Life Cycle Assessment (LCA) of Activities in Project Schedule: Megaprojects

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Abstract: In this project, a novel technique of evaluating the environmental impacts of materials, construction methods, equipment and personnel is presented at an activity level of a Critical Path Method (CPM) based schedule. This method of detailed quantification of emissions of carbon dioxide equivalent (CO_2-eq) in Global Warming Potential (GWP) provides vital information to construction manager, agencies, and lawmakers for effective decision making in case of megaprojects. Megaprojects are often driven by government agenda and legislations, and mostly funded by taxpayer dollars. Resources, cost, risks and environmental implications are considered. However, there is a lack of quantitative evaluation of greenhouse gas (GHG) emissions due to megaprojects during construction. The new method developed by this research group incorporates GWP emissions associated with the various phases of the project into a project schedule, in addition to dates, durations, resources and cost. This is accomplished by employing a Cradle to Gate approach to Life Cycle Assessment (LCA) of materials and fuel used during each activity of the project schedule of a fictitious bridge project with scenic overlook and parking. This method can be scaled up for megaprojects as well. This will help owners or agencies, construction managers and lawmakers to explore ways of mitigating life cycle emissions by utilizing alternative materials and/or scheduling approaches (sequence of activities). Overall, this study will help the construction industry towards effectively identifying carbon emissions associated with projects, explore alternative measures to mitigate such emissions, and develop environmentally sustainable megaprojects.

1. Introduction

Megaprojects are complex endeavors which have long-term implications to a region or nation, various industries involved and the society in general. Megaprojects generally cost between 500 million and 1 billion US dollars [1]. Most researchers and engineers agree that such complex projects require separate set of governing principles and project management strategies due to their huge costs, extended durations, and geo-political implications. In addition to engineering techniques, means and methods, and resource allocation, the success of megaprojects also depend upon local administrative structure, legal systems and legislations. Such projects are mostly led by federal or state agencies and funded through taxpayer dollars. Therefore, the scope and continuity of such megaprojects often rely upon legislations driven by political will [2]. Prior researchers have concluded that the management of megaprojects rely upon resources, cost, risks and uncertainties, legal and regulatory issues, socio-economic value, and environmental implications [1].

Some of the ongoing and upcoming megaprojects in the United States include the $17 billion Second Avenue Subway Construction Project in New York, NY, $20 billion Hudson Yards in New York, NY, the $77 billion California High Speed Rail Construction Project in CA, the $1.18 billion Red River Valley Water Supply Project, Washburn, ND, and the $1.5 billion Portal North Bridge replacement project in NJ etc. [3, 4]. These projects and others like them will be subject to legislative priorities set by the government among other things. As outlined by a recent memo released by the American Society of Civil Engineers (ASCE) calling for climate resilient infrastructure, monitoring greenhouse gas (GHG) emissions by construction projects is of utmost importance [5]. Although the environmental implications of megaprojects are considered qualitatively, it is not common industry practice to quantify the environmental emissions due to construction materials and methods. In order to create climate resilient infrastructure, it is important to accurately quantify and monitor environmental emissions associated with megaprojects. This research group developed a novel technique of evaluating the environmental impacts of materials, construction methods, equipment and personnel at an activity level of a Critical Path Method (CPM) based schedule [6]. In this paper, emissions expressed as 100-year Global Warming Potential (GWP) CO_2-equivalent, as a function of materials, fuel, durations and cost. Additionally, the temporal changes in GWP emissions are also analyzed for a fictitious bridge project with scenic overlook and parking. This methodology can be scaled up on megaprojects and other projects.

2. Methods

2.1.CPM Schedule

A fictitious bridge project with scenic overlook and parking, is considered (Figure 1). The scope of work includes the construction of a bridge consisting of 4 piers with piles and pile caps as foundation and concrete bridge deck with handrails, sidewalk and lights, approach on both the ends (Southwest and Northeast) with helical piles as sub-structures and concrete superstructures, scenic overlook with strip footings and concrete deck, and concrete parking. 47 helical piles with depths of 30’, and 5 strip footings (6’x2’x2’) each are used. Piers P1, P2, P3 and P4 are supported by two piles each, consisting of 1/2” thick steel rings with 24” outer diameter and a depth of 100’. A rebar cage of 6 #11 vertical bars supported by a spiral with #3 bar with a pitch of 3.5” is included in each pile, which is filled with concrete. Seven different types of concrete are used. Details of materials used in these structures can be found in Table 1

A construction schedule is developed for the fictitious project. The work is planned in three phases: Phase I – Southwest section of bridge with approach, Phase II – Northeast section of bridge with approach, and Phase III – Scenic overlook and parking (Figure 2). Level of Effort (LOE) activities are added for site engineering, management and supervision, quality control and testing services, and the use of diesel generator (20 kW) to power the job site to last throughout the project. The overall duration of the project is NTP+22 months.

