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NURail2016-MTU-R15

LIFE CYCLE ASSESSMENT (LCA) OF ORE TRANSPORTATION ROUTE ALTERNATIVES FOR EAGLE MINE.

By

Soumith Kumar Oduru
Graduate Research Assistant, Rail Transportation Program
Department of Civil and Environmental Engineering
Michigan Technological University
Email: soduru@mtu.edu

Pasi Lautala, Ph.D., P.E.
Associate Professor
Director, Rail Transportation Program
Department of Civil and Environmental Engineering
Michigan Technological University
Email: ptlautal@mtu.edu

08-01-2017

Grant Number: DTRT13-G-UTC52 (Grant 2)

DISCLAIMER

Funding for this research was provided by the NURail Center, University of Illinois at Urbana - Champaign under Grant No. DTRT12-G-UTC18 of the U.S. Department of Transportation, Office of the Assistant Secretary for Research & Technology (OST-R), University Transportation Centers Program. The contents of this report reflect the views of the authors, who are responsible for the facts and the accuracy of the information presented herein. This document is disseminated under the sponsorship of the U.S. Department of Transportation's University Transportation Centers Program, in the interest of information exchange. The U.S. Government assumes no liability for the contents or use thereof.

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TECHNICAL SUMMARY

Title

Life Cycle Assessment (LCA) of Ore Transportation Route Alternatives for Eagle Mine.

Introduction

Transportation sector at large is a major consumer of fossil fuels and constitutes more than a quarter of the global greenhouse gas emissions. When making infrastructure route and mode choice decisions for new freight-oriented projects, it is important that emissions analysis is included as an integral part of the selection process. The most logical time for emissions analysis is during modal and route selections that are often made in the planning stage of a project. One component of such an analysis can be Life Cycle Assessment (LCA); a method for estimating emissions, energy consumption and other environmental impacts of a project over its life cycle. A major drawback of performing a detailed LCA comprising of all life cycle phases of a freight transportation project is the requirement for extensive data, human effort and expertise. Availability of resources and data required for LCA often tends to be a challenge at such early stage of the projects. This could be a discouraging factor for the stakeholders, resulting in simply neglect of an LCA evaluation.

This research applies the LCA evaluation toward transportation options of existing mining operations in the Upper Peninsula of Michigan. More specifically, it performs a comparative life cycle assessment of three different route alternatives for transporting copper/nickel ore from Eagle mine to Humboldt mill to quantify the potential environmental impacts of the transportation activities in terms of greenhouse gas emissions. The alternatives included the currently used highway route (CR-550), an alternative highway route (CR-595) considered in the planning stage of the mine, and a conceptual rail route designed for the purpose of this study.

This assessment was performed using two different methods; Detailed LCA and Operational LCA. The Detailed LCA incorporated the emissions arising from the complete life cycle of the transportation activity, including the construction, operation and maintenance phases of both Infrastructure and equipment. This method used SimaPro version 8 software along with Ecoinvent v3.1 database and several other custom datasets created using regional and study specific data.

It is apparent from previous research that emissions from the “Operations” phase often account for a major portion of the overall impacts, so part of this research investigates whether a process that includes only the Operations phase emissions would still provide reliable outcomes. The Operational LCA method considered the emissions only from the operations phase activities and the life cycle of the fuels used from well to wheel. This method used the in-built database of GREET 2016 model, along with case specific data on fuel consumption and type of vehicles used. The LCA was performed for the currently expected mine life of 8 years and also for 9, 10, 15, and 20-year mine lives, as the ongoing explorations around the mine may offer potential for mine life extension(s).

Case Study Introduction

Eagle mine (formerly known as Kennecott Eagle mine) is a high-grade nickel and copper mine located in Western Marquette County of the Upper Peninsula of Michigan. It is the only primary nickel mine in the United States. The mineral deposit at Eagle mine is classified as a high-grade magmatic sulphide deposit rich in economic minerals pentlandite and chalcopyrite. The deposit was first discovered in the explorations by the Rio Tinto group and later acquired by the current owner and operator, Lundin Mining Corporation. Eagle mine is expected to produce 182,500 US tons of nickel and 147,500 US tons of copper and minor quantities of other metals like cobalt, gold and platinum over an estimated mine life of eight years. The mine became operational in the fourth quarter of 2014 and has been operating in full capacity since. Figure 1 shows an aerial view of the Eagle mine.

