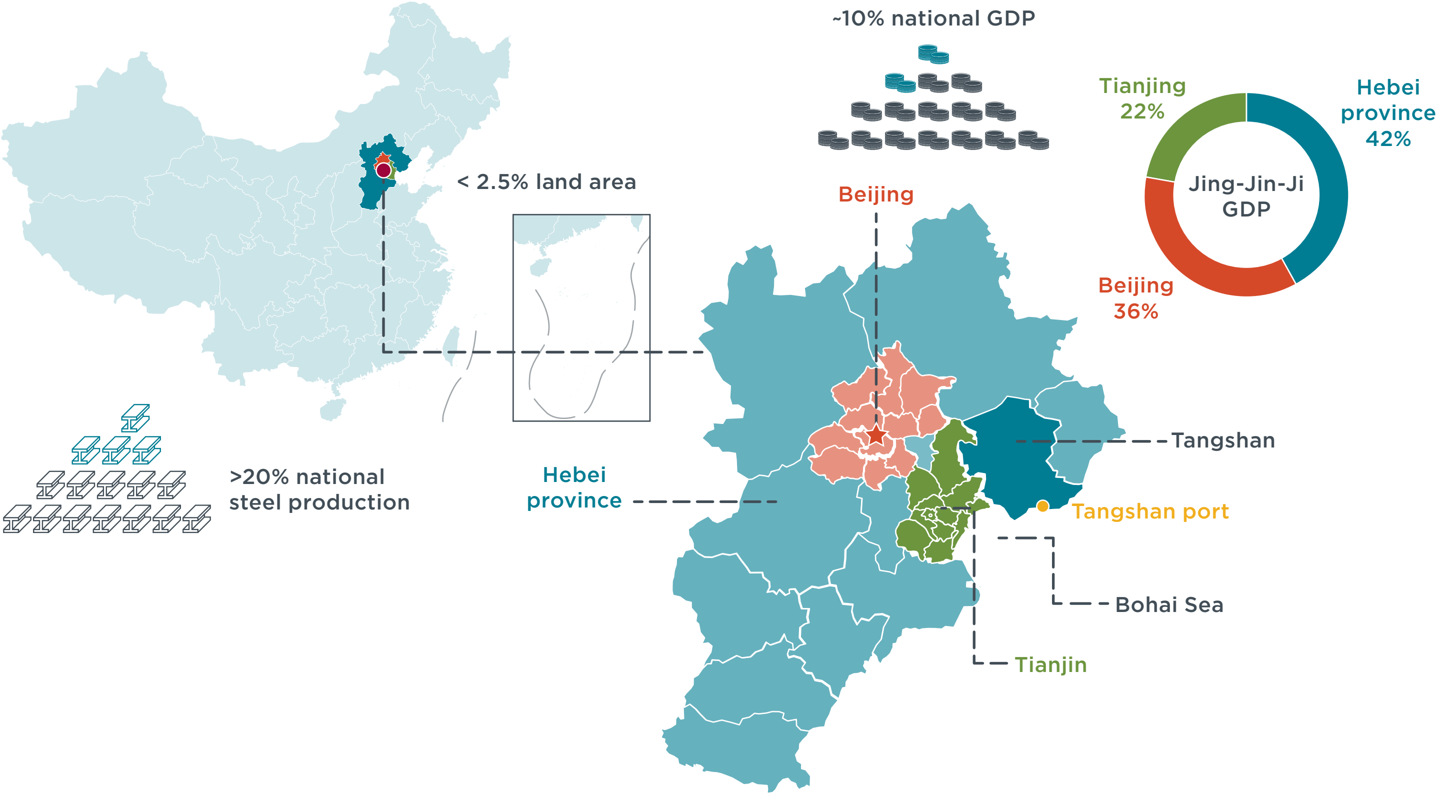

Figure 3. Jing-Jin-Ji maps

Located on the coast of the Bohai sea, Tangshan port is among the top 10 ports with the highest annual cargo volume in the world (Clemenson, 2017). Coal and iron ore were the top two products shipped through Tangshan in 2018; 262 million tons and 220 million tons, respectively, were transported, and almost all was moved via on-road diesel heavy-duty trucks (Tangshan Government, 2019b).

The dependence on diesel heavy-duty trucks around the port contributed to the poor air quality in Tangshan. Based on source apportionment analysis, motor vehicles were one of the top five contributors, and were responsible for about 10% of the poor air quality in Tangshan (Wen, Han, Chen, Cheng, & Zhang, 2015; Sun, 2015). The current freight diesel trucks used for port inbound and outbound shipping, though mostly China IV- or China V-compliant vehicles, emitted relatively high amounts of pollution due to a lack of state-of-the-art emission control technology and comprehensive in-use compliance program, resuspended road dust, and severe congestion due to the large number of truck trips required. Emissions were also elevated as a result of poor compliance and enforcement and overloading of trucks (Ding, 2018).

To address the air pollution caused by diesel HDVs and to echo the central government's modal shift strategy to railway, Tangshan plans to ship all bulk products to and from the Tangshan port via railway; this would begin in 2020 at the earliest (Hebei Government, 2018; "Tangshan city," 2018). The Tangshan government also set $PM_{2.5}$ concentration goals of 57 $\mu g/m^3$ for 2019, and 50–54 $\mu g/m^3$ for 2020, with the intention of removing Tangshan from the top 10 cities with the worst air quality ("Tangshan city," 2018; Tangshan Government, 2019a).

The city has prioritized the implementation of the modal shift to rail by banning the use of diesel trucks for iron ore shipping and providing more than 2.56 billion RMB (approximately $370 million in U.S. dollars) for building dedicated tracks between the 16 major steel companies and on-dock tracks in the port's terminals (VECC, 2018; VECC, 2019). The funding also subsidizes the relocating of smaller steel companies closer to the port (Tangshan Government, 2019c). This decision supports an ultralow-emission steel production industry, as suggested by the Ministry of Ecology and Environment (2019b).

Methodology and data

This study estimates the fuel life-cycle environmental impacts and energy use of the transport of today's more than 200 million tons annually of iron ore imports from the Tangshan port. We consider both modal shift to rail and other clean vehicle emission control technologies, as detailed in Table 1. The analysis models two truck and five railway scenarios and captures the change in emissions from each mode when combined with its technology potential.

