Clean Development Mechanism for Underground Corridor Metro Rail Project

Dr. Debasis Sarkar

Dept. of Civil Engineering, School of Technology, Pandit Deendayal Petroleum University, Gandhinagar, Gujarat

***Abstract:* - Clean development mechanism (CDM) can act as an effective instrument for mitigating climate change. This mechanism can effectively reduce the emission of CO_2 and other green house gases (GHG). Construction of a mega infrastructure project like underground corridor construction for metro rail operation involves in consumption of substantial quantity of concrete which consumes huge quantity of energy consuming materials like cement and steel. This paper is an attempt to develop a clean development mechanism for an underground corridor metro rail project in India during its construction phase. It was observed that about 35% reduction in CO_2 emission can be obtained by adding flyash as a part replacement of cement. The reduced emission quantity of CO_2 which is of the quantum of about 21,646.36 MT would result in cost savings of approximately INR 8.5 million (USD 1,29,878).**

***Keywords:*-Clean development mechanism (CDM), Metro rail, CO_2 emission, Certified emission reduction, Flyash**

I.INTRODUCTION

To deal with mitigate climate change emissions in the developing countries, the primary market based international instrument has been the clean development mechanism (CDM). Through CDM, industrialized countries can invest in emissions reductions in developing countries. This process would provide dual purpose of providing cost-effective emissions reductions to the industrialized world and also contribute towards the sustainable development goals of the developing countries (Zegras, 2007). According to (Bakker et al. 2010) the inclusion of CO_2 capture and storage (CCS) in the Kyoto Protocol's CDM is still subject to controversy and discussion. A myriad of barriers prevents CCS to be incorporated as a part of CDM. Apart from political barriers, economic, social and procedural barriers play a role. It has been observed that surplus bagasse in Indonesian sugar mills is potential for grid-connected electricity generating projects under CDM scheme (Restuti and Michaleowa, 2007). They aimed at analyzing the economic potential of bagasse cogeneration as CDM projects in Indonesia with main deliverables of total emission reductions per year and certified emission reduction (CER) earnings. For a residential building project, the embodied energy attributable to material manufacturing, building delivery process and demolition can account for over 35% of the life cycle energy demand (Chen et al. 2001, Sartori and Hestnes, 2007). For infrastructure construction projects like bridges and tunnels, the embodied energy can account for upto 90% of the lifecycle emissions (Maguire, 2009). Thus, for developing CDM for any construction project the key focus need to be in terms of reduction of the embodied energy of the primary materials and reduction of the CO_2 emissions from the major energy consuming materials. This paper is an attempt to develop a clean development mechanism for an underground corridor metro rail project in India during its construction phase. Construction of such mega infrastructure project involves in consumption of substantial quantity of concrete which consumes huge quantity of energy consuming materials like cement and steel. Thus CDM can be obtained by reducing the quantity of cement and steel used in the construction of the project.