Figure 1: Ariel View of Eagle Mine. [10]

There has been active exploration for additional mineral resources around the mine location. In July 2014, the company announced the discovery of Eagle East Mineralization, which is expected to yield an estimated 1.29 million tons of ore containing 5.2% nickel and 4.2% copper, classified as 'indicated' grading and additional 0.29 million tons of ore containing 1.7% of Nickel and 1.4% copper, classified as inferred grading. As a result, the company has announced the possibility to extend the mine operations by one year. As the exploration program continues, it is possible that more deposits are found, leading to further extension of mine life.

The mineral ore extracted at the mine is processed at the Humboldt mill to produce nickel and copper concentrates for shipments to various customers by rail. The mill is currently operating at full capacity, processing approximately 2,000 metric tons (2,200 US tons) of ore per day. The mill was located near operational rail line and a 1.8-mile long spur line was constructed to connect the existing line with production facility. The concentrates are loaded into covered gondola rail cars inside the Humboldt mill facility (Figure 2) and shipped to customers within the North America and overseas. The concentrate cars are first moved by Mineral Range Railroad (MRR), a local shortline railroad service provider, from the mill to Ishpeming where they are interchanged to CN Rail for transportation to their final destinations.

Figure 2: Concentrates Being Loaded into Railcars at the Humboldt Mill Facility. [13]

The primary focus of this project is to conduct the LCA on transporting the ore from Eagle mine to Humboldt mill. Three transportation alternatives, the CR-550 route (65 miles), CR-595 (24 miles) route and the conceptualrail route (24.6 miles), are investigated in this study. The general location of the mine and these routes is presented in Figure 3 and key parameters for each route are summarized in Table 1. When moved by trucks, the daily ore demand translates to 44 truckloads per day with 45 metric ton (49.6 US ton) capacity per truck. If rail option was used, 20 'Hopper cars' would be required per day, each with a capacity of transporting 100 metric tons (110 US ton) of ore.