The baseline scenario assumes that all iron ore is shipped by the *current truck fleet*, which is about 90% diesel and 10% compressed natural gas (CNG) powered, based on data the Tangshan port provided. The potential improvements from adopting advanced truck technology are estimated in the *China VI truck fleet* scenario, which assumes that iron ore would still be shipped by diesel trucks, but by China VI-certified ones only. To evaluate Tangshan's modal shift strategy, the *current train fleet* scenario assumes a modal shift to today's railway system, with 70% of the trains electrified and the remaining 30% powered by diesel. The electricity used in the *current train fleet* comes from a grid powered by 87% coal, 7% renewable energy, and other traditional sources, which is consistent with China's national average (State Grid Corporation of China, 2019). To isolate the emissions contributions from within the current railway system, the *all diesel train fleet* and *all electric train fleet* scenarios investigate the impacts of using all diesel trains without emission control technology, as is the case today, and all electric trains with the current power grid.[1] Lastly, the study examines scenarios of an *all electric train fleet with a cleaner grid*, which assumes that iron ore is shipped by electric trains powered by much cleaner electricity (20% or more renewal sources), and an *advanced diesel train fleet* scenario, which assumes that iron ore is shipped by diesel trains certified to U.S. Tier 4 emission standards.

The study assumes that no drayage trucks are needed in any railway scenario, to reflect Tangshan's efforts to build dedicated tracks between major steel companies

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[1] The rationale for modeling the *all diesel train fleet* is to examine the contribution of emissions from diesel trains in today's train fleet and does not suggest a transition to all diesel trains in China.

and terminals.[2] Thus, the same average shipping distance is assumed in all scenarios. Although the scenarios include future projections about technology and strategy uptake, the study does not take into consideration any changes in shipment amounts. This is to more clearly isolate the effects of the strategies on energy use and emissions.

Table 1. Scenarios and assumptions for shipping iron ore imports from Tangshan port, using data from 2018

Scenario	Mode	Fuel type	Technology highlights
Current truck fleet	Truck	Diesel – 90% CNG – 10%	Trucks: • 20% China III certified • 40% China IV certified • 30% China V certified • 10% CNG
China VI truck fleet	Truck	Diesel	Trucks: 100% China VI certified
Current train fleet	Railway	Electricity – 70% Diesel – 30%	Diesel trains: no emission control standards required Grid: 87% coal, 7% renewable
All electric train fleet	Railway	Electricity	Grid: 87% coal, 7% renewable
All diesel train fleet	Railway	Diesel	Diesel trains: no emission control standards required
Electric train fleet with a cleaner grid	Railway	Electricity	Grid: ~20% or more renewable sources, lower coal-based sources, and advanced emission control technology for plants
Advanced diesel train fleet	Railway	Diesel	Diesel trains: U.S. Tier 4 emission standards

The study estimates the impacts on carbon dioxide (CO_2) emissions, which make up the largest share of long-term climate impacts from freight transportation, particulate matter with a diameter of 2.5 µm or less ($PM_{2.5}$), and nitrogen oxides (NO_x). Emissions of CO_2, NO_x, and $PM_{2.5}$ are calculated as the product of freight volumes, travel distance, and emission factors/fuel efficiency, and then added to the emissions from upstream energy generation. Slightly different calculation procedures were adopted for railroads and trucks, due to the nature of the data collection process.

Regulatory context

China has continuously tightened its vehicle emission standards. The country began regulating vehicle tailpipe emissions in 2000, when the China 1/I vehicle emission standards were first adopted, and has subsequently tightened them to ensure that the standards keep pace with those adopted in the United States and European Union (EU) (Figure 4). The latest China VI HDV emission standards are among the world's most stringent; combined with an improved compliance and enforcement program, these efforts are believed to be key to cleaning up diesel emissions (Cui et al., 2018; Yang & He, 2018). The early implementation timeline in the Jing-Jin-Ji area makes it possible to use China VI certified diesel trucks only for freight shipping in and out of the port if needed.

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[2] Drayage trucks are on-road, diesel-fueled, heavy duty trucks that transport containers and bulk to and from the ports and intermodal railyards and to many other locations (California Air Resources Board, 2019).

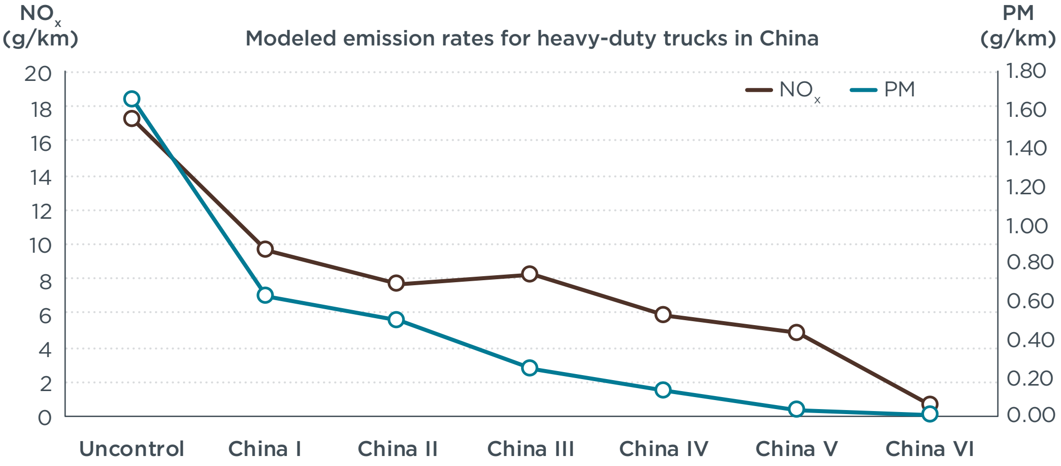

Figure 4. Emission rates used for heavy-duty trucks in China

China has not implemented emission standards for railway, but strongly promotes the electrification of the system. As a result, China has one of the fastest growing rail electrification rates in the world (International Energy Agency, 2019). The share of electrification increased from less than one-quarter in the late 1990s to almost three-quarters in recent years. While China does not include locomotives in the regulations of non-road tailpipe emissions, countries like the United States and EU member states have advanced regulations on locomotives' emissions. The current U.S. and EU regulations on locomotives are largely consistent, as both U.S. Tier 4 and EU Stage IV standards remove 90% of the PM and NO$_x$ emissions (Figure 5). The EU Stage V emission standards, phased in from 2020, will incorporate a particulate number (PN) standard that is expected to result in the adoption of particulate filters and another approximately 90% reduction in PM emissions from the HDV fleet (Shao, 2016b; Dallmann, 2016).