II. LITERATURE REVIEW

The study carried out by Mok et al. (2014), has highlighted that green house gas (GHG) emissions due to human activities are the primary contributors to global climate change. Through the CDM introduced under the Kyoto Protocol, developing countries are able to earn certified emission reduction (CER) credits through a myriad of emission reduction projects. Their study aimed to explore the potential of implementing CDM projects in the construction and built environment (C&BE) industry, which has been criticized for not only consuming an enormous amount of resources, but also for contributing to adverse environmental health. The surveys conducted by Mok et al. (2014) suggests that more proposals need to the made to promote CDM projects in C&BE industry, particularly for the different lifecycle phases of a building or infrastructure project. The majority of the experts unanimously agreed with the high potential of the application of CDM energy efficiency methodology (95%) and fossil fuel switch methodology (83%) in construction industry. Most of the experts also agreed that the solutions suggested can be generalized for both building and infrastructure industry. Some vital factors like construction materials, fuel, stakeholders, common practices and industry barriers which should be tackled strategically for implementation of CDM. The potentiality of application of CDM in small hydro power projects in India was explored by Purohit (2008). These projects could be of interest under the CDM because they directly displace greenhouse gas emissions while contributing to sustainable rural development, if developed correctly. According to Zegras (2007) theoretically CDM has the dual purpose of helping developing countries achieve “sustainable development” goals and industrialized countries meet their Kyoto emission reduction commitments. Gojash et al. (2007) highlights that CDM model can also be developed by achieving CO_2 emission reduction by using alternative fuels as energy sources. Use of bio-fuels and other renewable energy sources would drastically reduce the levels of CO_2 emission. Kyoto Protocol provides flexible mechanism for developed countries to achieve their targets in terms of reduction of emission of GHG (Zhang, 2001). Apart from emissions trading and joint implementation, CDM is the only unique flexible mechanism for increasing financial flows to developing countries for promoting clean technologies that not only contribute towards CHG emissions , but also contribute towards the sustainable development of the country (Philibert , 2000, Diakoulaki et al. 2007, Muller, 2007 and Resnier et al. 2007). A comparative study was carried out for Brazil, China, India and Mexico about the technology transfers induced by CDM projects. The authors aimed to do so because these four emerging economies are also the main recipients of CDM projects (Dechezlepretre, 2009). According to Spencer et al. (2012) quantifying civil engineering projects in terms of sustainability and meeting carbon dioxide reduction targets is a new challenge for the civil engineering industry. While the development of carbon accounting tools has helped to identify areas of bridge design and construction which have the greatest carbon dioxide emissions, quantifying sustainability overall has been less well studied. The sustainability index for bridges described in this paper is a significant step towards facilitating systematic quantification of the sustainability of schemes through a simple, graphical tool. Also it has been stated that low utilization of CDM in construction and built environment industry is mainly due to the limitations in CDM procedures and modalities including the requirement in methodologies (Cheng et al. 2008). According to (Long et al. 2008) sustainability is now recognized as a key issue that must be addressed in the design, construction and lifelong maintenance of civil engineering structures.

III. CONCEPTUAL FRAMEWORK

2006 IPCC guidelines recommend three different Tiers for calculating CO_2 emissions from cement production process.

A. Tier 1 Method

$$CO_2 \text{ emissions} = [\textstyle\sum_i (M_{ci} * C_{cli}) - I_m + E_x] * EF_{clc} \quad (1)$$

Where, CO_2 emissions = emissions of CO_2 from cement production (metric tons [MT]); M_{ci} = weight (mass) of cement produced of type i (MT); C_{cli} = clinker fraction of cement type i; I_m = imports for consumption of clinker (MT); E_x = exports of clinker (MT); EF_{clc} = emission factor for clinker in the particular cement, (MT of CO_2 per metric ton of clinker). The default clinker emission factor (EF_{clc}) is corrected for cement klin dust (CKD).

B. Tier 2 Method

$$CO_2 \text{ emissions} = M_{cl} * EF_{cl} * CF_{ckd} \quad (2)$$

Where, CO_2 emissions = process related emissions of CO_2 from cement production (MT); M_{cl} = weight (mass) of clinker produced (MT); EF_{cl} = emission factor for clinker (MT of CO_2 per metric ton of clinker). This clinker emission factor (EF_{cl}) is not corrected for CKD; CF_{ckd} = emissions correction factor for CKD.

Discussions about Tier 3 method is kept out of the scope of this paper. According to California Climate Action Registry, the proportion of clinker : cement = 0.9 :1, also,

Clinker CO_2 emissions factor = 467.0 kg CO_2 / metric ton (MT) clinker (3)

According to (Hassan, 2005) about 1.135 units of $CaCO_3$ are required to produce 1unit of cement or 1.6 tonnes of raw materials is needed for 1 tonne of clinker production. Approximately 50 % by weight of $CaCO_3$ is lost as CO_2 during the production. Roughly the industry emits 900 kg of CO_2 for every 1000 kg of cement produced. CER Estimation Tool kit, version 02, March 2007, states that the increase in the share of additives such as flyash, gypsum and slag to reduce the proportion of clinker in blended cement, and thus reducing the CO_2 emission, would act as an effective clean development mechanism. Further, for optimal utilization of clinker, the substitution of clinker by flyash in Portland pozzolona cement blend, the baseline benchmark for MT of clinker / MT of blended cement is about 0.65

IV. CASE STUDY AND ANALYSIS

The project considered for analysis is construction of an underground corridor for metro rail operations in a metro city of an emerging economic nation in South Asia. The scope of work is design and construction of an underground metro corridor with six underground stations and a twin tunnel system. The underground stations are referred to as ST_1, ST_2 up to ST_6. Here ST_6 is the terminal station equipped with an over-run tunnel. The client is a public sector company floated jointly by the State and Central Government. The principal contractor is a Joint Venture (JV) of three foreign contractors and two domestic contractors. Type of contract is Design Build Turnkey (DBT) where the principal contractor is required to design the underground corridor and execute it.