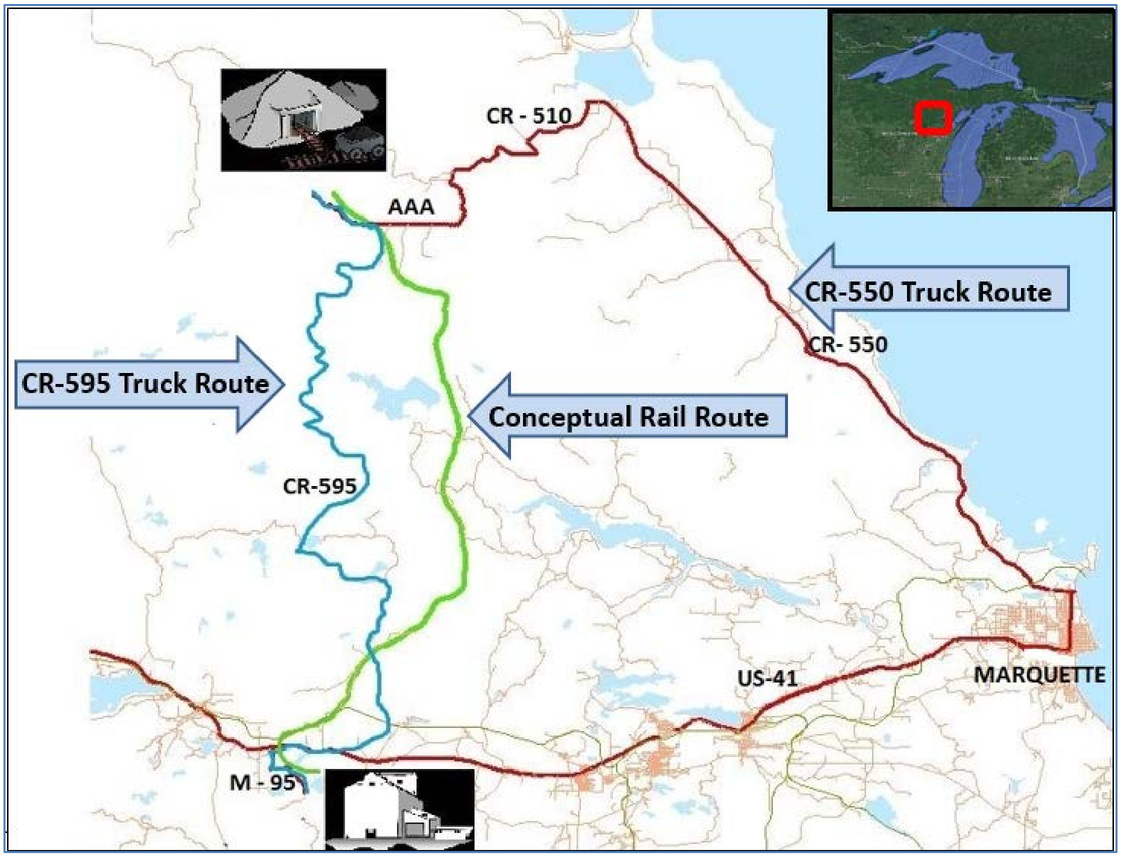

Figure 3: Map Showing the Three Alternatives; CR-550 Route, CR-595 Route, and Rail Route

Table 1: Infrastructure and Operational Requirements

	CR-550	CR-595	Rail
Total One-Way Distance (miles)	**65**	**24**	**24.66**
Heavy Reconstruction/ New Construction (miles)	14.4	22	21.06
Light Reconstruction (miles)	**12.1**	**0**	**0**
No major upgrades (miles)	38.5	2	0
Number of round trips per day	44	44	1 (with 20 car train)
Ore moved in each trip (US tons)	49.6 (~50)	49.6 (~50)	2,200 (110 tons per car)
Total number of vehicles/ equipment required for the operations	9 (11-axle Michigan ore trucks)	4 (11-axle Michigan ore trucks)	20 hopper cars and one AC 4400 locomotive

The conceptual rail alignment that connects the Eagle mine with the MRR tracks near Humboldt mill was designed as part of this research, based on guidance provided by Mr. Clint Jones from MRR. According to the MRR, construction of a track between the mine and the existing rail line near Humboldt mill was briefly considered an option during the mine planning stages. The main purpose of the conceptual alignment design was to develop sufficient route detail for estimating the emission from construction, operations and maintenance activities, if rail was used for ore movements. The geometric design was done in Power Geopak V8i software and several reference layers, such as contours, wetlands, roads and railroads, and the land ownership, were obtained from the ArcMap to support the design. Table 2 presents the main design criteria for the rail route. The design attempted to avoid 1) wetlands and 2) steep grades to the extent possible. Secondary consideration was placed on emphasizing the use of commercial forest lands for the route, both to be able to serve the prevalent timber industry in the area, and to avoid private land acquisitions. Other potentially important aspects for the route design, such as land ownership, permitting, access and cost of construction were not taken into consideration.

Table 2: Track Design Criteria

SL #	Description	Standard
1.	Track Classification	Industry Lead Track
2.	Design Speed	25mph
3.	Maximum Degree of Curvature	10 degrees
4.	Minimum Curve Radius	573.69 feet
5.	Minimum Tangent Between Horizontal Reverse Curves	100 feet
6.	Maximum Grade	2.5%
7.	Minimum Length of Vertical Curve	100 feet

The locomotive fuel consumption for ore movements was estimated using Rail Traffic Controller (RTC). The RTC simulation requires recreating the actual vertical profile of the track. The software also requires train data such as type/model and number of locomotives, number of loaded and empty rail cars in the train, length and weight of rail cars etc. The locomotives were selected based on the assumption that each train would consist of 20 hopper cars of 100 metric ton load capacity. Since MRR, the current service provider for Lundin, has GP-38-2 locomotives, those were initially used in simulations. After it was recognized that single GP-38-2 wouldn't be capable for hauling the load, the simulation was rerun with a 4400 HP AC locomotive. The Simulation revealed that the time on route for the loaded train is 60 minutes at the average speed of just below 21 mph. For the empty trains, the corresponding values were 53 minutes at average speed of over 23 mph. If the loaded and empty cars were ready to go on each end of the route, the time suggests that a round trip could be completed well within the 12-hour operational window for a train crew.

