THE ASSESSMENT OF GREENHOUSE GAS EMISSIONS FOR EVALUATING ACTUAL ROAD CONSTRUCTION OPERATIONS

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Assessment of greenhouse gas emissions of products using the life cycle inventory analysis (LCI), can be performed in both the pre- and/or post-construction phases of road construction. For the pre-construction phase, a bill of quantity (BOQ) is used to calculate emissions, whereas, in the post-construction phase, emission calculations are based on the actual work done. Road construction is one of the construction sectors which requires long project time and a great deal of machinery. The actual amount of total resources used is probably different from that which is stated in the BOQ. In general, greenhouse gas assessments consider only data from either the pre-construction phase or the post-construction phase. However, it is possible to control and monitor actual resource-utilization by comparing change at the post-construction phase in relation to the pre-construction phase. This can reveal construction operation performance and lead to the development of methods or construction operations resulting in a reduction of greenhouse gas emissions. The current research uses three road construction projects as case studies. It aims to improve the EIO-based inventory calculations of machinery used in road construction by adjusting the proportion of usage hours for that machinery. It achieves this by comparing actual data relating to energy, materials and machinery consumption with BOQ data. The results of this comparison help to identify the factors and causes that influence operational performance (in terms of greenhouse gas emissions) and lead to improvements in road construction operations. The key findings from emission calculation between pre and post-construction phases were that the project A had decreased the greenhouse gas emissions by 3.8%, contradictory with project B and C which had increased more gas emissions by 5.0% and 0.6% respectively. Considering with these figures it is reflected the resource management efficiency of each project. The main cause of greenhouse gas emissions on each project was the usage machinery which depended on the project period.

Keywords: greenhouse gas, monitoring, resource-utilization, road construction.

INTRODUCTION

Greenhouse gas emissions evaluation according to the life cycle assessment (LCA), according to the International Organization for Standardization (ISO); 2006 standard series, as displayed in Fig. 1, consists of 4 principal steps: 1. Goal and scope definition; 2. Life cycle inventory analysis (LCI); 3. Life cycle impact assessment (LCIA) and 4. Interpretation (Crawford, 2011). The LCI is an important step for compilation of quantities of inputs and outputs of concerned products throughout their life cycles. LCA may be conducted both prior to construction by the designer, policy

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maker and planner, to aid in the decision to choose the appropriate construction design, as well as post-construction by field operators and program evaluators, to evaluate the actual impact. Data sources to be entered into the inventory would differ according to the evaluation period. In other words, if evaluating prior to construction, the resource quantity data would be obtained from the design documents (pre-qualification data and BOQs), while post-construction data would be compiled from actual operations (data from field reports) and variety while in construction.