The contract period is about five years (exclusively for execution). The feasibility phase of the project is an additional five years. The project cost for execution is about INR 18 billion. The major scope of the project include about 3,00,000 cum of concreting, about 24,500 MT of structural steel struts, about 5000 nos steel piles installation, soil excavation about 1,09,000 cum and rock excavation about 2,15,000 cum.

The sample stretch considered for study comprises of a preceding tunnel (530m), station box (290m) and a succeeding tunnel (180m). The major cement consuming activities during the execution of the civil works of the underground corridor construction metro rail project for the sample stretch under study are pile footing concreting of soldier piles (A1), pile footing concreting of king piles (A2), concreting of diverted manholes (A3), concreting for timber lagging subject to leaching (A4), concreting for diversion roads (A5), shotcreting for rock surface stabilization (A6), tension piles below base slab (A7), base slab raft (A8), box tunnel walls (A9), box tunnel roof (A10), diaphragm wall concreting (A11). The approximate concrete, cement, clinker and emitted CO_2 quantity of some of the major cement consuming activities during the construction of the metro rail project are presented in table 1. According to the table 1, the approximate quantity of cement consumed in the major activities is about 37,245.28 MT. The approximate quantity of CO_2 emitted by 37,245.28 MT cement consumed is 33,520.75 MT. The approximate amount of clinker in 37,245.28 MT cement is about 33,520.75 MT (assuming clinker: cement is 0.9:1, according to California Climate Action Registry). This quantum of clinker is capable of emitting about 15,654.11 MT of CO_2.

A. *Proposed Clean Development Mechanism for Underground Metro Rail Project*

For formulating a CDM model for the underground corridor metro rail project under study it has been proposed that addition of flyash as part replacement of cement can act as an effective mechanism for reduction of CO_2 emission. Flyash would also contribute to increase the durability of the concrete and also contribute towards better placing of the concrete with concrete pumps. Further, as flyash is a very cost effective material, using flyash in concrete, the overall concrete cost would also be reduced and thereby the overall project cost can be reduced. Bureau of Indian Standard (BIS) has formulated IS 3812 Part-1 2003. In this code quality requirement for siliceous flyash (class F flyash) and calcareous flyash (class C flyash) with respect to its physical and chemical composition have been specified. The chemical requirements are given in table 2. The primary objective of using flyash in most of the cement concrete applications is to get durable concrete at reduced cost, which can be achieved by adopting one of the following two methods: (i) using flyash based Portland Pozzolona Cement (PPC) conforming to IS: 1489 Part -1 in place of Ordinary Portland Cement (OPC) and (ii) using fly ash as an ingredient in cement concrete. The physical requirements of flyash should also conform to IS 3812, Part-1, 2003. Table 3 indicates the proposed CDM with reduced clinker and reduced CO_2 emitted quantity from the major cement consuming activities. According to table 3, it is observed that CO_2 emission by 21,788.49 MT of reduced clinker quantity would be about 10,175.22 MT. Thus about 35% reduction in CO_2 emission can be obtained by using flyash as a part replacement of cement. The reduced emission quantity of CO_2 which is of the quantum of about 5478.89 MT would result in cost savings of approximately INR 2.1 million (USD 32,873.34) assuming carbon credit of USD 6 / MT of CO_2 emitted.