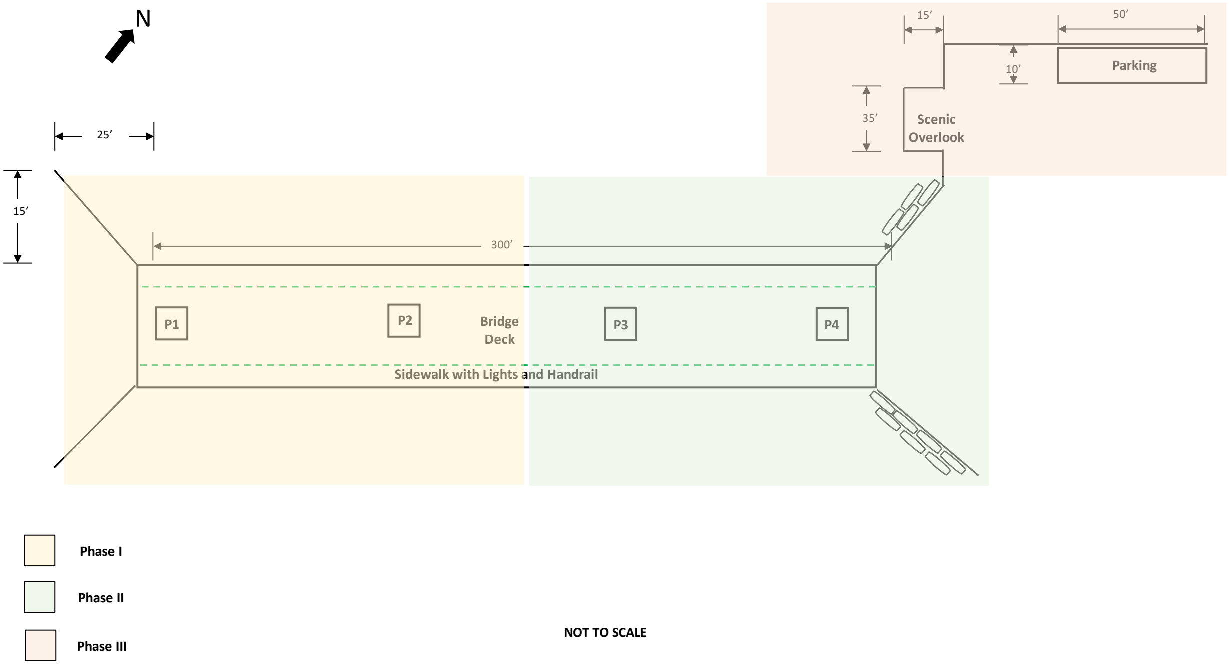
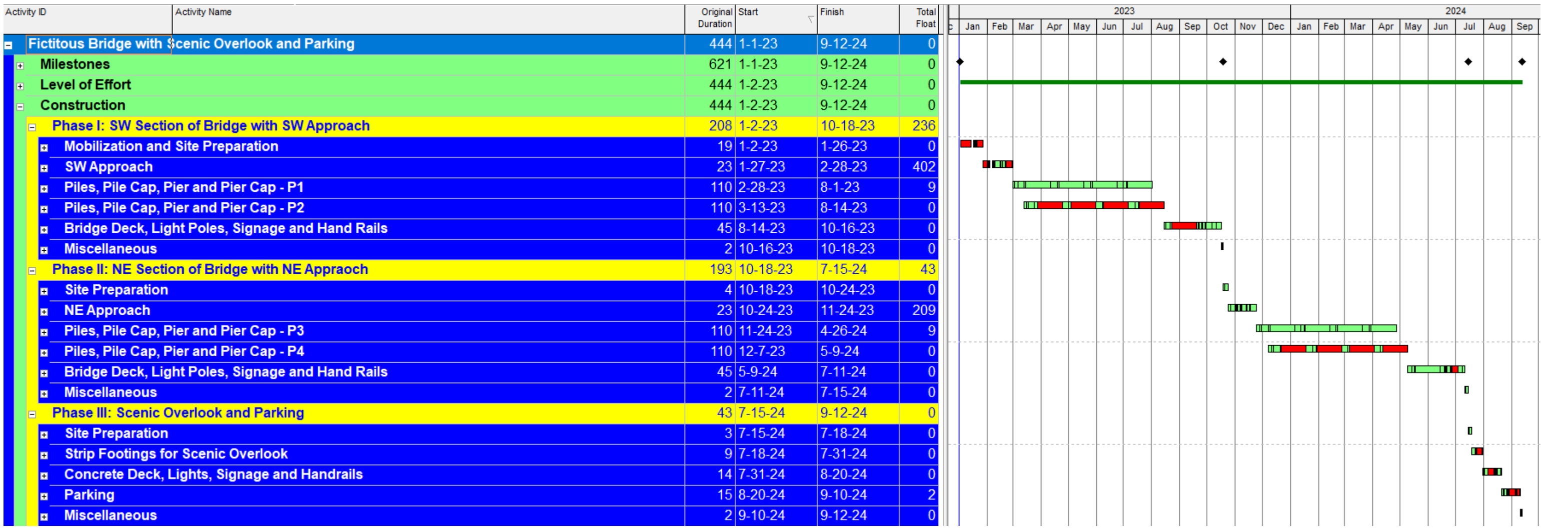