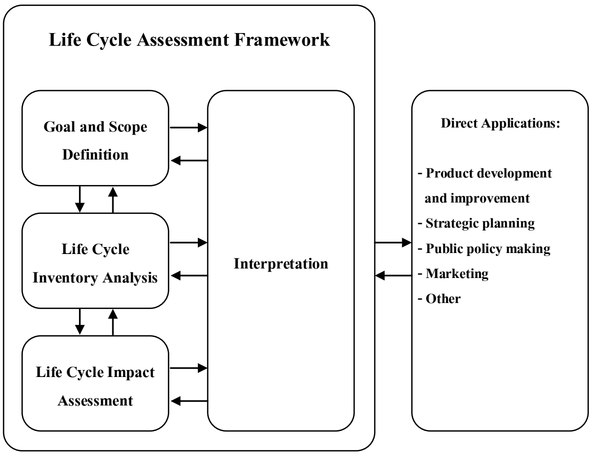

Fig. 1. LCA framework based on ISO 14040: 2006

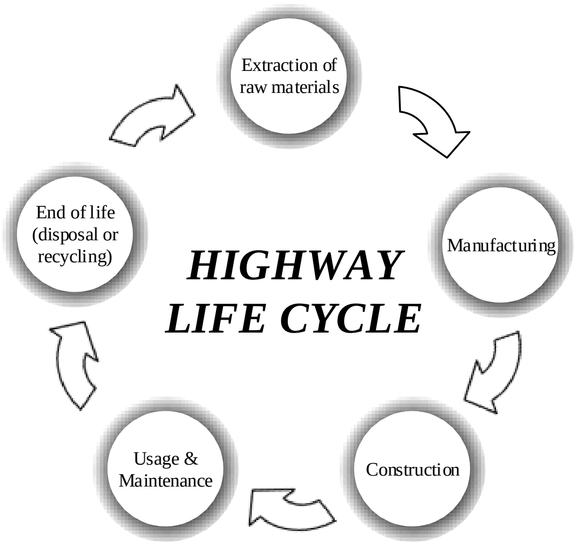

Fig. 2. Life cycle of highway construction product

Road construction uses a large amount of equipment or machinery in each project (Park *et al*., 2003; Payothornsiri and Phainai, 1999), indeed, much more than other types of construction. Such machinery is referred to as capital goods, that is, a goods or product that has already passed through the productions process and is used as part of another production process (BSI, 2008). Most of road construction machinery is that of the heavy type, such as backhoes, loaders, dump trucks, motor graders, asphaltic pavers, for example, and is part of the highway construction life cycle as shown in figure 2. Moreover, the construction process consists of a variety of activities which are of long duration in time along the life cycle of each project as well. However conducting an LCI at different time may cause differences in data obtained which maybe lead to different greenhouse gas emission evaluations as well.

It would be useful to compare such evaluations as to ascertain the efficiency of operations and to be data supporting methods or process development for improvement in that construction. Furthermore, previous studies do not considered these, most of their studies would be focussed on either pre or post-construction phase. If these is such follow up comparison of similarities or differences, there might be to answer the following questions:

Are the differences between evaluations from the BOQ and field reports?

If there are differences, what are the possible causes? Furthermore which source would be more appropriate for gas emission evaluations?

How can one use results from both sources data to the advantage of any aspect of construction development?

This research has considered three highway construction projects as to propose a directive to help improve data collection of input-output items concerning machinery in production basis of Economic Input-Output based (EIO-based), adjust proportions according to actual hours of operation. The evaluation provides a comparison actual field reports and BOQ data of energy, materials and machinery consumption, as to indicate factors and causes of efficiency of construction operations in terms of greenhouse gas emissions, useful for the improvement of hypotheses or data prior to construction, leading to improvement of the general construction process.

INVENTORY ANALYSIS OF ROAD CONSTRUCTION

The LCI is a procedure designed to collect input-output data in the production process. Generally, the GHG emission-assessment is performed using either an input-output-based (IO-based) or a process-based inventory approach (Cass and Mukherjee, 2011). Most of time, the process-based approach is used to generate an inventory process for each step or each activity of products system, which can generate specific input-output data for each process. The approach can produce an accurate inventory if accurate information for input-output data is obtained at each step of the process. Complicated processes render accurate information over their entire processing difficult to obtain it is determining the inventory accurately is a challenge. Furthermore, the approach requires a huge amount of time and money. The factors that limit the use of LCI arise from accurate machinery assessment in terms of production since the entire production process cannot be accessed. These reasons have led us to develop an approach to reduce they limitation.

The IO-based approach depend on an evaluation such as an energy input-output model or an economic input-output-based model (EIO) etc. A prevailing approach is EIO-based, which was developed in the 1970s. The approach uses information about the economic transactions of resources, and estimates the environmental emissions resulting from the materials and energy input resources required (Hendrickson *et al*., 2006). This approach of output information, represented average environmental impact in each industries. Limitations in the complex production processes of capital goods can reduced by the EIO-based approach. However, this approach has some disadvantages which was also average of industries. Perhaps, the results are inconsistent with the actual activities or projects operation, as in the case of the machinery in construction work (Park *et al*., 2003; BSI, 2008). This approach considers as if the machinery is used up in one project but in practice, most of machinery can have a useful life longer than one project and be reused in the next project. Therefore, the calculated emission levels will be exceeding and unreasonable.