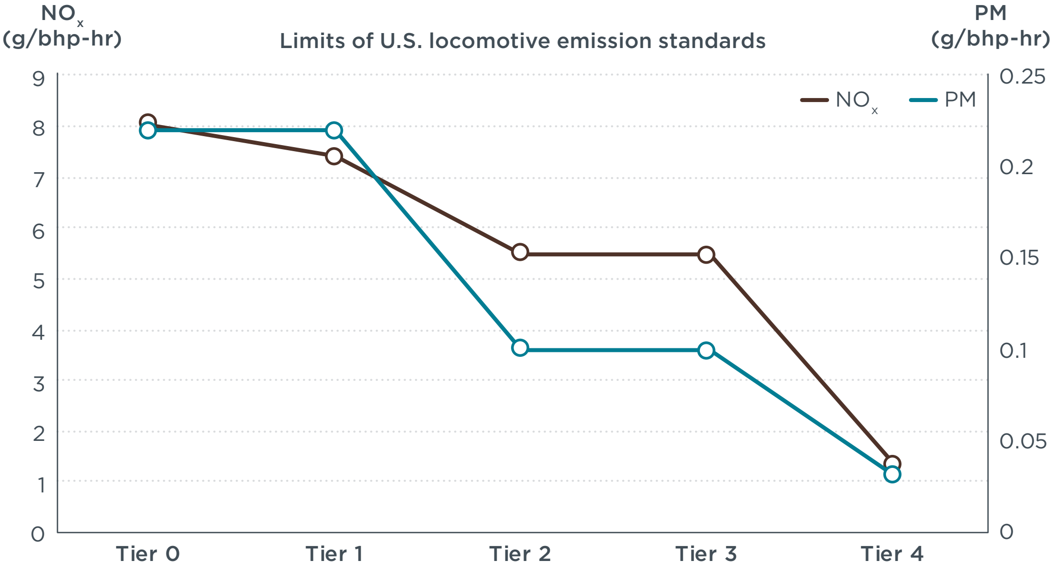

Figure 5. Limits of the U.S. locomotive emission standards

The inputs data used for the calculation are listed in Table 2. The inputs of average shipping distance, iron ore shipping volume, fuel blends, certified emission standards, average payload, and fuel efficiency of trucks came from the data collected by the Tangshan port. The emission rates used for the trucks are consistent with ICCT's study evaluating the costs and benefits of implementing China VI vehicle emission standards (Cui et al., 2018). Railway service data was gathered from a literature review and ICCT's previous studies. The emission rates of diesel locomotives were collected from the VECC and the Ministry of Ecology and Environment, and the fuel efficiency was determined using ICCT's Global Roadmap model (Façanha, Blumberg, & Miller, 2012). The emission rates of locomotives certified with more stringent emission standards came from ICCT's non-road model (Shao, 2016a) and the share of empty backhauls is consistent with ICCT's previous study (Yang, 2019). The carbon intensity of fuel and the upstream emission rates of China's electricity grid were based on several local studies with a focus on the fuel life-cycle emission rates of energy in China (Huo, 2010; Cai, Wang, Jin, & Chen, 2013; Jiang, Ou, Ma, Li, & Ni, 2013; Huo, 2015), and information from the Roadmap model (Façanha et al., 2012)

Table 2. Key inputs and their data sources

Inputs	Value	Source
Shipping distance	200 km	Tangshan Port
Iron ore volume	220 million tons	Tangshan Port
Trucks fuel blends	90% diesel 10% CNG	Tangshan Port
Locomotives fuel blends	70% electricity 30% diesel	National Railway Administration, 2019
Trucks emission standards	• 20% China III certified • 40% China IV certified • 30% China V certified • 10% CNG	Tangshan Port
Locomotive emission standards	No emission control standards	VECC
Trucks average payload	33 tons per truck	Tangshan Port
Locomotive average payload	8,400 tons per train	Tangshan Port
Fuel efficiency of trucks	60 L/100km	Tangshan Port
Fuel efficiency of locomotives	0.33 MJ/ton-km	ICCT Roadmap model
Trucks share of empty backhauls	40%	Yang, 2019
Railway share of empty backhauls	50%	"Internet+logistics," 2016

The scope of analysis performed is limited in several ways. First, the study does not consider future fuel efficiency improvements in the truck or railway scenarios; this is in order to reflect the current period. Second, because each scenario adopts only one mode (i.e., truck or rail), the study does not capture idling emissions or changes in emission rates and efficiency based on congestion levels; these are estimated to be an additional 20%–40% on top of vehicle running CO_2 emissions, based on a study of Shenzhen Port (Yang, Cai, Zhong, Shi, & Zhang, 2017). However, mode shift would be expected to reduce idling emissions and congestion. Finally, the study does not include the emissions and energy use of vehicle and locomotive production, maintenance, and end of life, or of the construction, maintenance, and end of life of infrastructure such as road, rail, and belt that would occur because of the change in shipping modes.

Results

If the 220 million tons of iron ore imports shipped annually from Tangshan port were shifted to rail, about 30,000 truck trips would be avoided daily. This would reduce congestion and lead to lighter traffic around the port and in the city of Tangshan. Additionally, this finding is consistent with an earlier report which indicated that about 17,000 truck trips would be avoided if the 100 million tons of iron ore imports from the port's Caofeidian area were shifted to rail (Si, 2018).[3]

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[3] Caofeidian port is an important component of the Tangshan port and shares about half of Tangshan port's annual cargo volume.

However, on its own, modal shift to rail might not reduce the fuel life-cycle emissions because trucks with advanced emission control technology are competitive in emission control when comparing fuel life-cycle PM, NO_x, and CO_2 emissions across all scenarios modeled. Full results of this analysis are shown in Figure 6, with tank-to-wheel (TTW) emissions of the *current truck fleet* normalized as one and the upstream emissions illustrated by the lightly shaded areas with a dotted border.

