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Reducing the Greenhouse Gas Emissions from Onsite Mechanized Construction

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ABSTRACT

Onsite mechanization in construction is characterized by the application of plant, equipment and machineries for carrying out complex construction activities. Although these mechanized equipment are considered essential for achieving high productivity, efficiency and quality of work. But nevertheless, they also impose serious threats to ecological system by emitting greenhouse gases (GHG) such as carbon dioxide, methane, nitrous oxide, hydro fluorocarbons, per-fluorocarbons and sulphur hexafluoride. The charter of Kyoto Protocol under the umbrella of United Nations Framework Convention on Climate Change (UNFCCC) imposed binding restrictions on developed and industrialized countries to cut down the GHG emissions. This charter has identified several sources and industrial sectors that are potentially responsible for damaging the climate system through high carbon emissions. Keeping this in view, the Malaysian government has already started initiatives to develop measures against the climate change. The aim of this research endeavour is to explore awareness among Malaysian construction firms to reduce GHG emissions by taking effective measures. A feedback on a structured survey questionnaire was solicited from the construction firms to develop an action plan to reduce GHG emissions due to mechanized construction. The results of the survey reveal that GHG mapping during onsite construction activities is still in its infancy stages. The study has prioritized a number of strategies for the efficient use construction equipment in order to reduce the carbon footprints.

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INTRODUCTION

The term ‘Greenhouse gas’ refers to the mixture of atmospheric gases which are abundant in nature. These gases mainly include carbon dioxide (CO_2), water vapours (H_2O), nitrous oxide (N_2O), methane (CH_4), ozone (O_3) and chlorofluorocarbon (Buchanan and Honey, 1994). These gases are playing a vital role in maintaining the earth’s surface temperature by absorbing and emitting infrared radiations (USEPA, 2009). The atmospheric concentration of GHG is balanced by the natural system. However, this equilibrium has been disturbing due to industrial revolution which subsequently increased the burning of fossil fuels (UNDSD, 2011). As a result, this has substantially raised the level of CO_2 (up-to 35%) which is considered as a major factor for the cause of the climate change around the globe (Saxena, 2009). The proportion of CO_2 accounts 77% of all emissions beside nitrous oxide and methane. It is due to this reason that calculation of CO_2 is taken as a benchmark for establishing future predictions and trends of GHG emissions from the consumption of fossil fuels (Buchanan and Honey, 1994; Saxena, 2009). A report from the Energy Information Administration of the U.S. Department of Energy (EIA, 2007) stated that there is gradual increase in the global emissions of carbon dioxide in the coming years. According to their forecasting, it will increase from a level of 26.9 billion tons (2004) to an amount of 33.9 billion tons in 2015, and 42.9 billion tons in 2030. This makes an average growth rate of 1.8% per year (USEIA 2011).

The excessive emissions of GHG are hazardous for the biological system and as well as for human beings. All transport vehicles including non-road construction equipment and machineries emit GHG. The burning of fossil fuels (mainly hydrocarbon) in the combustion chamber of diesel and gasoline engine lead to the formation of CO_2, water vapour and proportion of other GHG (Kim *et al.*, 2012). Though, the combustion of fuel in the engine is ideally considered to be complete.

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As a result of improper and incomplete oxidation of hydrocarbon mixture, carbon monoxide (CO) is produced as all the carbon contents does not converted into to the carbon dioxide (CO_2). In addition to this, inadequate amount of oxygen in the air/fuel mixture also elevates the formation of CO. However, if a complete combustion is taken place in the engine, then relatively a low amount of CO is produced and exhaust in the atmosphere (Lewis *et al*., 2009). CO is colourless, odourless and tasteless in its physical form. The percentage of CO present in the earth's atmosphere is mainly due to the burning of hydrocarbons from the combustion engines. Carbon monoxide is a toxic gas. It is injurious for human health as it reacts with haemoglobin and blocks the absorption of oxygen into the arteries. Carbon monoxide can negatively impact brain function, vision problems and severe chest pain in cardiovascular patients. If large amount of CO is inhaled for prolong period, it may cause human death as well (USEPA, 2008).