The hybrid LCA approach reduces the disadvantages by combining the advantages of both approaches. The approach leads to a better complete inventory (Crawford, 2011). Principles of this approach try to eliminate or avoid errors arising from the processes-based upstream of the supply chain (extraction of raw materials and manufacturing), and to remove the disadvantages of the EIO-based approach downstream of the supply chain (construction, usage and maintenance and end of product life). Therefore, the hybrid LCA approach is more efficient for estimating environmental impacts on road construction projects.

The inventory from collecting amount of materials and equipment are frequency performing at the pre-construction phase, as in Park *et al*. (2003) who evaluated the GHG emissions of highway construction projects. Cradle-to-grave was boundary definition for the products (manufacturing of construction materials, construction, maintenance and removal and reuse). The study focuses on ways to help assess more environmental friendly design options, with special attention about energy consumption in project activities. The hybrid LCA used for the inventory analysis collected the input-output data of the typical highway cross section from BOQ. In addition, the research of Kofoworola and Gheewala (2008) uses office building construction projects in Thailand as case studies. It aims to identify the factors and causes that influence environmental emissions from that construction and lead to improvements for sustainable construction operations.

Also, data were collected from actual work done in the post-construction phase. Cass and Mukherjee (2011) evaluated emissions generated during the entire life cycle of the project as assessed by the hybrid LCA approach. The inventory was collected from actual on-site data during the construction stage from information on emissions assessment of pavement rehabilitation and reconstruction project. The main purpose was to help support decisions of government policy makers to bring about a reduction of GHG emissions and minimize environmental impact in the long term. In addition, the research of Jiamvoraphong and Tongthong (2012) uses activities relating to the installation of pre-cast concrete walls as a result of a case study of a building construction project. It also collected labour and materials transportation information.

Monitoring or checking is a tool or technique of construction project management. Continuous control and monitoring of all the processes leads to improvements and greater operational efficiency. It is part of a set of procedures for production improvement, known as the Deming Cycle (Jiradamkerng, 2011) which consists of: a plan, the identification or planning to set up sequences, steps and procedures about the activities; do, performing actions or activities based on the objectives; check, monitoring the performance and comparing with the product of the previous plan; action, taking action on the basis of comparative results leading to revision or improvement leading to better products. Also, the cycle was continuously applied throughout the product processes. Performance-checking is important for project control and the actual operation and management practices need to be monitored following the objectives and the plans determined (Gould and Joyce, 2002). The checking of project-development has many aspects such as cost, materials, resources and energy that are their exactly objectives or not. Abnormal results from the plan can lead to sudden improvements or revision. Therefore, the checking or monitoring is the appropriate performance tool for product improvement.

RESEARCH METHOD

This research is focussing on the highway construction impacts assessment. It conducted a comparison between the data from two difference sources. These data were used to prepare the inventories for GHG emissions assessment. The functional unit was defined as lane-km and a boundary system was cradle-to-gate (or business-to-business: B2B), as shown in double dash line and shaded area (Fig. 3). The information consists of the main items on a highway construction project, i.e., earth work: soil excavation, embankment production and embankment construction; surface work: aggregate extraction, aggregate production, petroleum refinery, bitumen production and pavement construction; bridge and drainage work: lime stone extraction, iron ore extraction, equipment production, cement production, steel production and bridge and culvert construction. These include the usage of machinery in the construction stage, which represented by *"M"*, the amount of transportation which represented by *"T"*, and the installation of road safety and road sign. This study focuses only on the extraction of raw materials, the manufacturing, and the construction stages. It uses the emission factor (EF) from the conference of Intergovernmental Panel on Climate Change 2007 (IPCC, 2007) for calculating the GHG emissions on the operation level. The EIO-LCA on-line tool was used to evaluate the emissions from information about industry transactions - purchases of materials and/or machinery by one industry from other industries. This tool can be accessed through the Carnegie Mellon University website (EIO-LCA, 2014). The environmental impacts assessment considered only the global warming impact, which presented in terms of tons of carbon dioxide equivalent (t CO_2-e) and based on the multiplying factors introduced by IPCC's GWP100 (IPCC, 2007). Moreover, all machinery cost must be converted to the present value in year 2002 by using the formula in Equation 1, and also converted to US dollars (43 THB/1 USD approximately) (BOT, 2014). Consequently, the inventory cost were consistency with the EIO-US 2002 Benchmark Model - purchaser price (EIO-LCA, 2014)