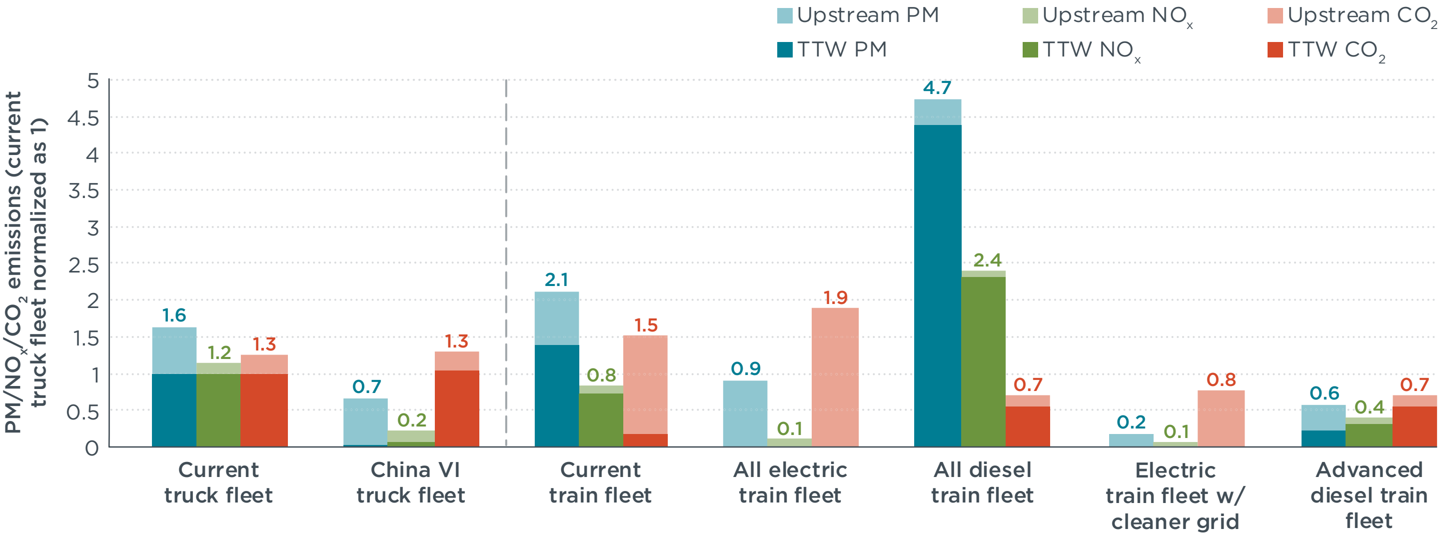

Figure 6. Well-to-wheel (WTW) PM, NO_x, and CO_2 emission comparison across scenarios

The analysis demonstrates that:

» Implementing the modal shift strategy using the *current train fleet* would reduce local emissions of NO_x but increase TTW emissions of PM over the base case. Additionally, when the upstream emissions are included, they are much higher than those in the *current truck fleet* for PM and CO_2 on a well-to-wheel (WTW) basis.

» Shifting the iron ore imports to an *all electric train fleet* removes all local TTW emissions. Additionally, the adoption of ultralow-emission standards for the grid would ensure the decrease of WTW PM and NO_x emissions when relying on electric trains solely for modal shift (Ministry of Ecology and Environment, 2015). But due to China's currently heavy reliance on coal power for electricity generation, this scenario increases WTW CO_2 emissions.

» The *all diesel train fleet* increases the TTW PM and NO_x emissions compared to the *current train fleet*, with the largest increase identified for local air quality. In this scenario, local emissions of PM quadruple and NO_x emissions double; meanwhile, WTW CO_2 emissions are reduced to the lowest level of all scenarios.

» Introducing sustainable power sources and advanced emission control technologies for the power grid, as assumed in the *electric train fleet with a cleaner grid* scenario, substantially reduces upstream emissions from electric trains, which already eliminate local TTW emissions. As a result, this scenario provides the lowest WTW PM and NO_x emission reductions of any of the scenarios. The WTW CO_2 emissions are not yet the lowest because coal power plants would still dominate the regional grid, albeit with advanced emission control technologies (e.g., carbon capture and storage technology) included.

» The *advanced diesel train fleet* scenario would cut WTW emissions of all pollutants in half compared to the base case, resulting in one of the lowest overall emissions of the scenarios considered.

- Using *China VI truck fleet* only removes more than 95% of the TTW PM and NO$_x$ emissions when compared with the *current truck fleet*. As trucks would continue to be diesel powered, no upstream benefits are identified. This scenario does not yield any CO$_2$ benefits due to a conservative assumption of no fuel efficiency improvements.

The results indicate that modal shift to rail can lead to substantial PM and NO$_x$ emission reductions only when combined with the cleanest technologies. The *current train fleet* scenario is not competitive in fuel life-cycle emission control when compared with the *current truck fleet*. However, with advanced emission control technologies, either for upstream emissions from electricity production or on rail engines powered by diesel, modal shift to rail in the *electric train fleet with a cleaner grid* and *advanced diesel fleet* scenarios would avoid a majority of the emissions associated with the transport of iron ore imports and help meet the targets for an ultralow-emission steel production industry.

Tighter emission controls on the railway system are required to match the environmental benefits that would be achieved by using China VI trucks. Taking advantage of the early adoption of China VI-b emission standards in Jing-Jin-Ji from 2019, the Ministry of Ecology and Environment recommends that only China VI-qualified vehicles or trucks powered by renewable energy be temporarily used for iron ore shipping if rail capacity cannot meet all demand (Ministry of Ecology and Environment, 2019b). Additionally, the zero-emission technology in freight trucks offers cost-effective options for deeper emission reduction when combined with a decarbonizing grid (Moultak, Lutsey, & Hall, 2017; Hall & Lutsey, 2019).