Figure 1: Fictitious bridge project with scenic overlook and parking

Table 1: Materials used in the Project

Code	Item	GWP CO2-eq 100 / unit Material
Steel Rebar	Steel reinforcement	2.10
HG Steel	Hot-dipped Galvanized Steel	2.90
WP Steel	Welded Pipe Steel	2.81
TI-P	Concrete with Type I Cement (high C_3A+C_3S), no SCMs, smaller aggregate fraction	451.04
TI/II-P	Concrete with Type I/II Cement, no SCMs, smaller aggregate fraction	451.04
TI/II-FF	Concrete with Type I/II Cement, 20% replaced with Class F Fly Ash, smaller aggregate fraction	380.33
TI/II-FC	Concrete with Type I/II Cement, 30% replaced with Class C Fly Ash, smaller aggregate fraction	346.08
TI/II-P-2	Concrete with Type I/II Cement, no SCMs, larger aggregate fraction	444.92
TI-FC-2	Concrete with Type I Cement (high C_3A+C_3S), 30% replaced with Class C Fly Ash, larger aggregate fraction	342.16

Code	Item	GWP CO2-eq 100 / unit Material
TIL-FC-2	Concrete with Type IL Portland Limestone Cement, 30% replaced with Class C Fly Ash, larger aggregate fraction	313.68



Activity ID	Activity Name	Original Duration	Start	Finish	Total Float
	Fictitous Bridge with Scenic Overlook and Parking	444	1-1-23	9-12-24	0
	Milestones	621	1-1-23	9-12-24	0
	Level of Effort	444	1-2-23	9-12-24	0
	Construction	444	1-2-23	9-12-24	0
	Phase I: SW Section of Bridge with SW Approach	208	1-2-23	10-18-23	236
	Mobilization and Site Preparation	19	1-2-23	1-26-23	0
	SW Approach	23	1-27-23	2-28-23	402
	Piles, Pile Cap, Pier and Pier Cap - P1	110	2-28-23	8-1-23	9
	Piles, Pile Cap, Pier and Pier Cap - P2	110	3-13-23	8-14-23	0
	Bridge Deck, Light Poles, Signage and Hand Rails	45	8-14-23	10-16-23	0
	Miscellaneous	2	10-16-23	10-18-23	0
	Phase II: NE Section of Bridge with NE Appraoch	193	10-18-23	7-15-24	43
	Site Preparation	4	10-18-23	10-24-23	0
	NE Approach	23	10-24-23	11-24-23	209
	Piles, Pile Cap, Pier and Pier Cap - P3	110	11-24-23	4-26-24	9
	Piles, Pile Cap, Pier and Pier Cap - P4	110	12-7-23	5-9-24	0
	Bridge Deck, Light Poles, Signage and Hand Rails	45	5-9-24	7-11-24	0
	Miscellaneous	2	7-11-24	7-15-24	0
	Phase III: Scenic Overlook and Parking	43	7-15-24	9-12-24	0
	Site Preparation	3	7-15-24	7-18-24	0
	Strip Footings for Scenic Overlook	9	7-18-24	7-31-24	0
	Concrete Deck, Lights, Signage and Handrails	14	7-31-24	8-20-24	0
	Parking	15	8-20-24	9-10-24	2
	Miscellaneous	2	9-10-24	9-12-24	0

Figure 2: High-level schedule (Details in Appendix)

2.2.Life Cycle Assessment (LCA)