$$COST_{2002} = COST_X (1 \pm i)^n \qquad (1)$$

where $COST_{2002}$ = the present value of cost in year 2002; $COST_X$ = the cost in year X which have to be converted) using minus if X is later than 2002 or plus if earlier than 2002); i = inflation rate) assumed to be 3%); and n = the amount of different years from X to 2002.

Consumptions at Pre-Construction Phase

The inventory which presents the amount of resources consumption at the pre-construction phase was prepared by using the BOQ stated in the contract. The inventory life cycle analysis or LCI in Fig. 3 (work flow of activities), the most activities were executed by the heavy machinery. The preparation of the machinery inventory was very complicated process but the EIO-based approach for evaluated the environmental impacts (depend on category of impacts) was selected and implemented in this study. At manufacturing stage, the machinery emissions do not considering the reused effect such in the research of Park *et al*. (2003). Therefore, this research presented its impacts by the repetition at pre-construction phase, it modified the proportion of the repetition from Cass and Mukherjee (2011) at post-construction phase as shown in Equation 2.

$$M_{BOQ} = \frac{Q}{P \times N} \qquad (2)$$

where M_{BOQ} = usage hours of machinery by adjusting the proportion for BOQ; Q = the amount of required products; P = production rate; and N = useful life of machinery (assumed to be 10,000 hrs)

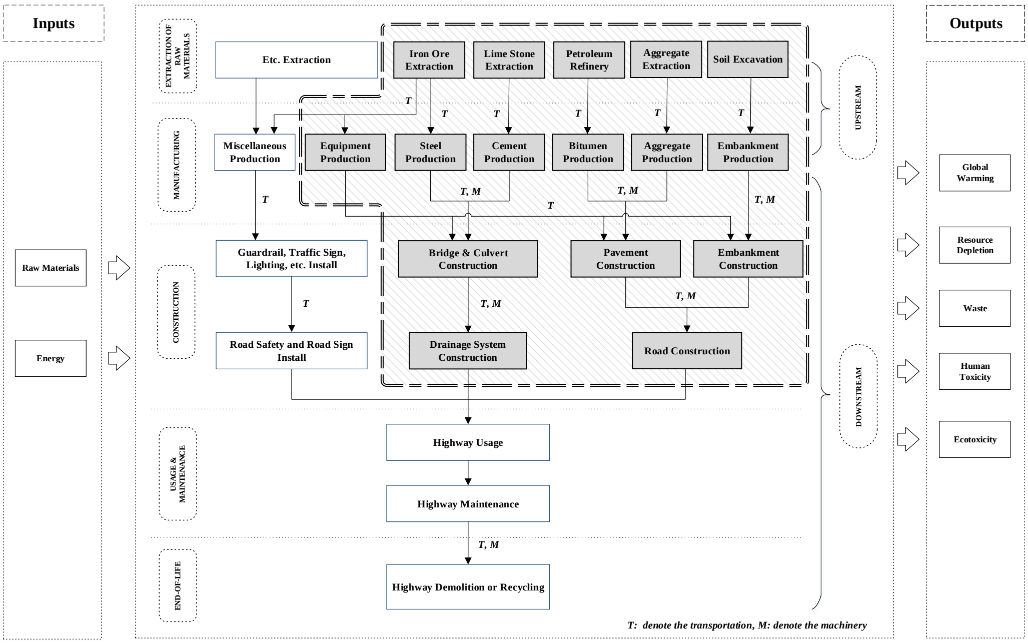

Fig. 3. Work flow of input-output for highway construction product life cycle and boundary study