It was recognized that the 4400 HP locomotive chosen for Eagle mine operations would not use its maximum hauling capacity with the 20 carloads or ore per day. Hence, RTC was used to estimate the maximum load and number of rail cars that could be placed in the train without adding another locomotive. It was found that a total of 43 fully loaded railcars, each with a 110 US ton payload capacity can be included the train without exceeding the maximum hauling limit. However, the power to weight ratio (P/W) at this level of loading would be as low as 0.68 HP/ton and a minor change in train composition could lead to stalling of the train mid-route. Nevertheless, even if the trains were limited to 35-40 cars to maintain the P/W close to 0.8HP/ton, there would be an opportunity for 15-20 additional car loads in the train that could be taken advantage of by the forest products industry.

Life Cycle Assessment

There are several definitions of the term LCA. For instance, the United Nations Environment Program (UNEP) defines it as a tool for the systematic evaluation of the environmental aspects of a product or a service system through all stages of its life cycle. ISO 14040 is the standard that describes the principles and framework for performing LCA. The LCA in this study was performed according to the ISO 14040:2006 framework. The framework divides the process into four main steps; Goal and Scope definition, Inventory analysis, Impact assessment and Interpretation.

Performing LCA of transportation systems is inherently time and data intensive process. If all life cycle phases are to be incorporated, it involves numerous processes pertaining to construction, maintenance and operation activities. Data on the different material and energy flows of each process needs to be acquired and the relationship between them need to be understood. Not all processes involved in a project have readily available datasets in the standard databases and some available datasets need to be updated with regional and case specific data for reliable results. In addition, performing an LCA requires sufficient understanding of the concept itself and expertise in using the selected LCA software.

The requirements above pose a concern when using LCA as part of mode/route analysis in freight infrastructure projects. Since the main objective of performing LCA is to compare the different alternatives under consideration, it generally needs to be performed early in the planning stage of a project. One of the major concerns is the availability of data and resources that are required to perform a "detailed LCA". Even though understanding the overall life cycle emissions is important, performing a detailed LCA at such early projects stage may be considered unfeasible or too resource intensive by the stakeholders. Hence, there would be a benefit, if the time, effort and resources required to perform an LCA in such projects could be reduced.

This research builds on such detailed comparative LCA process developed by Kalluri et al. (2016) and applies it to the Eagle mine case study. However, this study also investigates the merits of an "operational LCA" process that only includes emissions from operations phase and whether such an approach could be used as a less resource intensive option for the analysis. The procedure for each analysis type are summarized in Table 2.

Table 2: Summary and Comparison of Detailed and Operational LCA Methods.

	Detailed LCA	**Operational LCA**
Life cycle phases assessed	Construction, operation, maintenance	Operation
Software Used	Simapro 8	GREET 2016
Goal and Scope	**Goal**: to compare CR-550, CR-595 and Rail route emissions. **Functional unit**: mine life (in years). **System boundary**: construction, operation and maintenance phases of infrastructure and vehicles. Including production and transportation of raw materials.	**Goal**: to compare CR-550, CR-595 and Rail routes operational emissions. **Functional unit**: mine life (in years). **System boundary**: operation phase of vehicles and life cycle of fuels from well to wheel.
Data	• EcoInvent database. • Custom datasets built in Simapro (using inputs from local industry experts). • Datasets obtained from a previous study (Kalluri 2016). • Study-specific data parameters obtained through public documents and interviews. • Fuel consumption data obtained through RTC simulation of train runs on the rail route designed as part of the research.	• Life cycle inventory available within GREET. • Study-specific data parameters obtained through public documents and interviews. • Fuel consumption data obtained through RTC simulation of train runs on the rail route designed as part of the research.
Impact assessment method	IPCC 2013 GWP 100a (Calculates 100-year global warming potential of all the greenhouse gases emitted, in terms of Kg CO_2 equivalents).	GHG 100 (calculates 100-year global warming potential of major greenhouse gases emitted (CO_2, CH_4 and N_2O), in terms of Kg CO_2 equivalents).
Interpretation	Analysis of the project stages or assemblies created in Simapro. Direct output comparison of the three alternatives.	The GHG-100 results (GHG emissions per ton-mile) used to calculate the operation phase emissions of the three alternatives.