The contribution of each activity in the schedule towards climate change is measured by Life Cycle Assessment (LCA). LCA is a tool to quantify the impact of a product or process on the environment [7]. In this study, a Cradle to Gate approach is adopted, which is an analysis from the acquisition of raw materials to the end of a process, which may not necessarily mark the end of life of the product [8]. The LCA methodology consists of four stages as outlined in ISO 14040: determination of scope and boundaries, life cycle inventory (LCI), life cycle impact assessment (LCIA) and interpretation of results [9]. Impact assessment is performed by the 100-year time horizon approach outlined in IPCC Fifth Assessment Report, 2014 (AR5) [10]. Materials: For concrete, the functional unit is 1 m3. The system boundary consists of production of cement, extraction of raw materials and production of aggregates and admixtures, transportation of materials, mixing at the batching plant, and unit volume of concrete being ready for delivery. Green Concrete LCA webtool is used for the concrete analysis [11]. For steel, the functional unit is 1 kg. Open LCA commercial software program is used in this study for these materials [12]. Fuel: Environmental emissions leading to climate change due to gasoline use from passenger vehicles used by personnel in the project were calculated based on average fuel consumption, distance commuted, and emission factors defined by Intergovernmental Panel on Climate Change (IPCC), Fourth Assessment. Similarly, the emissions due to diesel from backhoe, crane and concrete truck used in the project are calculated based on hourly diesel consumption and emission factors by IPCC [13].

3. Results and Discussions

The emissions affecting climate change, expressed as 100-year Global Warming Potential (GWP) CO_2-eq analyzed in this study can be broadly classified as those due to materials used for construction, and fuel used. Two types of fuel are used throughout the construction phase – gasoline (gas) and diesel. The use of gas is from passenger vehicles used by personnel to commute to and from the job site. The use of diesel is from equipment used for construction, as well as for generating and maintaining power in the job site. From Figure 3, it may be observed that the 100 year-GWP emissions due to materials are significantly higher than those due to fuel, i.e., gasoline and diesel. Four major types of materials are used during construction (Figure 4). These are concrete, steel rebars, hot-dipped galvanized steel (HG Steel), and welded pipe steel (WP Steel). Noticeably, 100-year GWP emissions due to HG Steel are higher than those due to other materials.

This is mainly because of a higher quantity used, predominantly in helical piles, and a high rate of 100-year GWP emissions per unit material.