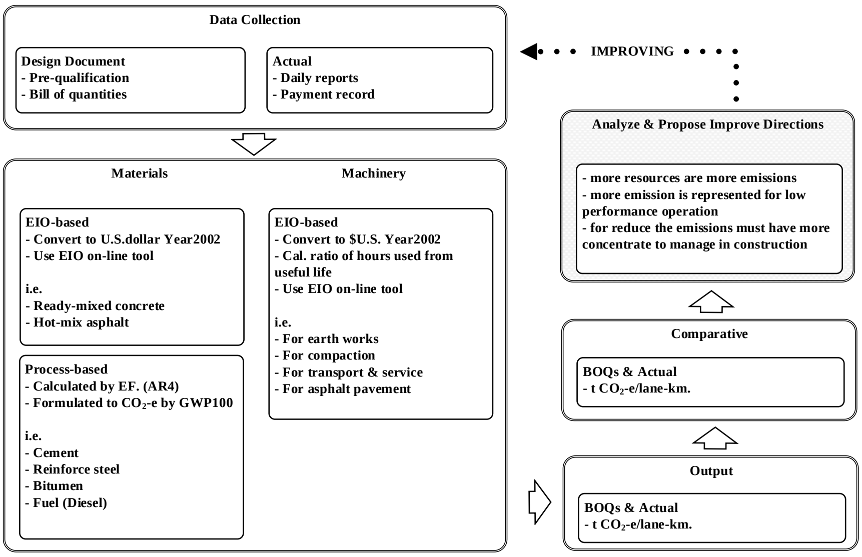

Fig. 4. Procedures of the evaluation GHG emissions

Consumptions at Post-Construction Phase

The inventory which presents the amount of resource consumption at post-construction phase was prepared by using the actual work done data on-site. These actual work done data had to be consistent with the payment record report. Cass and Mukherjee (2011) considered the repetition of that machinery manufacturing impacts. Therefore, at the post-construction phase, the actual amount of on-site usage hours have already been received. The adjustment proportion of machinery with the useful life as shown in Equation 3.

$$M_{actual} = \frac{h}{N} \quad (3)$$

where M_{actual} = the adjusted usage hours of machinery; h = the amount of usage hours from the on-site report; and N = the useful life of machinery (assumed to be 10,000 hrs).

The GHG emissions assessment method, which is proposed in this study, applies the proportion of machinery usage to adjust the impacts and can gives more reasonable results. The assessment procedures are shown in Fig. 4.

RESULTS

In this research, the highway construction projects in Thailand were selected as case studies studied to evaluate the environmental impacts of construction products. These cases were used to demonstrate the LCI that was related with the reuse of machinery manufacturing and machinery usage, and relied on the BOQ and actual work done data. Three case studies including project A, B, and C have a similar typical cross section of the highways. This is to illustrate the trend of comparative results. All case studies have two lanes of roadway construction and shoulder with 11.00 metres width and use the asphaltic concrete type of pavement. At the time of data collection (in December, 2014), the projects have approximately 95%, 70%, and 98% progresses, respectively.

Table 1: The resources consumption of case studies.