Apart from the carbon monoxide, the reaction of combustible fuel mixture with the atmospheric air produces nitrogen oxides such as Nitric oxide (NO) and Nitrogen dioxide (NO_2). The quantity of Nitrogen oxides (NO_x) is directly proportional to the high flame temperature which is achieved by the combustible mixture in the engine. This reaction is taken place in the presence of rich air-fuel mixture with high concentration of oxygen. The high temperature and high pressure expedites the reaction of nitrogen and oxygen atoms to form different compounds of nitric oxides. Nitrogen oxides present in the atmosphere are principal cause of acidic rain. It forms vapours of nitric acid by the reaction of ammonia in the presence of water. The absorption and breathing of nitric acid is dangerous for human beings as it may damage the lung tissue (Lewis *et al*., 2009). In addition to this, nitrogen oxides when reacts with volatile compounds present in the air, it forms ozone (O_3). The ozone has also adverse effect on human respiratory system and it gradually deteriorates functioning of lungs. Another aspect of ozone is that is transferred thorough winds to different geographical regions and potentially infecting agricultural lands (Seinfeld and Pandis, 1998).

The burning of hydrocarbons in the vehicles engines also contribute to the formation particulate matters (PM). These are small or fine particles of solids and liquids that are emitted by diesel or gasoline engine into the atmosphere. Particulate matters are main cause of atmospheric haze; it reduces visibility and directly affects the human health in terms of many chronic syndromes (Lewis *et al*., 2009; USEPA, 2008).

This study has first presented that importance of GHG emissions from the burning of fossil fuel and its harmful implications for the environment and human life. This research endeavour is envisaged to highlight this issue with specific reference to the construction industry. The succeeding sections will discuss the GHG emissions due to the construction activities, and its mitigation approaches.

Impact of Construction Industry on Ghg Emissions:

The above discussion shows that GHG are emitted from the fossil fuels and CO_2 is the major constituent for the greenhouse effect globally. It has significant impact on the climate change. Major contributor of CO_2 emissions are energy sector, road and transport, manufacturing and construction activities (Saxena, 2009). The scope of this study is mainly focused on the construction industry's emissions with a distinct focus on mechanized construction. U.S. Environmental Protection Agency (EPA) characterizes the emissions of GHG from different industrialized sectors (such as oil and gas; chemicals; construction; forest products; iron and steel; food and beverages etc.) and recorded their corresponding estimates. EPA has classified GHG from three generic sources of emissions such as ignition of fossil fuel (gasoline, diesel and coal), usage of electricity from the power plant and non-combustion chemical process. PA research work established that GHG emissions from the 14 main industrial sectors of United States account 84% of the of the over-all emissions. This report stated that construction sector is alone responsible for 6% of U.S. industrial GHG emissions in 2002 (USEPA, 2009). Another research established that construction of buildings annually utilize large amount of raw material in the form of stone, gravel and sand (40%), wood timber (25%) and (16%) water (Yan *et al*., 2009). In European Union (EU) countries, the whole life cycle of building construction consumes 50% of total energy and emits 50% CO_2 in the atmosphere (Dimoudi and Tompa, 2008). Beside this, it is also accountable for producing approximately 40% of all man-made waste (CIB, 1999). A research work on green performance rating in Malaysia indicates that building are responsible for 20% of GHG which ranked this sector third after transportation (27%) and industries (21%) (Samad, 2008). Furthermore, Malaysia has the 30^{th} ranked among the highest GHG emitter countries and construction industry share is 24% (Nation Mater Statistics, 2010).

The construction industry emits GHG in several distinct ways. The precedent research shows that key sources of GHG emissions in the construction of building are (Yan *et al*., 2009);

a. Manufacturing and transportation of building materials:

It includes embodied GHG emissions of building materials along with the shipment of raw material from the quarry to the manufacturing facility and final to the construction site. It depends on the amount of building material, emission factor of material, distance of transportation and emission factor for transportation either by land or sea. It accounts 90% of GHG emissions.

b. Energy Consumption of Construction Equipment:

Energy consumed by construction equipment is either in the form fossil fuels or electricity. The second part of GHG emissions are due to the burning of fossil fuel and utilization of electrical energy for running construction equipment and machineries. It depends on the amount of fuel, emission factor of fuel, amount of kWh of electricity and the emission factor of power supply Company. This part is responsible for producing 8.6% of GHG emissions.

c. Energy Consumption For Processing Resources:

The third part of GHG emissions is due to the usage of electrical energy for treatment and processing of fresh water and sewage. It is a product of quantity of water consumed and sum of emission factors of fresh water and sewage. This part emits minimal amount of GHG, as it accounts only 0.3% of the total emissions.

d. Disposal of Construction Waste:

This part of GHG emission is due to the combustion of fuel in transferring construction waste from the site to the landfill. It is a product of amount of waste transported, distance between the site and landfill and emission factor of the equipment. This part has a total share of 1.3% of GHG emissions.