Stringent emission control standards on diesel engines have proven effective in removing all types of pollutants. As detailed in Table 3, upgrading the truck fleet to comply with China VI standards (*China VI truck fleet*) would remove about 60% of PM and 80% of NO$_x$ compared to the existing fleet. A modal shift strategy that requires diesel locomotives to comply with the U.S. Tier 4 emission standards (*advanced diesel train fleet*) offers a similar benefit, and eliminates more than two-thirds of the PM and NO$_x$ from the *current truck fleet* and 88% of PM and 84% of NO$_x$ from the *all diesel train fleet*. Such standards involve the implementation of similar emission control technologies as introduced on the HDV fleet.

Table 3. PM, NO$_x$, and CO$_2$ emissions by scenarios, and the percentage change when comparing with the current truck fleet scenario

	PM (tons)			NO$_x$ (tons)			CO$_2$ (tons)		
	TTW	Uptream	WTW (%)	TTW	Upstream	WTW (%)	TTW	Upstream	WTW (%)
Current truck fleet	229	145	—	11,588	1,772	—	3,373,539	858,668	—
China 6 truck fleet	3	150	↓ -59%	657	1,838	↓ -81%	3,494,791	898,807	↑ 4%
Current train fleet	316	166	↑ 29%	8,465	1,105	↓ -28%	593,169	4,543,212	↑ 21%
All electric train fleet	—	205	↓ -45%	—	1,158	↓ -91%	—	6,409,720	↑ 51%
All diesel train fleet	1,003	81	↑ 190%	26,874	990	↑ 109%	1,883,076	484,298	↓ -44%
Electric train fleet w/ cleaner grid	—	38	↓ -90%	—	844	↓ -94%	—	2,558,771	↓ -40%
Advanced diesel train fleet	48	81	↓ -66%	3,476	990	↓ -67%	1,883,076	484,298	↓ -44%

Implications for diesel consumption

Shifting to any of the all-train scenarios reduces and removes the heavy reliance on diesel fuel when compared with either of the truck scenarios. As shown in Figure 7, modal shift to diesel trains in the *all diesel train fleet* and the *advanced diesel train fleet* reduces diesel consumption by more than 40%. Additionally, the *current train fleet* scenario would avoid about 85% of diesel usage annually, which is consistent with the finding for modal shift at the Caofeidian port (Hebei News, 2018). Shifting to electric railway in the *all electric train fleet* and *electric train fleet with a cleaner grid* scenarios would completely replace diesel fuel with electricity and reduce China's dependence on oil imports. Although, as related above, the *China VI truck fleet* scenario would generate measurable reductions in PM and NO_x emissions because of the advanced emission control technology required, it does not reduce reliance on diesel fuel because no fuel efficiency improvements are assumed for heavy-duty trucks in this analysis.

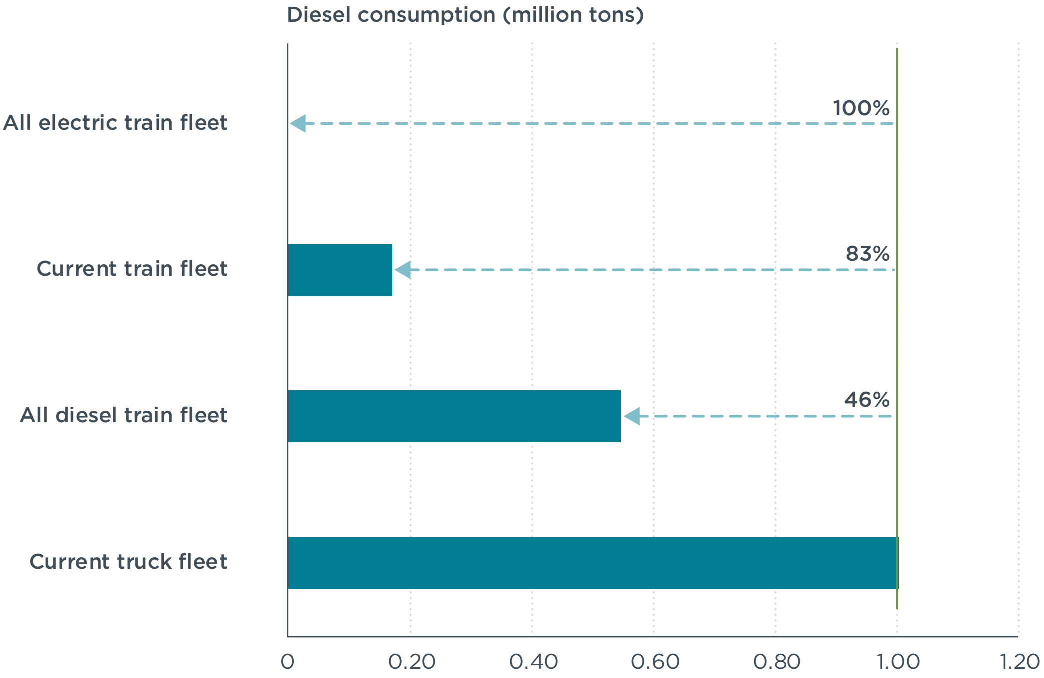

Figure 7. Diesel consumption by scenario.

The role of the grid

Currently, 70% of China's rail system is electrified. As the country continues to make efforts to increase this electrification, cleaning up the power grid will be critical in order to reduce overall emissions. Under the *current train fleet* scenario, PM emissions are increased by more than 30% and CO_2 emissions are increased by 15% when compared with the *current truck fleet*. Overall emissions trends are slightly better under the *all electric train fleet* scenario, but with increased upstream emissions; this demonstrates that electrification of the railway system is not enough, as it relocates the emissions to the area where power plants are located and can increase overall WTW emissions.

With a sustainable electrified railway system, including with more renewable sources, reduced reliance on coal, and improved upstream emission control technology, the *electric train fleet with cleaner grid* scenario avoids 90% of PM, 94% of NO_x, and 40% of CO_2 from the *current truck fleet* scenario, and 81% of PM, 27% of NO_x, and 60% of CO_2 emissions from the *all electric train fleet* scenario. While this is consistent with China's long-term plans to introduce more renewable energy sources and reduce dependence on fossil fuel (National Development and Reform Commission, 2016), the results show that shift to rail prior to this transition would increase the total life-cycle fuel pollutant emissions from iron ore transport in Tangshan, and increase its contribution to the overall air pollution levels in Jing-Jin-Ji.