Resources	Unit	BOQ	Actual	BOQ	Actual	BOQ	Actual
Earth Work		Project A		Project B		Project C	
- Cement	cu.m.	3,000	5,997	1,769	1,659	-	-
- Embankment	cu.m.	395,000	434,158	165,461	231,023	339,900	347,563
- Selected Material *"A"*	cu.m.	-	-	-	-	44,100	44,407
- Soil Aggregate	cu.m.	100,500	98,413	47,034	57,944	97,000	94,609
- Soil Agg. Type Base	cu.m.	75,000	74,848	44,226	41,469	67,500	65,661
Pavement							
- Bitumen	sq.m.	735,000	730,104	426,676	397,925	682,100	605,527
- Asphalt Concrete	sq.m.	727,000	710,485	423,861	398,989	632,900	606,797
Structures							
- Steel	tons	100	107	84	52	182	201
- Concrete	cu.m.	1,476	1,586	892	350	1,903	1,531
Fuel							
- Diesel	litre	846,936	580,592	601,504	687,471	991,121	1,276,255

Table 1 shows the items of the main construction materials, which are consumed by the activities such as earth work, structure work, and surface work etc. All data were collected from the daily reports by field inspectors. Table 2 shows the machinery usage in the analysis of the case studies, by assuming that usage hours were 7 hrs/day for the BOQ, and were 8 hrs/day for the actual work done. Their machinery price data were supported by both contractors and Metro Machinery Co., Ltd.

The comparison results of the total amount of emissions between pre and post-construction phases from the three case studies indicated that. Project B has the most different GHG emissions 12,414.82 t CO_2-e/lane-km, which had the increased emissions by 5.0%. Secondly, project C had different emissions 1,605.56 t CO_2-e/lane-km (increased emissions by 0.6%). On the other hand, result for project A had different emissions 10,285.25 t CO_2-e/lane-km (decreased emissions by 3.8%). Table 3, it is presented the different percentage of GHG emissions, and reflected the bar chart as shown in figure 5.

Table 2: The machinery usage hours of case studies.

Machinery	Capacity	Price	BOQ	Actual	BOQ	Actual	BOQ	Actual
(Earth Work)			Project A		Project B		Project C	
- Backhoe	128 hp	100,378	4,608	15,584	2,750	4,544	3,966	15,216
- Bulldozer	165 hp	112,670	7,065	408	4,570	NA.	5,941	3,200
- Motor Grader	150 hp	110,687	9,522	18,000	6,390	8,984	12,890	16,664
- Wheel Loader	220 hp	100,378	3,911	6,656	3,028	1,760	3,241	1,240
(Compaction)								
- Pneumatic Tire Roller	9 T	47,415	11,427	26,520	8,193	9,520	12,225	13,200
- Vibrating Roller	152 hp	61,091	8,519	18,784	5,777	8,592	9,694	18,976
- 3 Wheel Steel Roller	9.5 T	29,712	1,454	1,896	1,208	376	3,753	3,728
(Service)								
- Water Truck	16,000 T	38,991	9,772	14,904	6,810	9,944	10,863	14,832
- Dump Truck	10 cu.m.	40,403	5,816	73,384	4,830	34,496	5,063	37,856
(Pavement)								
- Asphaltic Mixing Plant	160 T/hrs	861,190	1,454	NA.	1,208	NA.	NA.	NA.
- Asphaltic Distributor	6,000 L	31,408	1,252	2,232	1,033	176	1,170	640
- Asphaltic Paver	114 hp	238,170	1,454	1,896	1,208	272	1,266	592

Note: Machinery prices in 2002 USD.