The above percentages of analysis for the GHG are taken from the case study of a commercial building project in Hong Kong. It is evident from the research data that manufacturing, transportation of building materials and utilization of onsite construction equipment has the highest impact on the GHG emission. The next section will discuss about the description of emissions due to fossil fuel consumption by the construction equipment.

GHG Emissions From Construction Equipment:

There is an expanded influence of construction industry on the GHG emissions. It encapsulates emission from the whole building life cycle (Hammond and Jones, 2011). During the construction phase, emissions from the non-road construction equipment and vehicles are considerably high as compared to the on-road automobiles (USEPA, 2005). As non-road equipment is heavy duty in nature and requires high energy consumption to meet operational demands. A report published by National Institute of Environmental Research of Korea in 2009 highlighted that off-road mechanized construction equipment are noticeably producing high amounts of GHG and it account 6.8% of total onsite emissions (KICT 2010). The emission of GHG from construction equipment is mainly due to the combustion of fossil fuel and electricity consumption (USEPA, 2009). Figure 1 shows the breakup GHG emissions from the construction sector in terms of Million Metric Tons of CO_2 equivalent ($MMTCO_2e$).

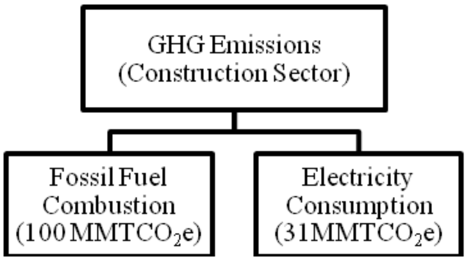

Fig. 1: Breakdown of GHG Emissions from Deployment of Construction Equipment (USEPA, 2009).

The above statistics of EPA report shows that a total of 131 MMTCO2e is produced by the U.S. construction industry in 2002. Out of 131 $MMTCO_2e$, 74% (i.e. 100 $MMTCO_2e$) of GHG emission is due to the fossil fuel combustion which includes burning of gasoline, diesel and any other hydrocarbon fuel by the construction equipment. Whereas, 24% (i.e. 31 $MMTCO_2e$) of emissions are produced as a result of electrical power generation for the construction sector. It has been found that emission of GHG varies with respect to the type of equipment and its usage. This is due to the difference of fuel that is used in heavy construction equipment, capacity, consumption and largely depends on the type of activity and working hours. For an example, out of 100 $MMTCO_2e$, the combustion of gasoline and diesel accumulated 88 $MMTCO_2e$. The rest of 12 $MMTCO_2e$ is due to consumption of natural gas in vehicles engines. Another study established that during road construction, earthwork has a high influence on GHG production as compared to pavement and utility work. It releases more than 90% of GHG than the any other type of work (Lewis *et al.*, 2009). In this regard, the main earthwork activities that produce high GHG emissions are excavation, transportation and embanking of topsoil, weathered rock, rock, subgrade and road bed. The U.S. Environmental Protection Agency (EPA) stated that U.S. construction industry is approximately utilizing two millions construction equipment and machineries and are vital source of GHG emissions (USEPA, 2005).

This section has emphasized that GHG from onsite construction equipment are important consideration for the decision makers to reduce overall impact of construction industry on the environment. Needful actions are required both at the government and industry level to collaborate the efforts for to reduce GHG emissions from the construction sector.

Strategies for Reducing GHG Emissions From Construction Equipment:

The need of carbon mapping in construction activities are gradually increasing in developed and industrialized countries. U.S. government have passed environmental regulations that mount pressure on construction companies to measure and reduce their carbon emissions. So far, such government regulatory efforts have paved the way for sustainable and green construction (Changbum, 2010). In this context, U.S. EPA has established procedures for non-road construction equipment (diesel engine) to comply with 'Tier System". This "Tier System" stipulates permissible emission rates for off-road diesel engines based on its manufacturing year and corresponding engine power (USEPA, 2004). Beside U.S.A., Canada has also imposed these binding conditions (Tier System) on construction carbon emitters to lower down the current level of CO_2 emissions due to the combustion of fossil fuel (Environment Canada, 2005). Similar regulations have been passed in European Union countries to reduce the emission or counterbalance its effects by adopting renewable sources of energy (Joan, 2010). The Dutch government has announced sustainable measures for acquiring off-road construction equipment and vehicles. This standard has established actions and plans for confirming environmental sustainability in acquisition, operation, maintenance of construction equipment (DMIE, 2011). As a result of this new carbon control regime, construction companies are being striving for adopting measures to reduce GHG emissions.