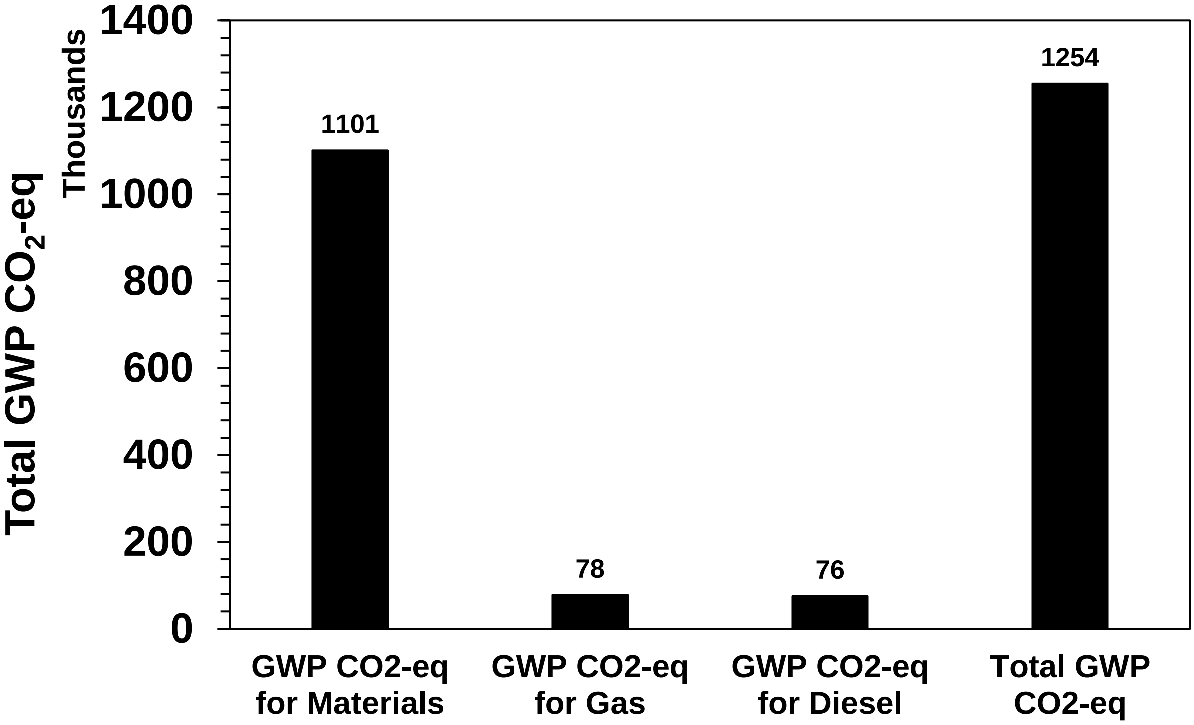


Figure 3: GWP emissions due to materials and fuel

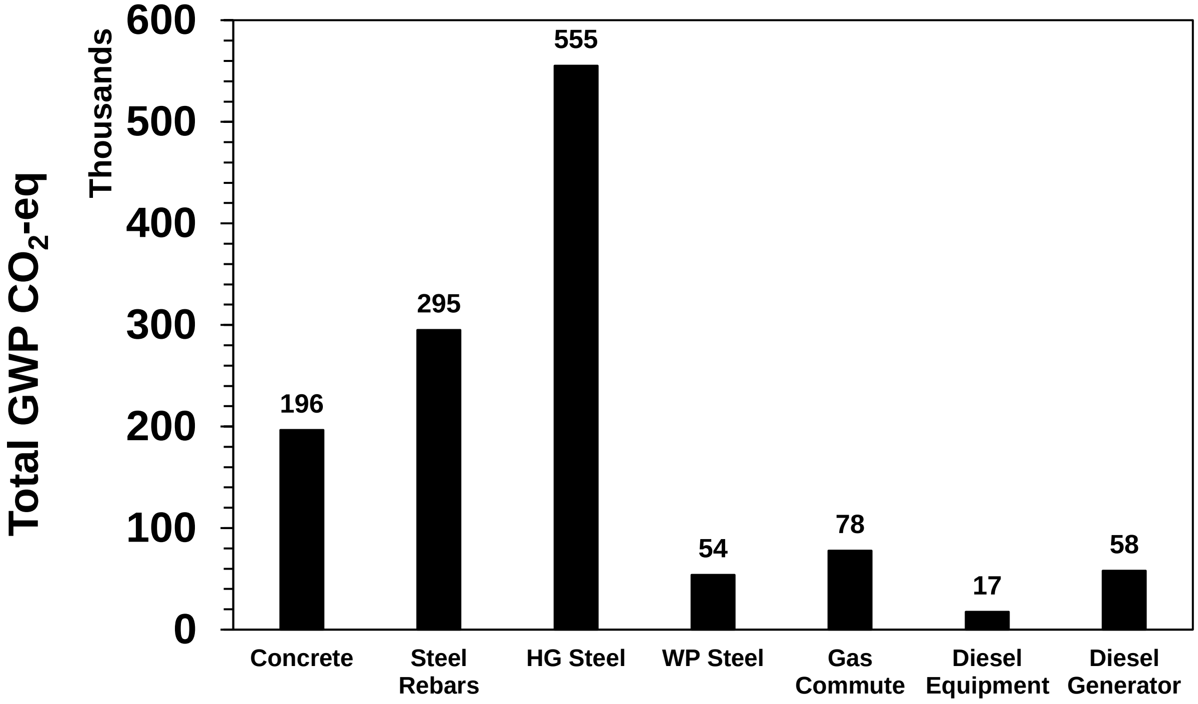


Figure 4: GWP emissions due to different items

3.1.Impact due to Materials: Steel and Concrete

From Figure 5, it is evident that the 100-year GWP emissions due to HG steel are 88.16% (Figure 5a) higher than that of steel rebar, even though the quantity of the former is only 36.13% higher than that of the latter (Figure 5b). This is notably because of a higher 100-year GWP emissions per unit quantity of HG Steel (2.90 GWP CO_2-eq/kg) over steel rebar (2.10 GWP CO_2-eq/kg).

This quantification of projected emissions provides the owners, construction managers and contractors the opportunity to consider alternative materials in their projects which may be more carbon efficient. In this case, an example scenario is considered where all HG Steel components are replaced with equivalent quantities (in kg) of electrogalvanized steel (EG Steel). The projected

100-year GWP emissions due to EG steel is notably 79.88% higher than that of steel rebar. Overall, EG steel is more carbon efficient than HG steel and would result in 4.6% less 100-year GWP emissions when compared to those due to HG steel.

