Environmental impacts of modal shift to rail in Tangshan

Author: Zhenying Shao
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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 (μg/m$^3$) set by the Tangshan government for 2020, and eventually meet the national standard of 35 μg/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 (μg/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,
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.

![Top 10 cities with the highest PM$_{2.5}$ concentration in 2013](image)

**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/m$^3$ and far above World Health Organization’s (WHO) recommended limit of 10 μg/m$^3$. This suggested that further action was needed to address air pollution in the region.
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 CO₂ emissions (Kodjak, 2015; Yang, Delgado, & Muncrief, 2019). Diesel vehicles are the third largest contributor to Jing-Jin-Ji’s local PM<sub>2.5</sub> 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 NOₓ pollutants and reduce the annual average PM<sub>2.5</sub> concentration for Jing-Jin-Ji by 1.46 μg/m<sup>3</sup> 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.

![Jing-Jin-Ji maps](image)

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 μg/m$^3$ for 2019, and 50–54 μg/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. 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.\footnote{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).} 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

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

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 I/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.
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 NOx 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).

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

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

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 CO₂ 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\textsubscript{x}, and CO\textsubscript{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.

![Graph](image)

**Figure 6.** Well-to-wheel (WTW) PM, NO\textsubscript{x}, and CO\textsubscript{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\textsubscript{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\textsubscript{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\textsubscript{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\textsubscript{2} emissions.

- The all diesel train fleet increases the TTW PM and NO\textsubscript{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\textsubscript{x} emissions double; meanwhile, WTW CO\textsubscript{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\textsubscript{x} emission reductions of any of the scenarios. The WTW CO\textsubscript{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 NOx 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 CO2 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 NOx 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 NOx 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 NOx from the current truck fleet and 88% of PM and 84% of NOx 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, NOx, and CO2 emissions by scenarios, and the percentage change when comparing with the current truck fleet scenario |
|-------------------------------------------------|----------------|-----------------|-----------------|-----------------|-----------------|-----------------|-----------------|
|                             | PM (tons) | NOx (tons) | CO2 (tons) |
|                             | TTW | Uptream | WTW (%) | TTW | Uptream | WTW (%) | TTW | Uptream | 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 NOx 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.

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 CO2 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 NOx, and 40% of CO2 from the current truck fleet scenario, and 81% of PM, 27% of NOx, and 60% of CO2 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 NOx impacts of empty backhaul for selected scenarios](image)

* 40% empty backhaul for trucks, 50% empty backhaul for trains

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. 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...
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