The GHG emissions from construction equipment can be controlled by adopting practices that led the way for sustainability. In a typical construct project, owner, architect and contractor are the main decision makers for evaluating opportunities to reduce emissions. Generally, a contractor may have a greater influence on some potential activities that are associated with the GHG emissions at construction site. These activities are more related to the efficient use of fuel and electricity. According to EPA, selection of fuel, equipment idling, maintenance and its proper selection are highly related to GHG emissions (USEPA 2009). A similar study has proven that appropriate selection and planning of construction equipment can led to the decrease in GHG emissions. As the emissions produced by a diesel engine is a product of engine horse power, operating hours, its emission and load factor. Due to which, emissions from non-road equipment are directly linked with the equipment operating hours. Thus, if the equipment is running for a longer duration. It will consume more amount of fossil fuel and the corresponding rate of GHG is high (Changbum *et al*., 2009).

As addressed above, environmental sustainable practices require contractor's interest in terms of management and expenses to meet the expenditures. It is a common perception among construction companies that sustainable practices are expensive and need ample amount of financing is required to adopt such innovations. In the presence of new regulations, adoption of cleaner technologies need large capital investment for buying new equipment or retrofit the existing equipment for meeting sustainable criteria. Beside this, use of bio-diesel, low sulphur fuels and other sustainable fuelling options adds extra cost to the contractor. All these expenses are considered as an extra financial liability for construction contractors (Lewis *et al*., 2009). In addition to the buying of new equipment and technologies, huge inventory of old and used construction equipment is another area of concern. The normal operating life of non-road diesel equipment and machineries has been estimated between 20 to 30 years (Avetisyan, 2012). The U.S. construction sector comprises of approximately two million construction machineries which are mostly owned by the private sector (Lewis *et al*., 2009). Nearly, 90% of construction equipment, machineries and vehicles are maintained by private sector. As these equipment are considerably old and aged, so new emissions standards (such as Tier 4) are not act in accordance in this new scenario. Hence, the impacts of such changes are likely to be felt and majority of aged equipment are replaced by equipment meeting newer and more stringent regulations (Changbum *et al*., 2010). So, private sector is a key stakeholder in controlling the change and its pace for meeting new standards and regulations. Thus, it is obligatory that private sector should facilities for a change ahead of natural equipment turnover rates may help make diesel emission reductions in the near future.

Keeping the above in view, U.S. EPA has launched a programme nationwide to promote the adoption sustainable and green technologies. This is a emission reduction funded programme and it offers monetary incentives to the operators of non-road diesel equipment and machineries (USEPA 2005). In this context, Voluntary Diesel Retrofit Program, Carl Moyer Program and Texas Emissions Reduction Plan are notable efforts by EPA and it offers incentive packages for participating construction firms to reduce the GHG emissions. These incentives were presented for those contractors who promote the use of exhaust treatment devices, upgrade their engines, use ultra-low sulphur, bio-degradable fuel and keep their equipments in good working condition (Changbum *et al*., 2010).

In the broader perspective, it can be stated that the control of exhaust emissions from the non-road diesel engines can benefit the whole society in terms of healthiness and provide them a safer and clean environment to live-in.

Aim of Research:

In view of the future low carbon demand from the Malaysian construction industry. It is imperative to think about the importance of carbon emissions from the construction processes. The main purpose of this research study is to recommend possible actions related to the reduction of GHG emissions from onsite construction equipment. These measures lead the civil contractors towards the most influential activities in their domain that are meant to affect GHG emissions during onsite construction.