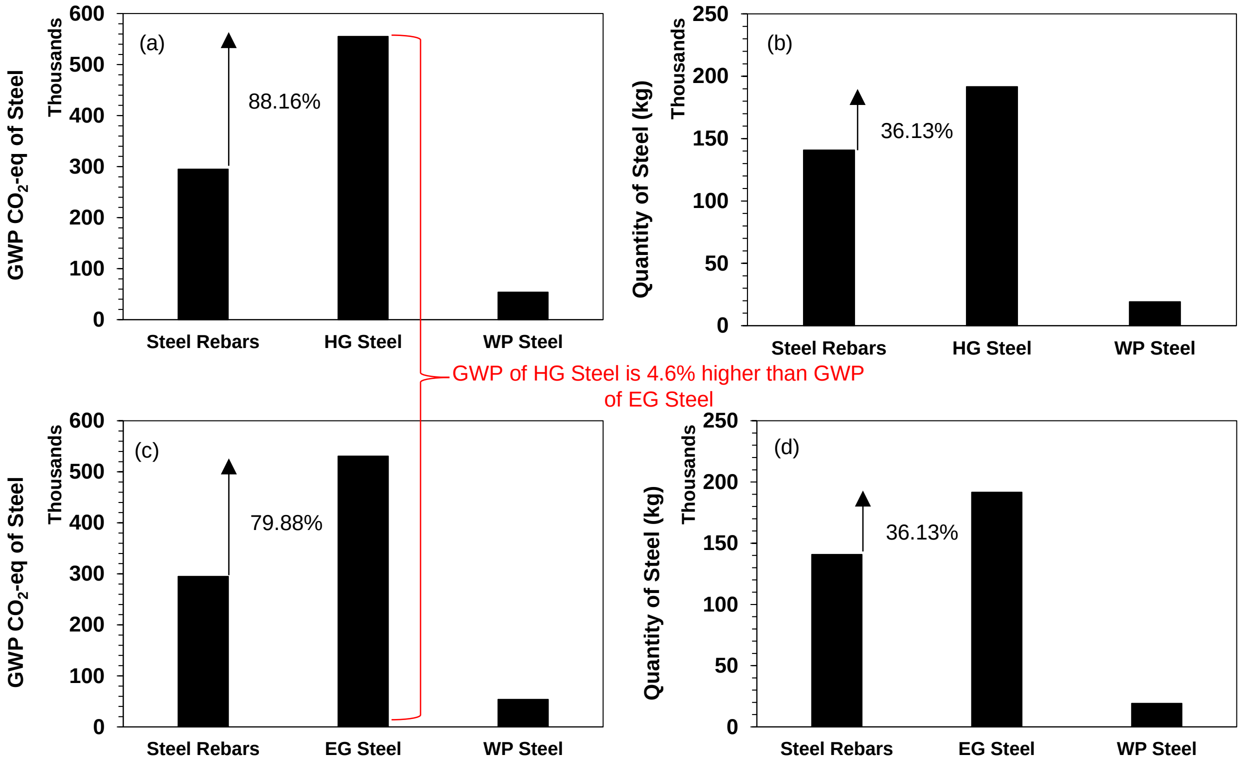


Figure 5: (a) GWP emissions due to steel categories, (b) Total quantities of steel used, (c) GWP emissions in example scenario, (d) Total quantities of steel in example scenario

Figure 6a shows the 100-year GWP emissions due to the seven different types of concrete used in this project. Figure 6b shows the corresponding volume of concrete used in the various phases of construction. Due to changes in the cementitious composition and aggregate content in the different concrete types used, the rate of emissions is varied. As an example, the volume of TIL-FC-2 is over 57% higher than that of TI/II-P. However, the estimated 100-year GWP emission of TIL-FC-2 is only about 10% higher than that of TI/II-P. This is due to a lower unit GWP emission of TIL-FC-2 due to the use of Type IL Portland limestone cement and partial replacement with Class C fly ash [14].

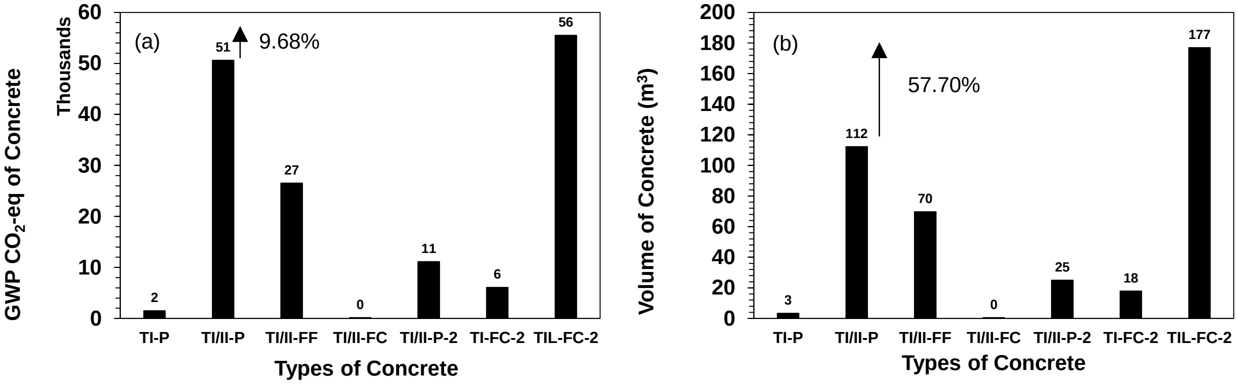


Figure 6: (a) GWP emissions due to different types of concrete used, (b) Volume of different types of concrete used