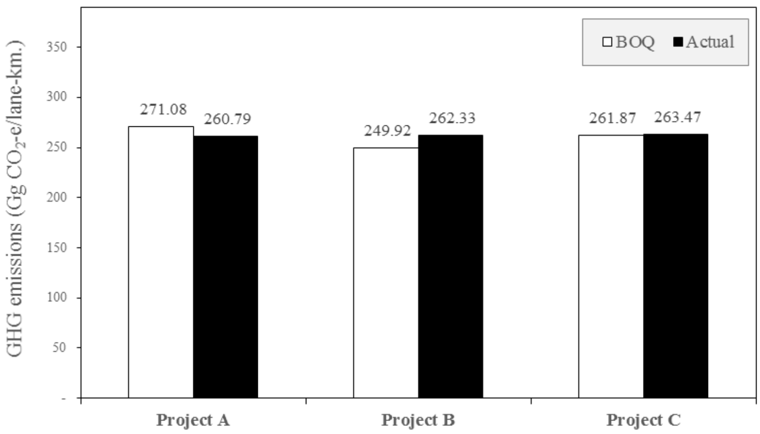

Fig. 5. GHG emissions from the three case studies

CONCLUSIONS

This paper presents the amount of GHG emissions for road construction projects. A comparison of results from the case studies between pre and post-construction phases. Project B were most different amount of GHG emissions 12,414.82 t CO_2-e/lane-km, which had the increased emissions by 5.0%. Secondly, project C had different emissions 1,605.56 t CO_2-e/lane-km, which increased emissions by 0.6%.

Contradictory with project A had different emissions 10,285.25 t CO_2-e/lane-km (decreased emissions by 3.8%). Considering in each stages of highway life cycle had the main cause of the different emissions was the fuel consumption by machinery at extraction and construction stages. While, overview of total amount emissions had the main cause were occur at the manufacturing stage, especially the surface course work were more than 80% of total emissions. Although, we have already adjust proportions of the machinery usage hours following in Equation 2 and Equation 3. This effect can just reduce for machinery manufacturing, but emissions from machinery usage were still the main cause of the projects. Another cause was some of the inconsistency of difference data sources, in particular day had work hours data from BOQ were 7 hrs/day, while the actual work data on the construction site were 8 hrs/day. Perhaps, that reason is more the energy consumptions and emissions at post-construction phase than at pre-construction phase. This reason made the assessment at post-construction phase will be appropriate way to assess for real emission in each projects. On the other hand, the assessment at pre-construction phase from BOQ data will be the reliable way, but must have improve some assumption of calculation for more data consistency, e.g., work hours per day of machinery usage etc. However, this research have purpose to comparison the efficiency of actual operations and the resources management on road construction project. Therefore, these data from different phase are the benefits and important also reflecting main causes of differently GHG emissions.

Table 3: The comparative emissions of the case studies between two different inventories.

		Extraction	Manufacturing	Construction	Total
Project A	BOQ	2.93	233.41	34.74	271.08
	Actual	2.77	232.12	25.89	260.79
	Diff.	-5.2%	-0.6%	-25.5%	-3.8%
Project B	BOQ	2.85	207.09	39.98	249.92
	Actual	4.12	206.95	51.26	262.33
	Diff.	44.6%	-0.1%	28.2%	5.0%
Project C	BOQ	6.33	214.80	40.73	261.87
	Actual	8.51	200.00	54.96	263.47
	Diff.	34.4%	-6.9%	34.9%	0.6%

Note: Emissions in Gg CO_2-e/lane-km.

The difference emissions of machinery usage is present the important of machinery cost management, it may be conducted to high or low emissions. As the results, project A had early complete project in contract four months, it reflects the better resources management. While, project C had accelerating at the end of period time for complete project by the due date of contract, it reflects the resources management in the secondary role. On the other hand, project B had delayed time and must have more accelerating for complete project by the new due date of contract, that is the worst management than the other projects and also may be the most GHG emissions project. This research proposed a new calculation method for emissions of machinery usage based on the proportion of usage hours and useful life. The operations monitoring on construction projects can be demonstrated the performance of the resources management in each of projects. The stakeholder should be awareness and attention of two important things, i.e., first thing is the machinery usage management for more performance; and the next thing is the design materials alternatives in pavement work for more performance, because there are the significant effects to GHG emissions if we want to reduce the serious emissions. However, this proposed method has some limitations are that it must be implemented on the on-going projects, and it requires pre-qualification data which are confidential information to owners only.

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