The role of empty backhaul

Another key element in the success of modal shift from truck to rail is the share of empty backhaul. This is particularly important because it is typically more challenging to reduce railway empty backhauls, due to less flexibility in scheduling and route design. The results presented in the previous charts and tables assume a 40% empty backhaul for both truck scenarios, and 50% for all railroad scenarios. Figure 8 highlights the possibility that even with the cleanest technology equipped, the *China VI truck fleet* and *advanced diesel train fleet* scenarios can be less competitive in PM emission reduction with the assumption of a 100% empty backhaul when compared with *current truck fleet* scenario with a 0% empty backhaul.

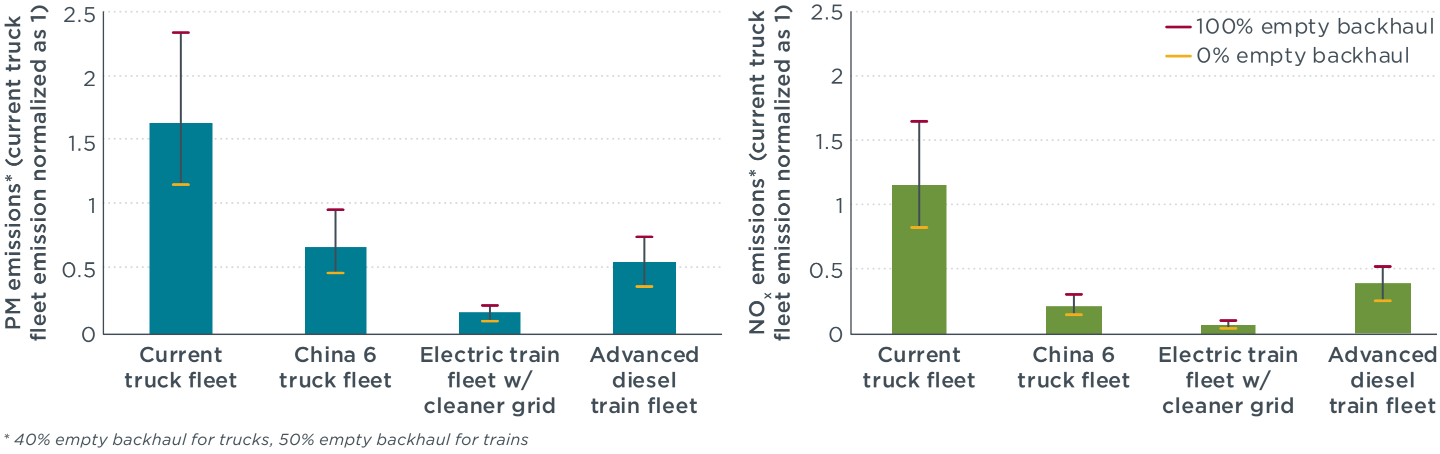

Figure 8. PM and NO_x impacts of empty backhaul for selected scenarios

The role of drayage

Emissions from first- and last-mile truck connections can further reduce any benefits from the modal shift to rail scenarios, although that was not captured in this analysis. Moving to rail can reduce the truck trips for origin–destination transit, but it might increase the use of drayage hauling if not well planned. Tangshan is in the process of building dedicated tracks so that the major steel companies can connect with on-dock tracks in the terminals; the city is also relocating smaller companies closer to the port for belt shipping.[4] These measures will eventually avoid the use of diesel drayage trucks for hauling iron ore. In other cities, however, it is possible that first- and last-mile truck connections could offset some or all the environmental and health benefits from modal shift to rail if China VI trucks and/or zero-emission trucks are not required for these activities.

Discussion and opportunities for future research

The environmental benefits of the modal shift strategy could be even larger than modeled. This is because improved traffic conditions would likely result in reduced idling time for all motor vehicles; this, in turn, would reduce the tailpipe emissions from and energy consumption of the other vehicles on the road. Moreover, while this analysis focused on today's iron ore shipping from Tangshan port only, an expanded evaluation would identify additional potential benefits. As the Jing-Jin-Ji economy grows, the Tangshan port is expected to have a larger role in processing imports and exports. A modal shift to clean transport can greatly reduce the associated pollution impacts on the city and the entire Jing-Jin-Ji area by eliminating thousands of tons conventional pollutants and millions tons of CO_2 emissions each year. In addition, most of the engines certified with the cleanest emission control standards last longer and can be quite cost-effective in the long term.

Modal shift to rail is expected to be widely adopted in almost all ports in China. This case study of Tangshan port illustrates how such a modal shift strategy would impact emission-reduction and energy-savings goals. The results highlight how modal shift to

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[4] Belt shipping is a widely adopted approach for shorter-distance transport of bulk products. Particularly for those companies located in or closer to the port area, belt shipping is a cost-effective shipping method and avoids the use of trucks.

rail could result in limited or even no reduction of air pollution, and how an advanced truck fleet that meets regulations already in place could provide significant reductions.

Nonetheless, modal shift to rail is quite effective in reducing reliance on diesel fuel and alleviating congestion. Railroads are also more efficient than trucks, and thus the shift can reduce diesel fuel consumption even if the rail engines are powered by diesel. Tangshan has taken an important step by building dedicated railway tracks that connect major steel companies and belt connecting smaller companies to completely eliminate the need for diesel drayage trucks. With fewer trucks needed on road, it is expected that congestion on major freight corridors will be lightener, and this would reduce both idling time and emissions.

However, the modal shift to rail strategy can only reduce fuel life-cycle emissions when combined with advanced technology. Tangshan's example shows that adopting electric trains along with a cleaner grid and/or diesel trains that comply with U.S. Tier 4 emission standards can yield significant fuel life-cycle emission reductions. Conversely, relying on the current train system, whether the locomotives are electric or diesel, might not yield the full air pollution benefits sought. And the ultralow-sulfur diesel fuel that would ensure the application of these advanced emission control technologies on diesel locomotives is available (Shao, 2018). Further, the recently implemented China VI heavy-duty emission standards support emission reductions, and China VI certified trucks would pollute substantially less. This might increase the pressure on railroads to accelerate the transition to advanced emission control technology.