Methodology:

The research methodology is divided into two parts. The first phase is qualitative data analysis based on a relevant literature review. It is an important phase and paved the way for achieving research objectives. Qualitative data analysis helps the researcher to understand the phenomenon to be investigated. In this regard, relevant literature from books, published data of conference proceedings and indexed journals were reviewed. Based on this data, a list of actions and plans was developed for an empirical testing from the construction industry professionals. The second phase of the research was based on quantitative data analysis. During this phase, a questionnaire was developed to determine the views and perception of construction contractors on the action plans of reducing GHG emissions from construction equipment. The questionnaire is comprised of closed end questions and has two sections. The first section inquires about the respondent demographic information whereas the second part is focused on GHG reduction strategies. The respondents were asked to highlight the importance level of GHG reduction plans and ranked their existing practices to show the commitment for this green agenda. A five point Likert scale was used to measure the preferences of the respondents. Before the main scale survey, a pilot study was also carried out to find out the reliability of questionnaire. The results of pilot study have verified the sufficiency of the survey instrument. The main constructs of the study were measured for reliability by using Cronbach’s alpha coefficient. Preferably, the value of Cronbach alpha coefficient should be greater than 0.70 (Iarossi, 2006). The reliability analysis revealed that most of the scale items have higher reliability values and it is in the range of 0.981. This value of Cronbach alpha coefficient is considered as satisfactory with respect to the past studies. For this study, random sampling method was adopted. A sample of 400 Grade G7 class ‘A’ contractors of Kuala Lumpur and Selangor were contacted to participate in this research survey. The Construction Industry Development Board (CIDB) of Malaysia has classified the civil contractors into seven categories (i.e. G1 to G7). According to their classification G7 contractors are large scale contractors and engage in heavy infrastructure and building projects within peninsular Malaysia. These large contractors are more equipped with heavy construction equipment, machineries and vehicles. Therefore, it is pertinent to send them survey questionnaire for their valuable and productive feedbacks. The next section will describe the results and analysis which were derived from this study.

Results and Analysis:

After repeated follow ups, a total of 82 completed responses were received from the respondents. This makes an overall response rate of 20.5%. It has been observed that responses of questionnaire survey in construction industry are normally in the range of 20% to 30% (Akintoye, 2000; Dulami *et al*., 2003). In this context, the received feedbacks are considered as satisfactory for further evaluation and appraisal.

The collection of demographic information as an integral part of survey is quite useful in many ways. It is helpful to understand the respondents’ professional background and the ability to provide authentic feedbacks. This will support the researcher to steer its findings towards some significant conclusions. This research survey has also soughted background and general information from the respondents. The scope of study is mainly related to the onsite construction phase of the project, so it is deemed necessary to get on board all the key stakeholders of contractor project team. The survey demographic information and few telephonic feedbacks signify that respondents have amply participated in this research campaign. The responses were received from professionals having different occupational background. Their participation is as: project manager (34%), construction manager (8%), manager (27%), engineer (11%), quantity surveyor (19%), and equipment manager (1%). The reliability of feedbacks is also related to the respondents academic education and field experience. It is important to note that all respondents are well qualified and have sufficient industry experience. Table 1 shows the summary of demographic information of respondents.

It is a common saying that “Get the facts or the facts will get you. And when you get them, get them right, or they will get you wrong.” Similarly, the measurement of energy consumption and carbon emissions from the construction equipment leads to its management and enable contractors to have an effective control on associated activities. It is envisaged that Ministry of Natural Resources and Environment Malaysia will launched voluntary carbon reporting scheme next year. This program will emphasize on the measurement of carbon emission and its subsequent reduction from the industrial processes. Energy consumption and GHG emissions are directly related to each other. For Malaysian construction industry, the calculation of energy consumption is still neglected by most of the operators of heavy construction equipment. The results of the survey also shows that GHG monitoring is not widely been practiced by the Malaysian contractors. The survey statistics indicates that only a small proportion of respondents have shown their concern towards GHG monitoring from the construction processes. Figure 2 shows their percentage in the area-chart format. As depicted from the chart, the ratio of energy consumption to GHG monitoring is 5:1. This ratio is quite low and a matter of concern for all stakeholders of construction industry.

Table 1: Respondents Background Information.