3.2.Impact due to Duration: Level of Effort Activities

Figure 7 shows three categories which are represented as Level of Effort (LOE) activities in the construction schedule of this project. The 100-year GWP emissions due to diesel used in powering the job site is projected to be the highest among the LOE categories (Figure 7a). It is assumed that the generator will be used for 8 hours every workday throughout the duration of the project. Compared to the commute of engineers and project managers, and quality engineering personnel for similar duration throughout the project (Figure 7b), the emissions from the generator are projected to be considerably higher (Figure 7a). Overall, these LOE activities and the resultant emissions are directly driven by the total duration of the project. Therefore, this tool provides the project managers and project controls personnel with an assessment of emissions due to potential delays in the project duration.

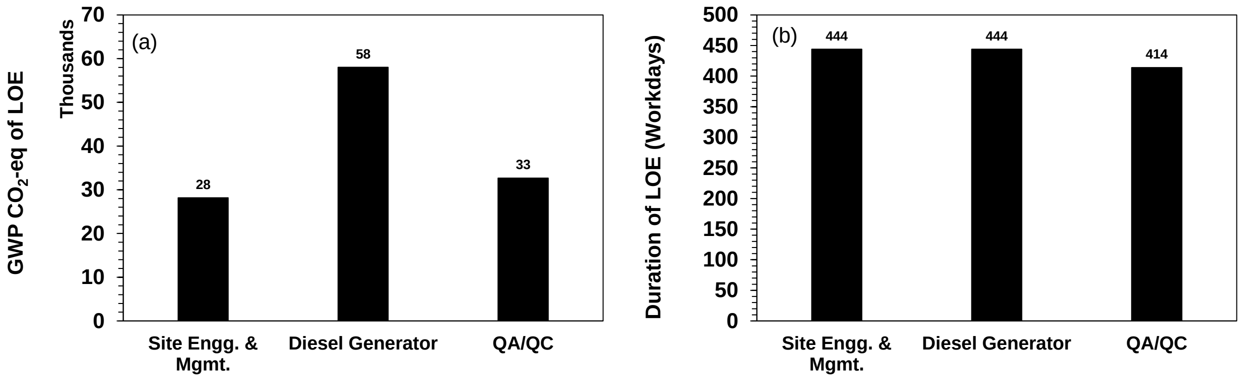


Figure 7: (a) GWP emissions for LOE activities, (b) Duration of LOE activities

3.3.Temporal Variations

Figure 8 shows the distribution of 100-year GWP emissions over the 22 months of the project. One of the major advantages of this new methodology is the ability of a construction manager or contractor to analyze the estimated emissions over the course of the project schedule. The temporal chart shows peaks of GWP emissions on some months over others. The highest peak emissions can be seen in March 2022 or 3 months after start of construction. The detailed schedule shows that the during this period, pile, pile caps, pier and pier caps of P1 and P2 will be installed during Phase I of construction. Significant amounts of concrete and steel will be used in this period, which explains the peak in GWP emissions. Prior studies have investigated relationships between the rate of GWP emissions and the impact on climate change [15]. This rate of emissions could be an important consideration as huge peaks of GWP emissions within short periods of time may be more detrimental to climate change compared to a steadier release of such emissions.