Lastly, areas for future research include estimation of the environmental impacts of improved shipping of all commodities—imports and exports—in Tangshan port and evaluation of the near- and long-term air quality and public health impacts for Tangshan port. Other work could analyze the potential environmental impacts of modal shift for major ports in other areas and assess the energy and environmental performance of commodities supply chains and their estimated costs.

References

Cai, W., Wang, C., Jin, Z., & Chen, J. (2013). Quantifying baseline emission factors of air pollutants in China's regional power grids. *Environmental Science and Technology, 47*(8), 3590–3597. doi: 10.1021/es304915q.

California Air Resources Board (2019). *Drayage trucks at seaports and railyards.* Retrieved from https://ww2.arb.ca.gov/our-work/programs/drayage-trucks-seaports-railyards

China Air Quality Monitoring and Analysis Platform (n.d.). *唐山空气质量指数月统计历史数据 (Tangshan city monthly air quality data).* Retrieved from https://www.aqistudy.cn/historydata/monthdata.php?city=%E5%94%90%E5%B1%B1

China Industry Information (2018). *2017年中国辽宁省、河北省钢材行业产量、消费量及政策分析(Analysis of steel production, consumption, and relevant policy for China Liaoning and Hebei province).* Retrieved from http://www.chyxx.com/industry/201801/605711.html

Clemenson, D. (2017, October 15). Tonnage titans—top 20 ports by annual cargo throughout. *Fairplay Magazine*. Retrieved from http://portsl.com/wp-content/uploads/2017/10/2017_10_15_IHSFairplayMag_Top_20_World_Ports.pdf

Cui, H., Posada, F., Lv, Z., Shao, Z., Yang, L., & Liu, H. (2018). *Cost-benefit assessment of the China VI emission standard for new heavy-duty vehicles.* Retrieved from the International Council on Clean Transportation, https://www.theicct.org/sites/default/files/publications/China_VI_cost_benefit_assessment_20180910.pdf

Dallmann, T., & Menon, A. (2016). *Technology pathways for diesel engines used in non-road vehicle and equipment.* Retrieved from the International Council on Clean Transportation, https://www.theicct.org/sites/default/files/publications/Non-Road-Tech-Pathways_white-%20paper_vF_ICCT_20160915.pdf

Ding, Y. (2018). *2+26城市重型货车的排放情况 (Heavy-duty trucks' emissions in 2+26 cities).* Vehicle Emission Control Center. Retrieved from http://www.vecc-mep.org.cn/ke/three/159.html

Façanha, C., Blumberg, K., & Miller, J. (2012). *Global transportation energy and climate roadmap*. Retrieved from the International Council on Clean Transportation, https://www.theicct.org/publications/global-transportation-energy-and-climate-roadmap

Government of Tangshan (2019). *我市集中开展全域无超载超限城市创建统一行动(Tangshan creates actions on preventing overrun and overloaded issues).* Retrieved from http://www.tangshan.gov.cn/zhuzhan/zhengwuxinwen/20190409/684839.html

Greenpeace (2014). *Infographic: 2013年全国74个城市$PM_{2.5}$排行榜 (Infographic: 2013 PM2.5 ranking for 74 cities in China).* Retrieved from http://www.greenpeace.org/china/zh/news/stories/climate-energy/2014/01/PM25-ranking-infographic/

Hall, D., & Lutsey, N. (2019). *Estimating the infrastructure needs and costs for the launch of zero-emission trucks.* Retrieved from the International Council on Clean Transportation, https://theicct.org/sites/default/files/publications/ICCT_EV_HDVs_Infrastructure_20190809.pdf

Hebei Government (2018). *河北省人民政府关于印发河北省打赢蓝天保卫战三年行动方案的通知 (Hebei Government released three-year action plan on winning the BlueSky Defense War). Retrieved from http://info.hebei.gov.cn/hbszfxxgk/6806024/6807473/6806589/6806185zc/index.html*

Huo, H., Zhang, Q., Wang, M., Streets, D., & He, K. (2010). Environmental implication of electric vehicles in China. *Environmental Science and Technology*, *44*, 4856-4861. doi: 10.1021/es100520c

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*, 107–116. doi: 10.1016/j.atmosenv.2015.02.073

"Internet + logistics" saved trucks' empty backhaul for almost 2 billion kilometers in Henan province in about 10 years (2016, August 8). *(互联网+物流"河南10年前就有 减少货车空载里程近20亿公里).* *Ifeng News*. Retrieved from http://inews.ifeng.com/yidian/49737202/news.shtml?ch=ref_zbs_ydzx_news

International Energy Agency (2019). *The future of rail – opportunities for energy and environment.* International Energy Agency. Retrieved from https://webstore.iea.org/the-future-of-rail

Jiang, L., Ou, X., Ma, L., Li, Z., & Ni, W. (2013). Life-cycle GHG emission factors of final energy in China. *Energy Procedia, 37*, 2848–2855. doi: 10.1016/j.egypro.2013.06.170

Kodjak, D. (2015). *Policies to reduce fuel consumption, air pollution, and carbon emissions from vehicles in G20 nations.* Retrieved from the International Council on Clean Transportation, https://www.theicct.org/publications/policies-reduce-fuelconsumption-air-pollution-and-carbon-emissions-vehicles-g20

Ministry of Ecology and Environment of the People's Republic of China (2012). *Ambient air quality standards.* GB 3095-2012. Retrieved from http://210.72.1.216:8080/gzaqi/Document/gjzlbz.pdf

Ministry of Ecology and Environment of the People's Republic of China (2015). *关于印发《全面实施燃煤电厂超低排放和节能改造工作方案》的通知 (Notice about implementation of ultra-low emission and reducing energy for coal-fired electricity plants).* Retrieved from http://www.mee.gov.cn/gkml/hbb/bwj/201512/t20151215_319170.htm

Ministry of Ecology and Environment of the People's Republic of China (2019a). *柴油货车污染治理攻坚战行动计划 (Diesel Truck Pollution Control Battle Plan).* Retrieved from http://www.mee.gov.cn/xxgk2018/xxgk/xxgk03/201901/t20190104_688587.html