Demographic data	Percentage (%)
Working experience	
< 5 years	4.03
6 - 10 years	16.12
11 - 20 years	36.2
> 20 years	43.54
Education	
Bachelor	88
Master of Science	3.2
Master of Business Administration	1.6
Master	4.8
PhD	1.6
Age of organization	
< 5 years	4.83
6 - 10 years	27.41
11 - 20 years	34.67
> 20 years	37.9
Field of Specialization	
Roads & highway	60
Railway	6.5
Dams & irrigation	15.3
Bridges	25.8
Ports	8.9
Tunneling	7.3
Airports	21.8
Pipelines	33.9

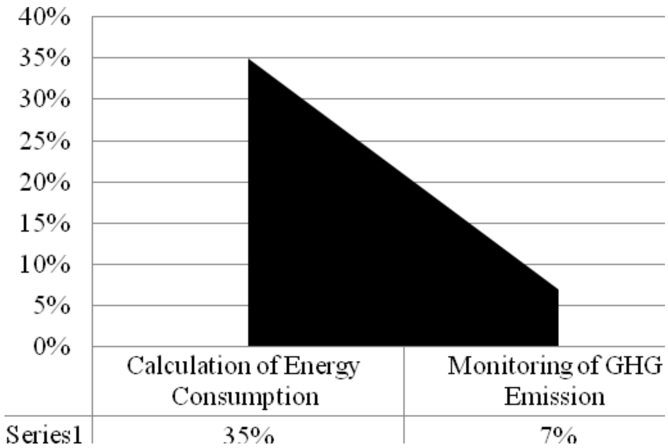

Fig. 2: Monitoring Trend of Energy Consumption and GHG Emissions.

This research survey succeeded in developing an action plan for reducing GHG emissions from the operation of onsite construction equipments. In this regard, a list of nine recommended activities was developed which is based on precedent literature. Table 2 presents respondents perceptions on the action plans that influence GHG emissions.

GHG reduction from construction equipments and machineries is a multifaceted task. It has many viable options and strategies. Table 2 has ranked nine potential strategies for the control of GHG emissions from onsite construction equipments and vehicles. It has included measures related to equipment planning, operation, procurement and training needs of operators. During the construction phase, careful analysis and assessment of earthmoving operations have a direct impact on equipment idling time. It has been observed that reducing equipment idling directly effect the consumption of fossil fuel and appreciably cut down the GHG emission level. The second priority action is the identification of properly sized equipment for the particular construction activity. It has a positive impact on fuel saving and minimizing associated emissions. GHG emissions can also be reduced by taking advantage of timely and preventive equipment management plan. As fuel savings can be achieved by proper maintenance. Another option for fuel saving is to opt engines that are best for an application and burn less fuel. Equipment operators or drivers are the assets of any construction firm. Their proper training can raise their level of expertise in performing their jobs efficiently. In the current scenario of high fuel prices, it is now becoming essential for achieving high fuel efficiency. From contractors point of view, procurement of energy efficient equipment reduces the fuel cost and thus by reducing the GHG as well. The advent of new technologies in construction equipment embarks opportunities for the users. A careful selection of an innovative procuring option will reduce the impact of emissions. Last but not least, there is also an opportunity to reduce the emissions with the use of biodiesel. It is low-carbon based fuel but its cost effectiveness is still a matter of concern for the contractors.

Table 2: Activities for Reducing GHG Emissions.

Potential Measures for GHG Reduction	Overall mean score	Rank
Efficient use of equipment by reducing idling time	4.07	1
Opt properly sized equipment	4.02	2
Timely and preventive equipment maintenance	3.84	3
Opt for the best engine power for equipment	3.70	4
Effective operator training programmes	3.68	5
Procure energy efficient equipment	3.67	6
Adopt new technological instrumentation and controls	3.60	7
Reduce fuel usage by planning travelling routes	3.55	8
Use of biodegradable fuel	3.22	9

Conclusion:

GHG emissions are the results of wide verities of human and industrial activities on the globe. The growing importance of carbon mapping in the construction industry is mounting pressure on contractors to cut down their current level of GHG emissions. This study has characterized GHG emissions from the construction activities. The scope of the research has focused on many specific actions pertinent to emissions from the construction equipment. In view of the upcoming “MYCarbon” voluntary scheme for carbon reporting in Malaysia, it is important for companies to audit their activities for GHG emissions. The questionnaire survey was able to get the perceptions of Malaysian contractors for GHG reduction strategies. The results of the survey reported that GHG monitoring and control is still infancy stages in local construction industry. A small number of G7 contractors are currently been concerned for energy efficiency, fossil fuel consumption and measuring carbon footprints. As a start towards green and sustainability environment, a list of nine key action plans is being proposed. A better and through understanding of these measures will enable many construction contractors to reduce the GHG impact from the current level and contribute towards a green environment in the coming years.

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