LCA Results

The results obtained after performing the two versions of LCA represent the 100-year global warming potential of GHG emissions in terms of tons of CO2 equivalents. Figure 4 presents the cumulative results of the detailed LCA of CR-550, CR-595 and the conceptual rail route over 8, 9, 10, 15 and 20-year mine lives and shows the breakdown of emissions from construction, operations and maintenance phases. According to the results, the total operation phase emissions dominate the emissions over construction and maintenance phases for the road alternatives, while the construction phase dominates the emissions for the rail alternative for all mine lives. The operation phase emissions increase linearly with an increase in mine life while the infrastructure emissions remain fairly static, as major portion of construction activity takes place during initial construction. The linear increase in emissions from operations is expected, as the annual ore transportation remains stable and each additional load of ore adds to the cumulative operational emissions. Rail alternative follows the same linear pattern, although the operational emissions are much lower and grow at a slower pace. The maintenance emissions account for much smaller portion than the other two categories and slowly escalate for longer mine lives, due to aging equipment.

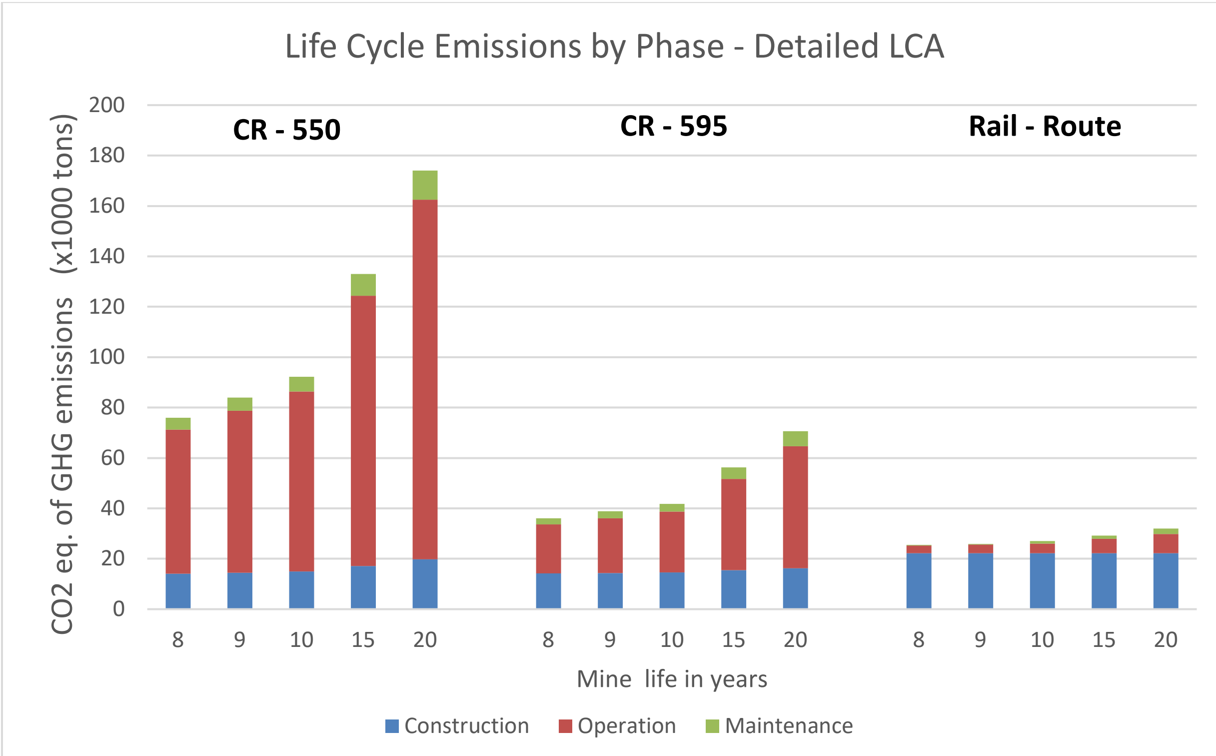

Figure 4: Phase-Wise Life Cycle Emissions Estimated Using Detailed LCA.

In the operational LCA, the emissions results per ton-mile were obtained from GREET, together with the route lengths and number of trips for each alternative. Figure 5 represents the results of the operational LCA for the three routes over 8, 9, 10, 15 and 20-year mine lives. The emission variation between the two truck routes is proportional with the difference in transportation (route) distances. When comparing the rail route with the CR-595 route, the efficiency of rail transportation becomes evident. The length of each route is fairly similar, but the emissions arising from rail operations are much lower, irrespective of mine life.