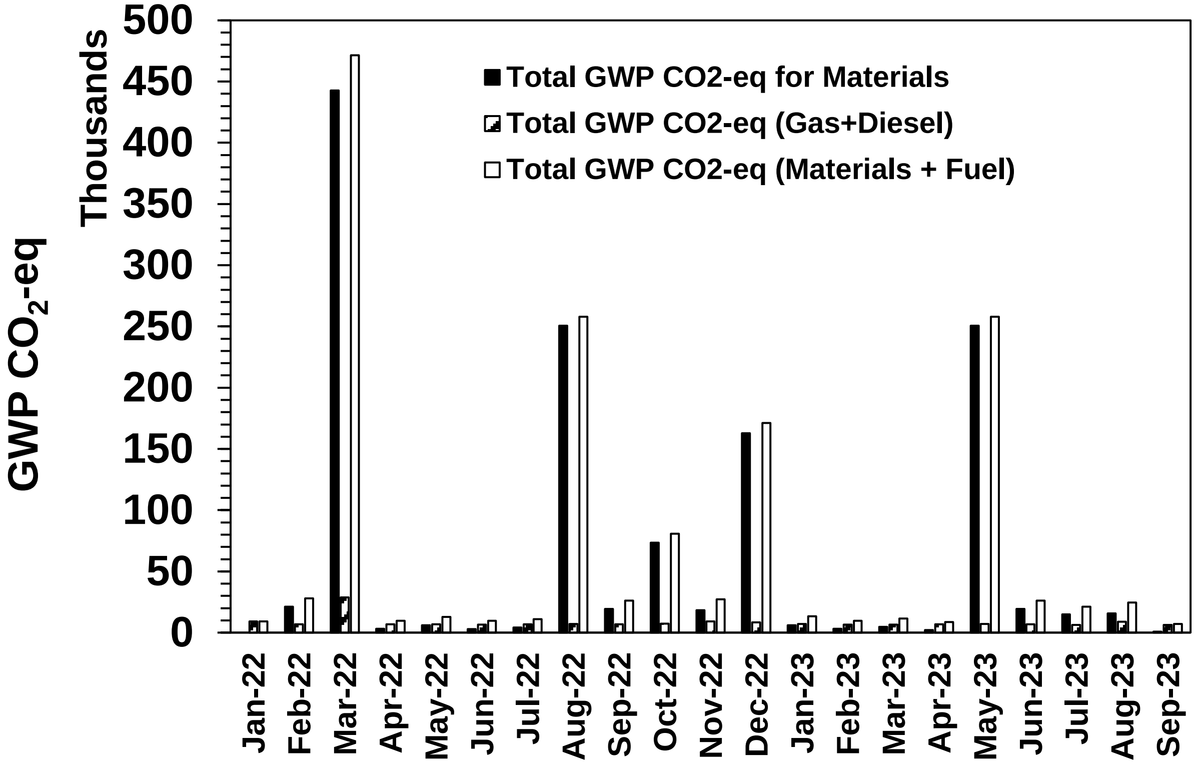


Figure 8: GWP emissions throughout the life cycle of the project

3.4.Correlations with Cost

Figure 9 shows log-log correlations between 100-year GWP emissions, and cost and manhours. Figure 9a shows that the total budgeted cost of equipment is directly proportional to the 100-year GWP emitted by the use of diesel, on a log-log plot. Similarly, Figure 9b shows that the total budgeted manhours in the project is directly proportional to the 100-year GWP emitted by the use of gasoline during commute, on a log-log plot. Such correlations between emissions and cost and manhours could be seen because the use of gas or diesel is considered in terms of miles commuted or hours of operation. Similarly, GWP emissions due to gas and diesel are also calculated based on the average consumption per mile or per hour. However, such correlations were not obvious in case of materials used in the project. This is due to a more complex nature of estimating emissions due to different materials and their varied quantities.

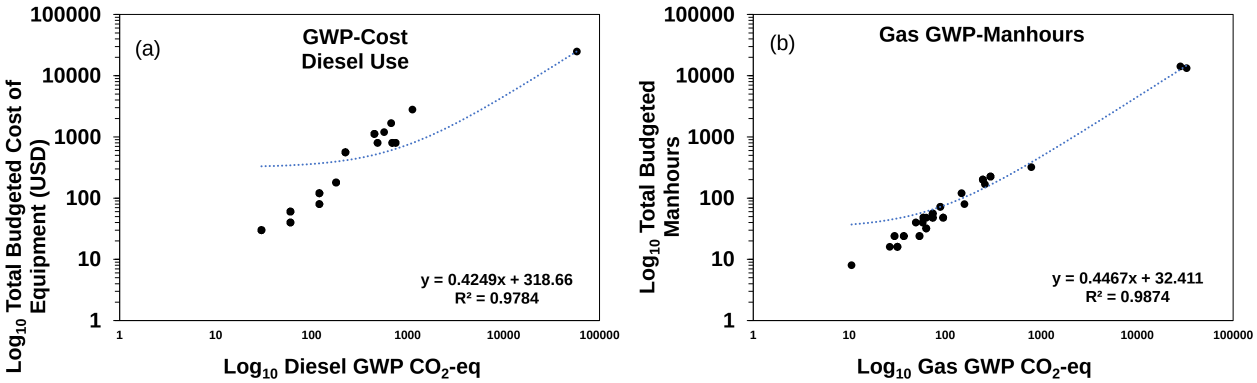


Figure 9: Correlation between (a) cost and GWP due to diesel use of equipment, (b) manhours and GWP due to gas use by personnel

4. Conclusions

In this work, a novel technique of evaluating the environmental impacts of materials, construction methods, equipment and personnel is presented at an activity level of a Critical Path Method (CPM) based schedule of a fictitious bridge project with a scenic overview and parking. This technique can be scaled up for megaprojects. The following are the key conclusions:

- The 100 year-GWP emissions due to materials are significantly higher than those due to fuel.
- GWP emissions due to HG Steel are higher than the other steel types due to a higher unit emission; EG Steel can be alternately used to reduce emissions.
- GWP emissions plotted per time showed peaks in specific periods, thereby throwing light on differing rates of emissions.

5. References

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