Table 1

Approximate Concrete, Cement, Clinker and CO_2 Quantity for Some Major Cement Consuming Activities for the Metro Rail Project

S No.	Major activity description (concrete grade)	Approx concrete quantity (m^3.)	Approx cement quantity (m^3)	Cement quantity (MT)	Clinker quantity (MT)	CO_2 emitted (MT)/ specified MT of cement	CO_2 emitted (MT) / specified MT of clinker
1	A1(M20 grade)	2220	626.04	939.06	845.15	845.15	394.68
2	A2 (M30)	1032.5	337.63	506.45	455.81	455.81	212.86
3	A3 (M20)	70	19.74	29.61	26.65	26.65	12.45
4	A4 (M20)	20	5.64	8.46	7.61	7.61	3.55
5	A5 (M20)	50	14.10	21.15	19.04	19.04	8.89
6	A6 (M25)	25	7.5	11.25	10.13	10.13	4.73
7	A7 (M40)	763	283.84	425.76	383.18	383.18	178.94
8	A8 (M40)	249.57	6773.38	10160.07	9144.06	9144.06	4270.27
9	A9 (M40)	10496	3904.51	5856.77	5271.09	5271.09	2461.59
10	A10 (M40)	18796	6992.11	10488.17	9439.35	9439.35	4408.13
11	A11 (M40)	15768	5865.69	8798.53	7918.68	7918.68	3698.02
	TOTAL	49490.07	24830.18	37245.28	33520.75	33520.75	15654.11

Table 2

Chemical Requirements of Flyash as per IS 3812 Part -1 2003

S No.	Characteristic	Requirements	
		Siliceous flyash (Class F)	Calcareous flyash (Class C)
1	Silicon dioxide (S_iO_2) + Aluminum oxide (Al_2O_3) + Iron oxide (Fe_2O_3), in percent by mass, Min.	70	50
2	Silicon dioxide in percent by mass, Min.	35	25
3	Reactive Silica in percent by mass, Min.(Optional test)	20	20
4	Magnesium Oxide (MgO), in percent by mass, Max.	5.0	5.0
5	Total sulphur as sulphur trioxide (SO_3), in percent by mass, Max.	3.0	3.0
6	Available alkalis as Sodium oxide (Na_2O), percent by mass, Max.	1.5	1.5
7	Total Chlorides in percent by mass, Max.	0.05	0.05
8	Loss on Ignition, in percent by mass, Max.	5.0	5.0

Table 3

Proposed clean development mechanism with reduced clinker and reduced CO_2 emitted quantity

S No.	Major activity description	Clinker quantity (MT)	Reduced clinker quantity (MT)	Reduced CO_2 emitted (MT) /specified MT of clinker
1	A1	845.15	549.35	256.55
2	A2	455.81	296.28	138.36
3	A3	26.65	17.32	8.09
4	A4	7.61	4.95	2.31
5	A5	19.04	12.38	5.78
6	A6	10.13	6.58	3.07
7	A7	383.18	249.07	116.31
8	A8	9144.06	5943.64	2775.68
9	A9	5271.09	3426.21	1600.04
10	A10	9439.35	6135.58	2865.31
11	A11	7918.68	5147.14	2403.72
	TOTAL	33520.75	21788.49	10175.22

V. CONCLUSIONS

The present study shows that for an underground corridor metro rail project, during the construction phase, the amount of cement consumed can be substantially reduced by adding flyash as part replacement of cement. It is observed that CO_2 emission by 21,788.49 MT of reduced clinker quantity would be about 10,175.22 MT. Thus about 35% reduction in CO_2 emission can be obtained by using flyash as a part replacement of cement. The reduced emission quantity of CO_2 which is of the quantum of about 5478.89 MT would result in cost savings of approximately INR 2.1 million (USD 32,873.34) assuming carbon credit of USD 6 / MT of CO_2 emitted. Thus for the entire 6.5 km underground corridor project with 6 underground stations, for about 3,00,000 cum of concrete consumption, the quantum of reduced CO_2 emission would be 21,646.36 MT. The approximate cost savings would be to the tune of INR 8.5 million (USD 1,29,878). This would act as CDM effective for reduction of CO_2 emission. Flyash would also contribute to increase the durability of the concrete and increase the pumpability of concrete to facilitate its placing through concrete pumps. Further, as flyash is a very cost effective material, using flyash in concrete, the overall concrete cost would also be reduced and thereby the overall project cost can be reduced. As a future scope of study the CDM model can be further strengthened by exploring the potential of use of alternative fuel for operation of the transportation system.

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