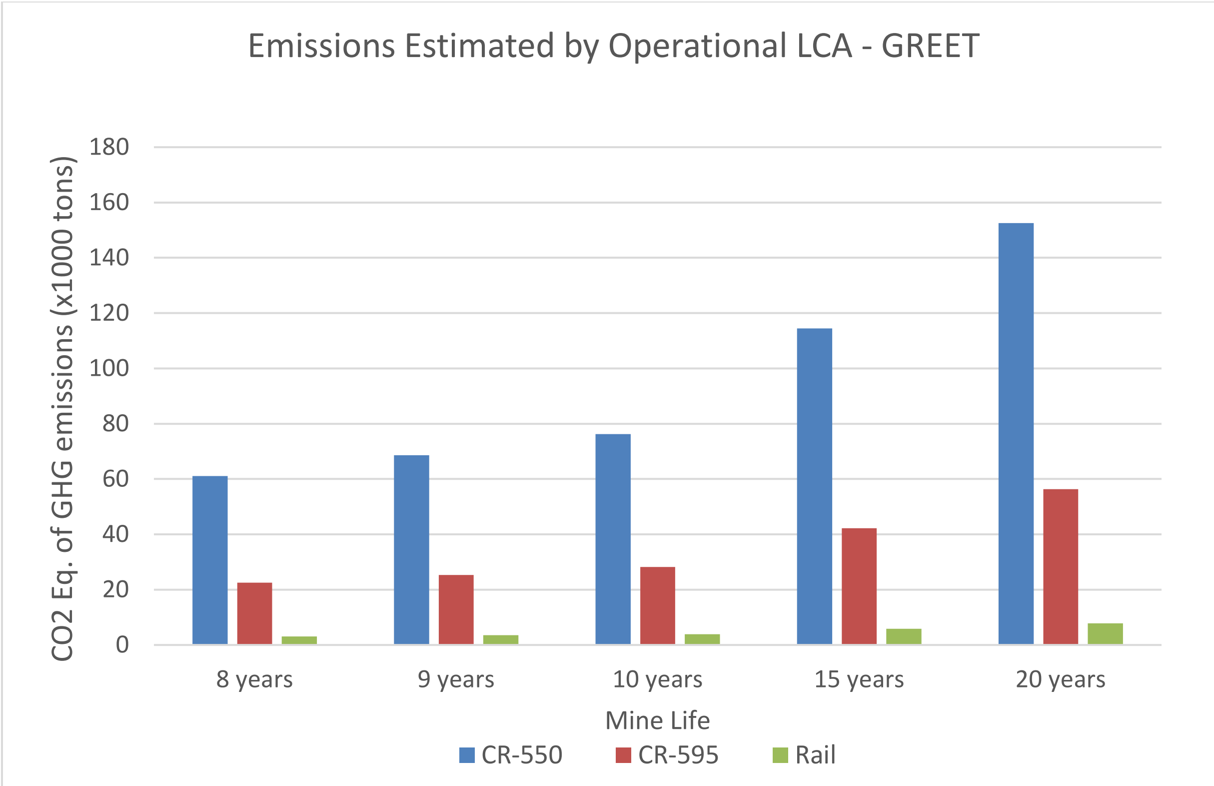

Figure 5: Results of Operational LCA

As the final step of the analysis, it was investigated whether the results for operations phase from each method were comparable. Figure 6 provides the operation phase emissions from detailed LCA with those estimated by the operational LCA method side by side. While the two methods yielded similar results, the operation phase emissions obtained from GREET are higher by an average of 6%, 16% and 2% for CR-550, CR-595 and the rail option, respectively. The difference