Ministry of Ecology and Environment of the People's Republic of China (2019b). *关于推进实施钢铁行业超低排放的意见 (Requirements on promoting super low emission in steel production industry).* Retrieved from http://www.mee.gov.cn/xxgk2018/xxgk/xxgk03/201904/t20190429_701463_wap.shtml?from=timeline&isappinstalled=0

Moultak, M., Lutsey, N., Hall, D. (2017). *Transitioning to zero-emission heavy-duty freight vehicles.* Retrieved from the International Council on Clean Transportation, https://www.theicct.org/sites/default/files/publications/Zero-emission-freight-trucks_ICCT-white-paper_26092017_vF.pdf

National Bureau of Statistics of China (2019). *National Data.* Retrieved from http://data.stats.gov.cn/

National Development and Reform Commission of China (2016). *能源生产和消费革命战略 (2016-2030) (Energy production and consuming revolution strategy [2016-2030]).* Retrieved from http://www.ndrc.gov.cn/zcfb/zcfbtz/201704/t20170425_845284.html

National Railway Administration (2019). *国家铁路局关于发布«2018 年铁道统计公报» 的公告 (National Railway Administration release "2018 railway statistics report").* Retrieved from http://www.nra.gov.cn/xwzx/zlzx/hytj/201904/P020190426367686178375.pdf

Shao, Z. (2016a). *Non-road emission inventory model methodology.* Retrieved from the International Council on Clean Transportation, https://theicct.org/sites/default/files/publications/ICCT_nonroad-model-method_20160224.pdf

Shao, Z. (2016b). *European stage V non-road emission standards.* Retrieved from the International Council on Clean Transportation, https://www.theicct.org/sites/default/files/publications/EU-Stage-V_policy%20update_ICCT_nov2016.pdf

Shao, Z. (2018). *Early adoption of China VI vehicle fuel standards in Jing-Jin-Ji and surrounding areas*. Retrieved from the International Council on Clean Transportation, https://www.theicct.org/publications/early-adoption-china-vi-vehicle-fuel-standards-jing-jin-ji

Si, S. (2018, December 4). 探索曹妃甸港区"公转铁"：汽车少了 污染排放降了(Explore Caofeidian port area with modal shift to rail: Less trucks, less pollution). *Hebei Daily*. Retrieved from http://hebei.ifeng.com/a/20181204/7075078_0.shtml

Sun, M. (2015, May 15). 河北11市完成PM2.5源解析 污染源各不相同(Various emission sources found in the source apportionment analysis for eleven cities in Hebei province). *Hebei News.* Retrieved from http://hebei.hebnews.cn/2015-05/15/content_4773685_2.htm

State Council (2013). *国务院关于印发大气污染防治行动计划的通知 (State Council announced air pollution prevention and control action plan).* Retrieved from http://www.gov.cn/zwgk/2013-09/12/content_2486773.htm

State Council (2018a). *打赢蓝天保卫战三年行动计划 (Three-year National Plan of Blue-Sky Defense).* Retrieved from http://www.gov.cn/zhengce/content/2018-07/03/content_5303158.htm

State Council (2018b).*推进运输结构调整三年行动计划（2018—2020年）(Three-year Action Plan on Promoting Shipping Structure Adjustment [2018-2020]).* Retrieved from http://www.gov.cn/zhengce/content/2018-10/09/content_5328817.htm

State Grid Corporation of China (2019). *清洁能源 (Clean sources).* Retrieved from http://www.sgcc.com.cn/html/sgcc_main/col2017041274/column_2017041274_1.shtml?childColumnId=2017041274

Tangshan city defined workplan for winning Blue-Sky war action items (我市制定工作方案 部署打赢蓝天保卫战暨"退出后十"三年行动) (2018, October 12). *Sohu News.* Retrieved from http://www.sohu.com/a/259088292_100193195

Tangshan Government (2019a). *2018年全市大气污染防治情况 (2018 Tangshan city air pollution prevention updates)*. Retrieved from http://www.tangshan.gov.cn/zhuzhan/2019zyfb/20190125/671445.html

Tangshan Government (2019b). *2018年唐山港货物吞吐量6.3亿吨(2018 Tangshan port reached 630 million cargo throughout).* Retrieved from http://www.tangshan.gov.cn/zhuzhan/shehuixinwen/20190112/668675.html

Tangshan Government (2019c). *Tangshan government work report*. Retrieved from http://district.ce.cn/newarea/roll/201903/06/t20190306_31623304.shtml

Vehicle Emission Control Center (2018). *唐山港京唐港区首列铁矿石专列开进滦南 (First iron ore train from Tangshan Jingtang port drove to Luannan).* Retrieved from http://www.vecc-mep.org.cn/work/two/905.html

Vehicle Emission Control Center (2019). *推进"公转铁"，年底前唐山16家钢铁企业铁路专用线将建成 (Promoting "rail instead of road", dedicated railways will be built into 16 steel companies by the end of the year).* Retrieved from http://www.vecc-mep.org.cn/tabloid/1329.html

Wen, W., Han, L., Chen, X., Cheng, S.Y., & Zhang, Y.L. (2015). 唐山市PM$_{2.5}$ 理化特征及来源解析 (Tangshan's PM2.5 physical and chemical characteristics and source apportionment analysis). *Journal of Safety and Environment, 15*(2), 313–318.

Xue, S. (2018, May 22). Coal burning, industry and diesel vehicles are the largest contributors to air pollution in Jing-Jin-Ji and surrounding regions. *Xinhua News Agency*. Retrieved from http://app.xinhua08.com/print.php?contentid=1761471

Yang, L., Cai Y., Zhong, X., Shi, Y., & Zhang, Z. (2017). A carbon emission evaluation for an integrated logistics system – a case study of the port of Shenzhen*. MDPI Sustainability, 9*(3), 462. doi: 10.3390/su9030462

Yang, L., & He, H. (2018). *China's stage VI emission standard for heavy-duty vehicles (final rule).* Retrieved from the International Council on Clean Transportation, https://www.theicct.org/sites/default/files/publications/China_VI_Policy_Update_20180720.pdf

Yang, L., Delgado, O., & Muncrief, R. (2019). *Barriers and opportunities for improving long-haul freight efficiency in China.* Retrieved from the International Council on Clean Transportation, https://theicct.org/publications/barriers-and-opportunities-improving-long-haul-freight-efficiency-china