is not uniform between the routes, but it remains fairly consistent across the mine lives. It was concluded that the main cause of deviation in these operations emission from SimaPro versus GREET was the difference in the approach of calculating emissions in the two methods, i.e. based on total fuel consumption in SimaPro (Detailed LCA) in contrast with emissions per ton-mile calculation in Operational LCA (GREET).

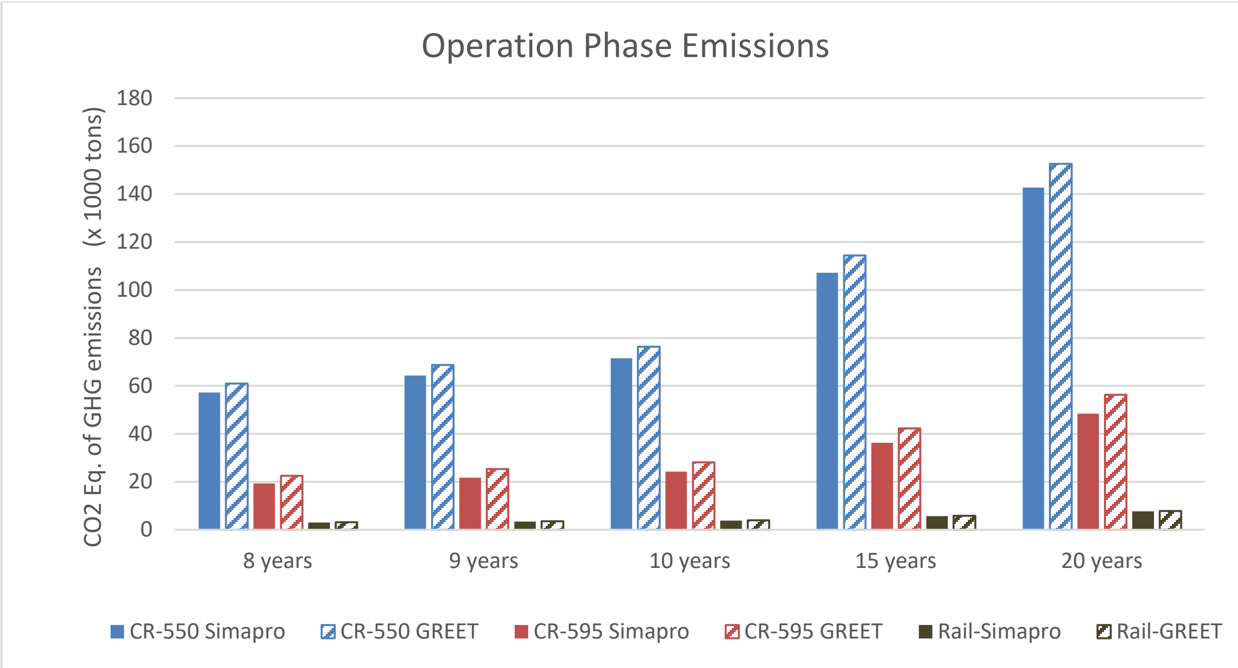

Figure 6: Comparison of Operation Phase Emissions Estimated by the Two Methods.

Discussion and Conclusions

The study estimated the potential greenhouse gas emissions for Eagle mine ore transportation over various mine lives. Detailed LCA covered the emissions from the complete life cycle, including construction, operation and maintenance phases of infrastructure and vehicles, while operational LCA covered only the operation phase emissions, which included the combustion of fuel in the vehicles and the full life cycle of those fuels. The detailed LCA was performed using SimaPro version 8 software with the support of the EcoInvent database v3.1 and other custom datasets created using regional and case specific data. The operational LCA was performed using the GREET 2016 model with the help of the stock database available in the model itself. In addition to comparing the emissions effects of each alternative, another objective of this study was to investigate the breakdown of emissions between the construction, operations, and maintenance phases and to investigate how closely the operational LCA results matched the operations phase emissions obtained from the Detailed LCA.

The results indicated that from an emissions perspective, CR-595 is a superior alternative between the two road options and the rail option is clearly the superior option among the three, especially for longer mine lives. The emissions of road alternatives arising from the operation phase are significantly higher than those from the construction and maintenance phases and they increase linearly with mine life. On the other hand, operation phase emissions are much lower than construction phase emissions in rail alternative and only increase marginally with mine life. Maintenance emissions are lower than the other categories and only increase moderately in all options. However, for the rail option, maintenance becomes almost equal to operational emissions for the longest mine lives.

There was a slight difference between the operation phase emissions estimated by the two methods. This difference grew with increased total emissions and is presumably caused by the differences in equipment data available, and the life cycle inventories used by the two software. The operational LCA approach was able to provide the same ranking for compared alternatives, but this result only reflects the outcomes of this case study and may not always hold true for other cases. Based on the outcomes, it can be speculated that the operational LCA method is valid for projects that require only limited or very similar infrastructure upgrades for all the alternatives involved. However, with the infrastructure component gone, the detailed method also becomes more manageable. For projects with significant amount of new/reconstructed infrastructure, the operational method will give erroneous results, especially in the case of alternatives involving different modes of transportation. This is because the distribution of emissions between construction and operation phases is highly inconsistent between different modes. The detailed method is certainly preferred when it comes to generating accurate results, but operational method is better than simply ignoring the emission aspects, especially for projects with long mine lives.

Another interesting outcome of this study is the potential for the rail route to serve the timber and forest products industry in the region. Since the majority of the conceptual rail alignment (19.5 out of 21.06 miles) passes through commercial forest area known for its logging activities, the timber companies operating in this area could benefit from the alternative rail option, at the same time reducing emissions caused by their truck operations. The daily volumes of logs tend to be low and operating a train exclusively for log movements may not be feasible. However, it was found that approximately 15-20 additional railcars, each with a 100 US ton payload capacity can be added to the train without exceeding the maximum hauling limit for a single 4,400 HP AC locomotive. Even though this would result in slight increase of fuel consumption and maintenance requirements, taking advantage of such synergies would result in reduction of overall emissions (and improved economics) from both Eagle mine and timber operations. The additional infrastructure/operational costs could be recovered through the increased revenue from log movements.

Acknowledgements

The research team wants to thank Mr. Clint Jones of Mineral Range Railroad for his help and guidance for the rail route design, M.J.VanDamme Trucking for providing information about various aspects of the trucks used for transporting Eagle mine ore, and Mr. Joe Pertocik from Eagle mine for his valuable support in providing critical information about Eagle mine operations.

Publications

- Oduru, S. (2017). Life Cycle Assessment (LCA) Of Ore Transportation Route Alternatives for Eagle Mine. (Master of Science Report)
- Oduru S, and Lautala P. (2017). “Incorporating Life Cycle Assessment (LCA) In Freight Transportation Infrastructure Project Evaluation”. Joint Rail Conference. American Society of Mechanical Engineers.

Primary Contact

Principal Investigator
Pasi Lautala, Ph.D., P.E.

Associate Professor
Director, Rail Transportation Program
Department of Civil and Environmental Engineering
Michigan Technological University
Phone: (906) 487-3547
Email: ptlautal@mtu.edu

Other Faculty and Students Involved

Soumith Kumar Oduru
Graduate Research Assistant,
Rail Transportation Program
Department of Civil and Environmental Engineering
Michigan Technological University
Email: soduru@mtu.edu

NURail Center
217-244-4999
nurail@illinois.edu
http://www.nurailcenter.org/